Utilising innovative management techniques to reduce waterlogging

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by Greg Gibson

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Scholar Contact Details
Greg Gibson
Gibson Ag P/L
Hagley Tasmania
Australia

Phone: +61419528165
Email: gibsonag@bigpond.com

NUFFIELD AUSTRALIA Contact Details

Nuffield Australia
Telephone: (03) 54800755
Facsimile: (03) 54800233
Mobile: 0412696076
Email: enquiries@nuffield.com.au
PO Box 586 Moama NSW 2731

Executive Summary

As the world's population grows, farmers, as caretakers of the land, will need to produce more high quality food off less land - and in a sustainable way. Crop losses caused by waterlogging cost the agricultural industry greatly on an annual basis. The potential to produce a consistent yield without saturated portions is of great priority and this can be achieved by utilising the world's best water management practices.

The purpose of this study is to research management techniques to reduce waterlogging in high rainfall zones of Australia. The author found that implementing an integrated systematic approach is the most effective way to achieve this.

This report contains findings on causes of waterlogging and options to mitigate it. An efficient monitoring program will highlight affected areas and this allows informed decisions to be made to reduce its effects. Monitoring tools can give a very clear picture of non-performing areas, however, these zones must also be 'ground-truthed', or manually inspected, to confirm direct causes of waterlogging. Once this information has been collated, a management plan can be put into place to combat these issues. This may include Variable Rate Irrigation (VRI) to reduce over watering, Controlled Traffic Farming (CTF) to limit compaction or surface/subsurface drainage to alleviate problem areas. In most instances, multiple strategies will be utilised.

The agricultural community is renowned for being industrious and innovative, and this, combined with new technologies and techniques, ensures no waterlogging problem is unmanageable.

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Foreword

My interest in land drainage started in the mid 1980's. My father, Ross, started installing 300 mm long clay tiles in wet parts of fields working with a local contractor, using a pull type Bruff chain trencher guided by laser. The advantage of tiling was evident straight away. Since the eighties, most of the wet portions of fields have been drained using random drainage. Present day, plastic pipe (containing slotted holes) is installed using a trenchless Mastenbroek, also operated by a local contractor using a laser control system.

As our farm is an intensive poppy, vegetable, seed, cereal and prime lamb property, every part of it needs to be productive. As costs rise, the importance of keeping non-performing areas of fields to a minimum is imperative. Our property, 'Mill Farm', is situated in the northern midlands of Tasmania, Australia. Soil type is mostly Cressy Clay/Loam. The topsoil and subsoil layers are each only 125-150 mm thick and then becomes a heavy clay, therefore water penetration is very slow. Likewise, drainage of subsoil is slow. In the last few years a mole drainage program has been undertaken to enlarge the footprint of the tile system.

My Nuffield scholarship journey started in the spring of 2012. Two local farmers and I chartered a light aircraft to undertake crop inspections over our properties. At the time, most crops were at full growth stage. Onions, processing peas and all seed crops looked a picture, and poppies were in full flower. I thought we had been doing a great job of reducing the crop stress to waterlogging and was extremely disappointed to see the crop losses. We quickly came up with an estimated average loss of 30%, with some crops showing up to 50% loss. The cost of these reductions in yield can be quite easily calculated and can quickly run into hundreds of thousands of dollars. Because none of our crops were being yield mapped at the time, differences of that extent had not been realised. I felt I was failing to mitigate losses and needed more information. Some friends had been awarded Nuffield Scholarships over previous years and after sourcing some information from them I decided that this would be a great vehicle to study world's best practice on drainage. In September 2013, much to my surprise, I was awarded a scholarship. After a lot of research, I realised there are quite a number of things that can cause waterlogging. I decided to keep my study topic broad to allow multiple subjects to be researched. My main aim was to investigate ways of reducing waterlogging.

The Global Focus Program took my group to Philippines, China, Canada, USA, Netherlands, Belgium, France, Ireland and UK. The highlight of this trip was the introduction to global agricultural issues as a whole. My personal study topic led me back to the UK, Netherlands, USA and Canada where I gained global exposure to my field's most knowledgeable people and technologically advanced practices.

Figure 1: Bob Clark, Clark Farm Drainage, Indiana, USA and author Greg Gibson.

Source: G. Gibson, Indiana (22 August, 2014).

Acknowledgements

I would like to take this opportunity to sincerely thank my beautiful wife, Sarah, without whom this whole Nuffield mission would have spun off into the abyss. Sarah's enthusiasm kept the home fires burning and helped get this report across the line. I must thank my awesome children, Nina and George. They have been very patient and mature and have given me the time needed to both travel and put this report together. Thanks to my mum and dad for providing me with the opportunity to fulfil my dreams and for passing on the love of agriculture.

A big thank you must go to the Mill Farm team - Andy, Craig and Owen for their extra effort in my absence and for their ongoing commitment.

Thank you to Fiona and Michael Chilvers for their unwavering support and encouragement throughout my Nuffield journey.

Thank you to my official investor, Sidney Myer Fund. They have given me the opportunity of a lifetime and I look forward to fulfilling their expectations in promoting better environmental outcomes in agriculture.

Thanks also must go to 'Team China' Global Focus Program (GFP) group. Travelling for six weeks to nine countries around the globe brings out the best in people. To travel and share these experiences with the calibre of people in our group was very humbling.

Finally, I would like to thank Nuffield Australia for having the faith in me to represent Australia and the organisation. This experience has certainly been life changing and I will be forever grateful for the exposure it has given me to agriculture globally.

Abbreviations

AWC: Available Water-holding Capacity

CEC: Cation Exchange Capacity

CTF: Controlled Traffic Farming

DPEI: Department of Environment and Primary Industries

DPIWE: Department of Primary Industries, Water and Environment

EC: Electrical Conductivity

EMI: Electro-Magnetic Induction

GFP: Global Focus Program

GIS: Geographical Information System

GPS: Global Positioning Systems

GRDC: Grains Research and Development Corporation

HRZ: High Rainfall Zone

ID: Inside Diameter

LIDAR: Light Detection and Ranging

NDVI: Normalized Difference Vegetation Index

OARDC: Ohio Agricultural Research and Development Centre

OMAFRA: Ontario Ministry of Agriculture, Food and Rural Affairs

SANTFA: South Australian No-Till Farmers Association

TEAGASC: Agriculture and Food Development Authority

TIAR: Tasmanian Institute of Agricultural Research

UK: United Kingdom

USA: United States of America

USDA: United States Department of Agriculture

VRI: Variable Rate Irrigation

WANTFA: Western Australian No-Till Farmers Australia

WUE: Water use efficiency

Objectives

The objectives of this study are:

- To research monitoring tools available for determining the causes of waterlogging.
- To explore the world’s best techniques in reducing waterlogging.
- To implement an integrated systematic approach to reduce waterlogging and, in turn, yield losses.

Chapter 1: Introduction

Of the estimated 235 million hectares (ha) of irrigated land in the world, 10 to 15% has been affected by waterlogging and salinization (Ritzema, Kselik, et al., 1996).

One of the biggest agricultural production restrictions across the globe is too much water. Waterlogging itself, by 2001, affected 10% of all irrigated crops, and decreased productivity by 20 % (Stockle, 2001). Waterlogging occurs when soil cannot absorb any more water, leaving plants in an anaerobic state. The consequence is that the plant’s growth and development is stalled and if these circumstances continue for a considerable time the plant eventually dies (Cotching, 2012).

The High Rainfall Zones (HRZ) of Tasmania are renowned for growing high value crops such as vegetables, poppies, pyrethrum and a myriad of seeds. High value crops require high inputs therefore any crop loss proves expensive. High Rainfall Zones are prone to waterlogging which is a major cause of crop losses.

This report highlights the causes of waterlogging. It seeks out the tools available to observe its effects and what modes of action can be taken to bring affected ground back into production. Importance is placed on implementing a systematic approach to reduce waterlogging utilising multi point interventions.

Chapter 2: Observing the causes of waterlogging

Monitoring to observe the causes of waterlogging is an important part of any farming business. There are many ways to monitor factors causing waterlogging in the field. Preferably, crop stress is best picked up as early as possible so a remedy can be administered as soon as practicable. Measuring equipment is best put in place early on in the plant life cycle. A continuation of a well-planned monitoring program can minimise the risk to crops.

2.1 Causes of Waterlogging – a brief description

- Over-Irrigation

  Waterlogging occurs when more water than the plant can utilise is applied. Soil type needs to be taken into consideration when determining irrigation schedule, for example, heavy clay soil will hold water for a longer period than sand. Irmak (2014) explains that overwatering results in nitrogen leaching and runoff. He goes on to say that research has shown that excess water can increase weed pressure and create an environment favourable to diseases. Overwatering negatively impacts yield causing a decrease in soil temperature (thus reducing root growth) and disturbs the oxygen balance of the root zone, drowns roots, reduces plant water uptake, and thus stresses plants (Irmak, 2014).
- Compaction

  Soil compaction is a form of physical degradation resulting in densification and distortion of the soil where biological activity, porosity and permeability are reduced, strength is increased and soil structure partly destroyed. Compaction can reduce water infiltration capacity and increase erosion risk by accelerating run-off (Houskova, 2014). Soil compaction is largely caused by field traffic. Further discussion on this topic can be found in section 3.2 of this report.
- Poor Drainage

The purpose of drainage is to lower the water table in the soil to enhance crop production. Lack of good drainage systems can lead to ponding, which can have dire consequences on plants. To reduce crop losses, it is imperative to reduce ponding by draining water to a drainage outlet.

- Rainfall Events

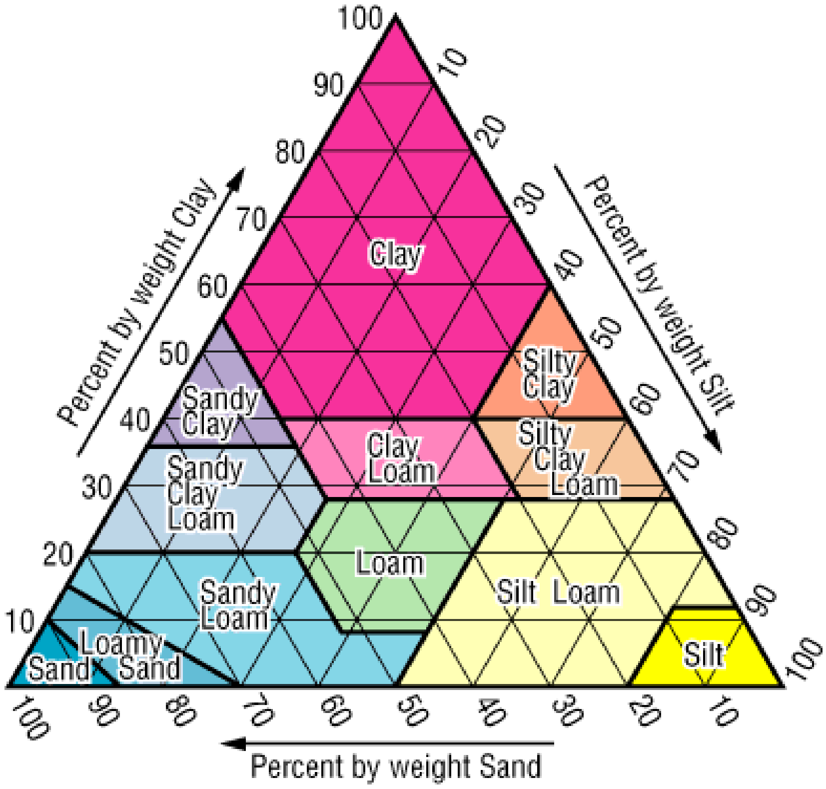
  The cause of waterlogging which is mostly out of human control is rainfall. Discussion later in this report looks at ways to be prepared for large rainfall events. Weather forecasts are often inaccurate but with modern-day modelling and multiple local weather stations, forecasting is improving and will lead to easier management decisions with regard to water management.

2.2 Soil

For plants to grow to their full potential, soil must provide them with a satisfactory environment. Plant growth is determined by soil structure, texture and chemical makeup. Soil texture is an important part of determining management systems including drainage, irrigation and crop inputs. An information sheet on how to determine soil texture is detailed in Appendix 1. A soil texture triangle (figure 2) can be used to determine the best management practices required for a particular soil texture type.

Soils are categorized into four basic components: minerals, organic matter, air and water.

Figure 2: Soil Texture Triangle.



Source: USDA. www.texture.s4ag.com

2.2.1 Moisture Sensing

The importance of monitoring soil moisture content cannot be overstated. As changing moistures are encountered at differing times of the year, options for planting times, variety or even species may change to suit soil moisture in the growing environment. This is especially so when planting windows are very narrow, for example, when soil moisture is in the drying out cycle, as in late spring.

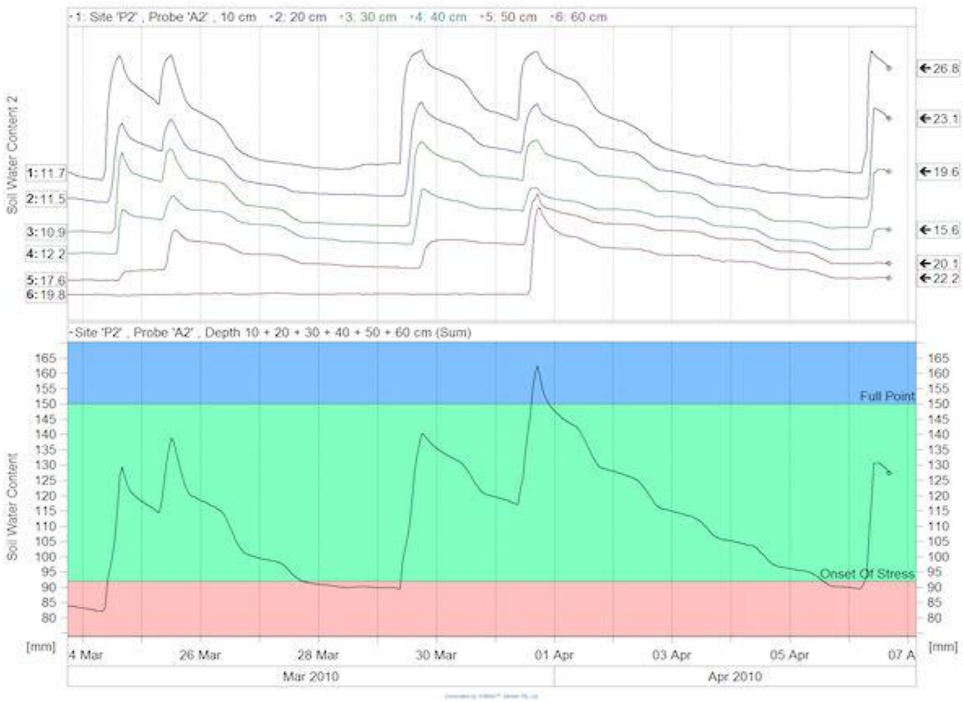
Soil moisture probes are a very quick and economical way to monitor soil moisture. By using these probes to their fullest advantage, irrigation scheduling can be decided using the data provided. Utilising units with data loggers and wireless connection to smart phones or tablets enables scheduling to be done in the field or from afar.

There are an array of different sensors/probes on the market, some of these include:

- **Watermark® sensors** - respond to soil water by measuring electrical resistance. Electrical resistance increases as soil suction increases, or as soil moisture decreases.
- **Capacitance sensors** - measure changes in the dielectric constant of the soil with a capacitor, which consists of two plates of conductor material separated by a short distance (less than 10cm). A voltage is applied at one extreme of the plate, and the material that is between the two plates stores some voltage. A meter reads the voltage conducted between the plates. When the material between the plates is air, the capacitor measures one (the dielectric constant of air). Most materials in soil, such as sand, clay and organic matter, have a dielectric constant of two to four. Water has a higher dielectric constant of 78. Hence, higher water contents in a capacitance sensor would be indicated by higher measured dielectric constants. Thus, by measuring the changes in the dielectric constant, the soil water content is measured indirectly.
- **Tensiometer sensors -** measure the tension of soil suction. As soil dries out it contracts creating a suction that can be measured by using a sealed water filled tube with a vacuum gauge. This gives a reading to verify soil moisture.
- **Neutron probes -** estimate the amount of water in the soil by measuring the amount of hydrogen that is present. A measured amount can then be highlighted (Enciso, Porter, et al., 2007).

Figure 3 shows moisture probe readings over one month. The top graph focuses on six different depths recorded from 10cm through to 60cm in 10cm increments. The peaks indicate rainfall or irrigation events and the descent of the line represents plant use drying the soil profile. The second graph highlights the green “plant happy zone”. Plant stress points are indicated by the red (too dry) and blue (too wet) zones.

Figure 3: Moisture Probe Software.



Source: Irrimax, Sentec Technologies.

2.2.2 Water Table Depth

It is important to know the depth of the water table to be able to make informed decisions for drainage control and irrigation scheduling (discussed in chapters 2 and 3 respectively). The depth is defined by the balance point of the ground water pressure and the atmospheric pressure. Below this point is the saturated zone and above the unsaturated zone the soil spores are partly filled with air and water in the form of soil moisture. To determine the water table, a hole can be bored into the soil and a floating level indicator can be placed inside. As the water table rises, the float rises. The marker shows the current depth.

2.2.3 Soil Scanning/mapping

- Electrical Conductivity (EC)

Soil Electrical Conductivity (EC) is a measurement that correlates with soil properties such as soil texture, Cation Exchange Capacity (CEC), drainage conditions, salinity, and subsoil characteristics (Grisso, Alley, et al., 2009).

Mapping EC shows variance across a field and will need verification to determine the reading. Mapping is done by either contact sensor measurement (for example, MSP3, manufactured by Veris technologies) or non-contact Electro-Magnetic Induction (EMI) (for example, Em38-MK2 manufactured by Geonic Limited). Readings can highlight salinity (salt concentration), pH, organic matter level, top soil depth and available water-holding capacity (AWC). These attributes can be used to develop management zones for seed varieties, crop inputs, drainage and irrigation scheduling. EC can also be used to position soil moisture probes in a representative area of the field to eliminate field anomalies.

- Test Pits

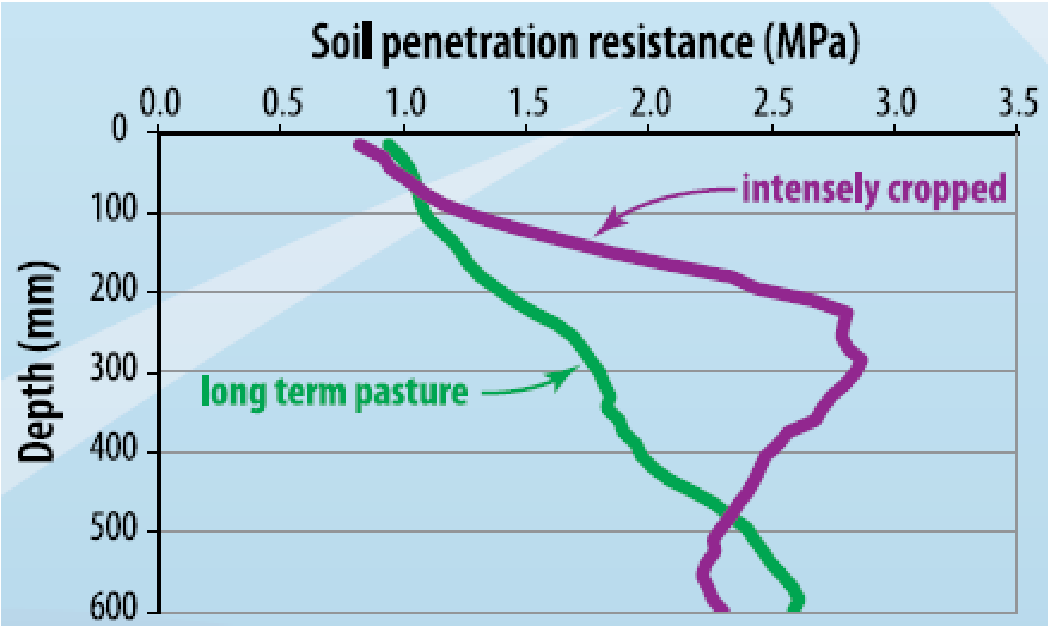
Digging a soil test pit provides a better understanding of what type of soil/clay is under the surface. A large amount of information can be gained while examining soil profiles. Inspect the layers for texture (sand, silt, clay) and thickness. Place attention on where permeable layers are, indicated by seepage. Take note of the depth of plant rooting as shallow roots indicate poor drainage (TEAGASC, 2013). This is usually caused by compaction.

2.2.4 Compaction testing

Compaction is a major contributor to waterlogging. An easy way to test for soil compaction in a field is by using a penetrometer. The Oxford Dictionary (2015) defines a penetrometer as an instrument for determining the consistency or hardness of a substance by measuring the depth or rate of penetration of a rod or needle driven into it by a known force. In a field environment, a penetrometer can be carried across a field and either grid tested or just indiscriminately used. All that has to be done is to insert the probe into the soil to obtain a reading. There are two common types used - analogue and a digital version for more accurate readings. The digital option can be connected to a data logger/Global Positioning Systems (GPS) to log readings across a field to create a better understanding of problem areas.

Figure 4 is a graph representing soil penetration resistance between a long term pasture and an intensively cropped sandy soil. The intensively cropped (purple line) data shows the amount of extra resistance between 100mm and 300mm of depth. This field traffic compaction is the result of intensive cropping.

Figure 4: Plot showing the difference in penetration resistance between a long-term pasture and intensively cropped deep sand.



Source: Cotching/Davies. Soil compaction fact sheet, soilquality.org.au.

2.2.5 Topography

Topography has a big effect on water movement. Slope determines which way water will exit the field. This information forms the basis of a design for drainage systems. Any major and minor differences in topography will change the design.

- Surveying

  A survey will highlight the physical features of a field and this will help when making drainage design decisions. With modern software, survey results can be produced in the form of a very detailed contour map. For feasibility studies on future drainage systems, Light Detection and Ranging (LIDAR) scanning can be used. This technology allows elevations to be surveyed by light aircraft. This system works by emitting thousands of laser pulses at the ground and then reads the reflected signal to calculate range or topography. As the accuracy is not yet 100%, this can only be used in the planning process at this stage.

- Watershed mapping

Watershed mapping is used to predict characteristics of water movement, including flow calculations, across elevated areas; stream point creation; and likely points of erosion, water velocity and direction. Ag Logic consultant, Reuben Wells (Personal contact, March, 2015), explained that, by using software and data collected when surveying, modelling can be done to highlight outcomes on a range of events using simulation. Large rainfall events can be entered with known factors such as topography, soil type and saturation point to simulate what occurs in an event over varying time frames. The modelling highlights water flow path accumulation, ponding and field exit points. This software also allows drainage lines to be changed so the user can ascertain what happens if different lines are added, subtracted or moved. This also applies to surface drainage depth and placement, raised bed configurations and even tram lines – all of which are not always set up to follow the best direction of water flow. Simulation will provide the information to rectify problem areas and give options to change where field drains intersect tram lines or raised beds to alleviate ponding. When the mode of action has been decided upon, drainage lines can be entered into existing GPS equipped machinery. This ensures that surface drainage (see Chapter 3.1) is placed in the correct position and likewise, with raised beds and tramlines, installed in the best direction for water flow.

2.3 Gathering Plant Health Information

Ongoing plant health is essential to ensuring profitable crop returns. Monitoring plant health, utilising crop sensing equipment, allows informed decisions to be made. This equipment can be used to check on crop health and vigour during the growing season. Knowing crop water requirements is also very important and can be determined by plant stress. As waterlogging affects how vigorous a crop can be, good monitoring is essential for early detection of crop stress. Stress can be attributed to moisture and weed, insect and fungal infestations. On closer inspection (ground-truthing), mitigation of most of these issues can be achieved. Without in-crop monitoring, problems may only be discovered during harvest.

2.3.1 Normalized Difference Vegetation Index (NDVI)

Plant health can be determined by vigour mapping. A Normalized Difference Vegetation Index (NDVI) image can be produced utilising near infrared technology. This can be done by satellite, plane, drone or ground-based rovers such as spray rigs or quadbike. The GreenSeeker, OptRx and CropSpec sensors are responsive to both crop biomass (amount of vegetation) and crop colour (which relates to chlorophyll concentration and/or nutrient concentration). A darker green crop gives higher values than a paler green crop for the same given biomass. While the use of this technology is slowly evolving, growers are starting to apply this information to vary inputs during the growing season, for example nitrogen, trace elements and herbicides (McCallum, Whitlock, et al., 2010). NDVI can be used to determine the amount of stress a plant is under. Variance maps are produced and can be used to determine problem areas. As with all monitoring, manual investigation, or ground-truthing, is of utmost importance for verifying the correct cause of poor crop vigour. An NDVI map is an inexpensive way of determining vigour/vegetation variance throughout the growing season and can usually be produced by local service providers. The cost of NDVI mapping varies, depending on location and how many maps are produced for an individual grower. With better access to mobile sensors and drones in the near future, this cost will most likely decrease.

Figure 5 shows an NDVI image of an onion field on the author's property. The image was taken at peak growth. It clearly shows the amount of biomass/vigour difference across the field. Upon ground-truthing, after receiving this image, it was decided that the portion of the field in red and yellow was waterlogged for longer than the remaining part of the field after a rainfall event. The soil type in this area has a higher clay content, meaning the permeability is low. Water that otherwise would have been absorbed into the soil profile was trapped on the surface, waterlogging the onions and stunting their growth. In this case, it was too late to rectify the problem in the current season but the information can be used for future reference when planning a drainage program. An explanation of how NDVI works can found at www.fsnau.org/downloads/Understanding_the_Normalized_Vegetation_Index_NDVI.pdf.

Figure 5: NDVI of onion field on author's property, Northern Midlands, Tasmania, Australia.

Source: Terrapix (2015).

2.3.2 Yield Mapping

It is now commonplace that most late-model harvesters are fitted with yield mapping capabilities. The yield is determined by the flow of grain over a plate in the clean grain elevator of the harvester. This yield data is then attached to GPS co-ordinates to build a map showing yield across a field. Data generated with a yield monitor, however, is only as good as the correct installation, calibration and maintenance of the unit and its components (Franzen, et al., 2008). The data is usually 'cleaned' before it can be used. This is a process that can be done using software to take out anomalies in the data. These errors are created from unrealistic highs and lows created by the harvest process or grain flow irregularities. The cleaned data can then be used to view variables across a field. In the same way an NDVI map is viewed, coloured yields are highlighted to show variance. By using computer software, the computer cursor can highlight any part of the field to show its actual yield and income if the correct information has been entered. Yield mapping highlights non-performing ground which may be caused by waterlogging.

Nuffield Scholar, Robert Burtonshaw (personal interview, August, 2014), in Warwickshire, United Kingdom, stated that his drainage business workload had not changed over the years prior to farmers utilising yield mapping. He stated that growers who were using this technology could see the losses in monetary terms across their fields and in turn started asking questions about the variation in crop yields. After closer inspection, waterlogging was quite often the cause. Since then, Rob said his business of installing drainage pipe has seen a rise in work load.

Summary

Observing causes of waterlogging using multiple monitoring techniques builds a broad view of issues that can be rectified. Before any modification of farming practice can be done, information needs to be collated and scrutinised. Information is derived from moisture sensing, soil scanning/mapping, compaction testing and topography. Plant observations come from NDVI and yield mapping. Combining this information form the basis of an integrated systemised approach to mitigate crop losses attributed to waterlogging. Ground-truthing problem areas is critical as visual inspection will confirm points of interest to focus rectification on.

Chapter 3: Drainage

Out of the 1,500 million ha of cropped lands (irrigated and rain-fed) of the world, only about 14% is provided with some form of drainage. The total area in need of artificial drainage can be roughly estimated at 300 million ha, mainly in the arid and tropical humid zones of the developing countries (Nijland, et al., 2005).

Planting crops at the correct time is critical to achieving high yields, and to enable this, the condition of the soil is critical. If planting is postponed for a period of time due to waterlogged soil, losses in yield can occur. A well planned drainage system can reduce the losses by keeping the soil in an aerobic state to allow for timely plantings. Research into corn planting times in the USA has proven that there are modest yield increases in early plantings (15 April) and severe yield penalties if planted after the 15 May (Nafziger, 2012). The yield loss per day on 30 April is around 31kg/ha and by 31 May is up to 155kg/ha per day (Nafziger, 2012).

With information collected in the observation and monitoring phase, a list of problematic areas can quickly identify issues to be rectified. It is important that the list be detailed to expose any potential patterns that may not otherwise emerge. Determining which issues to deal with first is not always obvious, but it is most important to build a plan. Some problems are quick-fixes and others may take a decade to rectify, therefore, a long term action plan needs to be put into place. The idea behind a multi-point program is that bigger gains can be made by working on the problem from all sides. Maintaining an aerobic, well drained healthy soil and in turn, a healthy crop, is key to these outcomes.

The objective of drainage is to take excess water from the surface and the soil profile to allow for plant root development. Drainage controls the depth of the water table to a desired level and also removes excess soluble salts. “In some soils, the natural drainage processes are sufficient for growth and production of agricultural crops, but in many other soils, artificial drainage is needed for efficient agricultural production" (US Environmental Protection agency, 2012).

Drainage recoups its cost over a very short time. For every $1 spent on drainage technology, producers get $3 to $4 back in corn and soybean profits. This is based on data collected over 25 years from 1984 to 2009 (Reeder, et al., 2011).

A range of elements are to be considered before implementing a comprehensive drainage system. A list can be found in Appendix 2.

3.1 Surface Drainage

Surface drains are used to remove excess water from the surface of fields. Large amounts of water can be removed very quickly without causing any environmental damage if used in the correct manner. The planning and design of a surface drainage system is most critical to achieve outcomes. There are differing styles of surface drainage:

3.1.1 Shallow Field Drains

Field drains are installed across fields using either a grader or spinning disc drainer that makes a depression to direct ponding water to nearby larger drains.

There are two different designs of spin drainers - the vertical spinning disc (Hurricane design) and the more horizontally angled drainer (Dennison design). Both designs are very proficient in removing water from fields. The more vertical Hurricane design is available in many different sizes and hitch points including a 'side arm' design that allows ditching as far as 4.2m from the centre of the tractor. The Dennison design is available in two sizes, being a 1.5m disc and 1.8m disc. The diameter of the disc creates a very gentle entry and exit point, which allows machinery to cross through with little loss in speed.

Both farm and construction graders can also be used to form field drains. With the use of GPS technology, drains can be placed in the lowest parts of the field. Extra care must be taken when sweeping spoil away from drains to not create a mound on either side of the drain. This will impede the water's capability to enter the drain on the ascending side of the mound. Graded spoil should be swept out wide to not restrict water flow to the drain. If this is not possible due to the land being very flat, the use of a 'W' design drain can be used. This design utilises two drains running parallel with the spoil placed in the middle. This design will then allow water to enter from both sides, unimpeded.

3.1.2 Land forming

Surface drainage may be achieved by land forming. This type of drainage changes the topography of a field to allow water to flow to the lowest point. By using heavy construction machinery, higher areas of the field can be cut and used to fill lower lying areas. This technique can also be used to release water out of ponding areas in fields by cutting through higher ground down to the depth of the pond. By cutting a wide, shallow swath creating an extremely wide waterway allows the area to be cropped and reduces the exposure to ponding and production loss. Using modern day GPS software, cut and fill maps can be created and used to control machinery, as grade and depth is key when building a waterway.

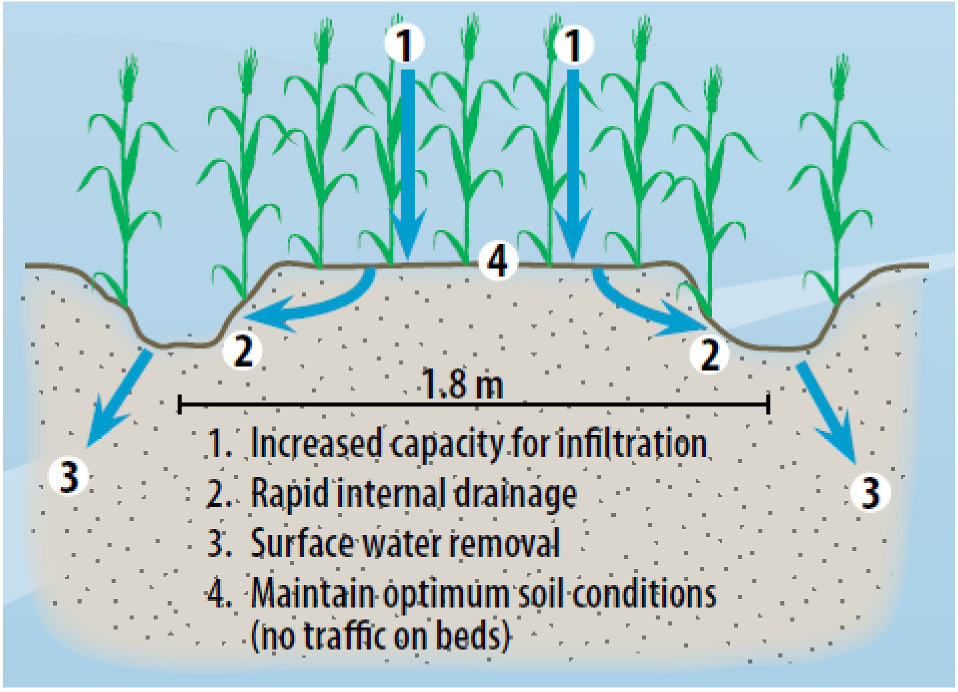
3.1.3 Open Excavated Drains

This style of drain allows large quantities of water to be moved from fields to creeks or rivers in a short amount of time. Open drains can be installed by an excavator using a "V" bucket or normal straight bucket. It is important to have enough slope to remove water quickly without causing scouring of the sides or bottom of the drain. If draining a slope where water velocity is too high and there is a need to reduce scouring and washing, weirs should be used to impede water flow. Water velocity must be slower on sandy soils but can be higher on clay loam or clay type soils. Disadvantages of open drains are that they need regular maintenance to be kept sediment and weed free; there is a need to fence stock out in order to retain the shape of the drain, and they can be perceived as lost ground. An advantage is the use of open drains for outfall installation of subsurface drainage tile.

3.1.4 Raised Beds

Raised beds can be used in High Rainfall Zone (HRZ) farming locations. Beds are formed 100mm – 300mm high to create an uncompacted, free draining root zone to allow maximum plant growth (refer to figure 6). Beds are usually installed 1.8m - 2m wide. Planning is important when considering installing raised beds so that the widths of tractors, sprayers and harvesting equipment can use the furrows, creating a controlled traffic opportunity. A well planned design of the field is of major importance. The direction of beds must enable water to exit the field. Bed hollows, or trenches, must be able to drain into field drains in low lying areas. As discussed in chapter 1.2.4 with regard to topography and watershed mapping, computer software and drainage design can aid immensely when considering raised bed installation. Construction of raised beds is usually by special purpose designed and manufactured machines.

Figure 6: Cross-section diagram of a raised bed and the way it operates to drain, aerate and prevent waterlogging.



Source: soilquality.org.au fact sheet: Raised Bed Farming

3.1.5 Hump and Hollow

Hump and Hollow drainage is used in extremely wet ground that is usually grazed. It consists of a series of drains 10m – 20m apart with crowns in the middle. Water is directed from the crowns into the drains which discharge into headland ditches. The water then exits into open ditches or creeks. The main advantage of this system is that it enables grazing of extremely wet ground made up of soil types unsuited to subsurface drains. The disadvantage is the need to maintain the shape of the drain as cattle tend to plug the drainage line in wet conditions.

3.2 Sub-surface Drainage

The use of sub-surface drainage removes excess water from the soil profile. This is done by the use of drainage pipe. The pipe used has slots to allow entry of water. Pipe is installed on a grade that allows water to flow off the field via open drains or creeks.

3.2.1 Planning

One of the main differences between planning a sub-surface drain and a surface drain is the need to know some additional soil attributes. A test pit can highlight the characteristics of the soil. Hydraulic conductivity is a measure of the water-transmitting capacity of soil, which is extremely important as this value aids in determining the drainage requirement. If draining coarse or sandy material (permeable), hydraulic conductivity is extremely high as the water moves through the soil pores very easily (up to 28 000 millilitres per second) (Tan, Dr C. Personal communication, 2014). If the soil is of high clay content (less permeable), the hydraulic conductivity will be extremely low (as low as 566 millilitres per second), requiring additional pipe per hectare of land. Drainage co-efficiency also comes into this equation. The drainage co-efficiency, or drainage rate, is a design standard that reflects the amount of water that can be drained from a watershed in a 24 hour period (Ritzema, H. Personal communication, 2014). Observing these features of the soil to be drained will facilitate calculating the capacity of the drainage system required.

3.2.2 Design and Design Software

Whether using GPS drainage software or a professional drainage consultant, designing the correct system for a particular field is critical. Both options use the same information to design an efficient system which provides adequate capacity. Modern day GPS offers a complete system including surveying, design and grade control. A survey taken by a scout vehicle collects data for a design to be completed. The design software will determine pipe placement, sizing and amount required. Growing season and historic rainfall should also be considered.

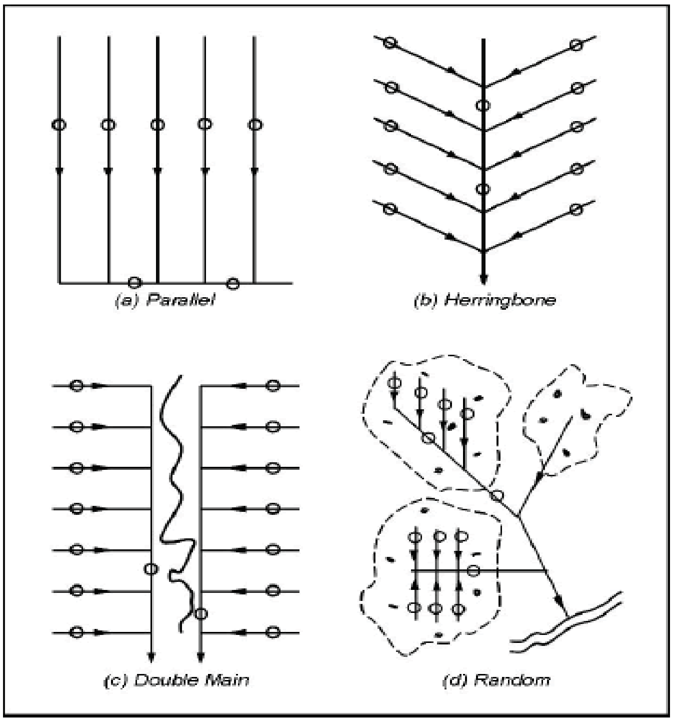
Utilisation of survey information provides the following data:

- Minimum grades;
- Efficient pipe size selection ;
- Flow rates;

- Drainage co-efficiencies;
- Hydraulic conductivity;
- Depth of pipe installation; and
- How to drain undulating ground.

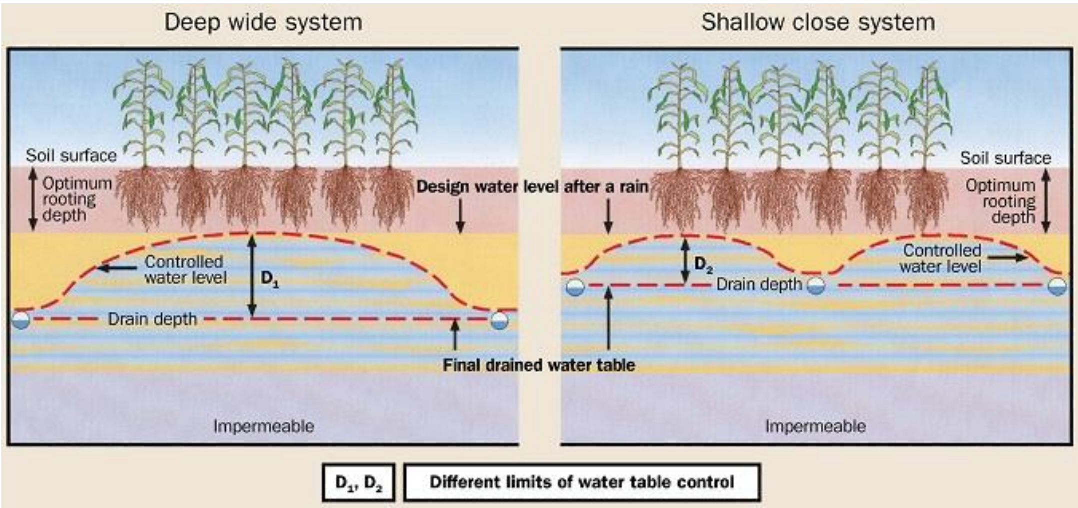
Diagrams in Figure 7 show different options in sub-surface tile layout design. The majority of drainage seen in Tasmania is of 'random' design (Figure 9 (d)) which is mostly caused by the undulating topography. The topography determines where pipe can be laid. If pipe installation is placed directly downhill, water velocity can burst the pipe. When draining steep sections, plan to drain across the slope. The 'random' design is also observed in the UK (Burtonshaw, personal communication, 2014), however, the majority (Netherlands, USA and Canada) use 'parallel' designs. The lateral drainage lines are shown in Figure 9 to exit into the collector main, but these can also exit straight into open excavated drains. Common drainage practice in the Netherlands showed the majority of drainage pipe exited straight into open excavated drains (Van Der Geest, 2014). The benefit is not needing to use a large collector main pipe.

Figure 7: Subsurface drainage designs.



Source: Iowa State University.

Figure 8: Importance of pipe placement width highlighting differing depths.

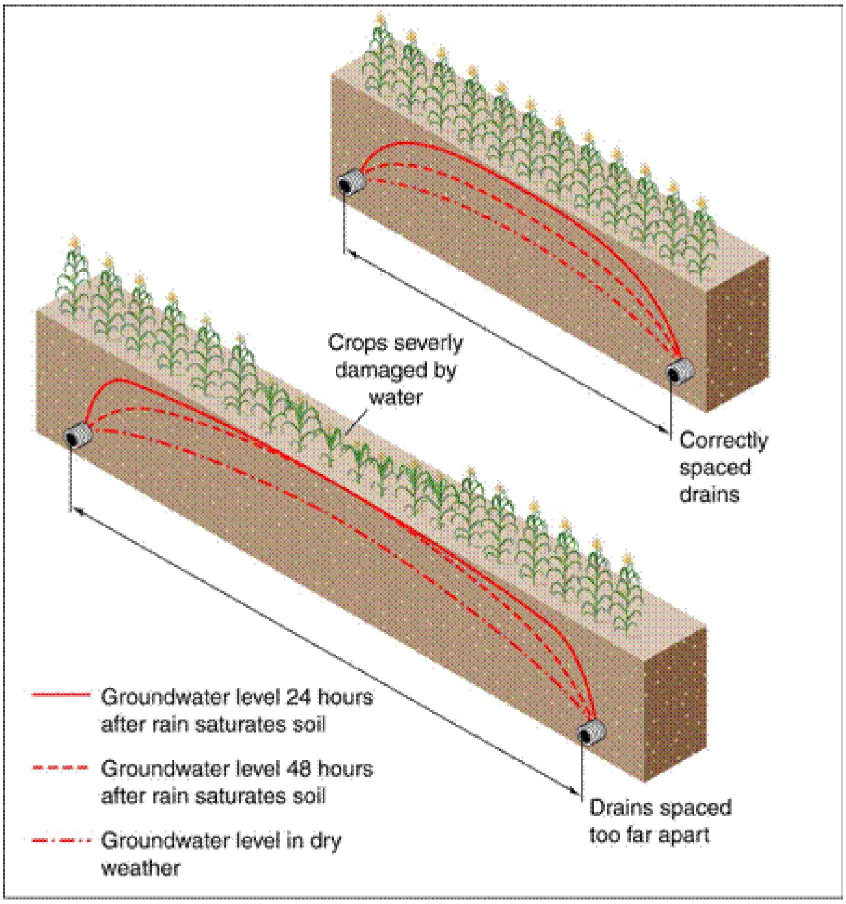


Source: Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA).

Figures 8 and 9 show the importance of pipe depth as well as the effect on plant growth if pipes are placed incorrectly. If installing pipe in a shallow format (due to unsuitable ground), extra laterals are required to keep the water table below the desired depth. Desired depth is determined by the soil type and profile. The pipe needs to be placed in good rock/mud free solid ground reducing the risk of sinking or moving.

Figure 9 highlights the water table being in a raised state for an extended amount of time and the damage it causes to crops.

Figure 9: The importance of drainage pipe width.



Source: Illinois Drainage Guide.

3.2.3 Machinery Grade Control

Machinery grade control maintains a positive grade by regulating the hydraulics on the boom of the drainage plough. If the plough moves up and down while crossing undulating ground, the control unit will either lift or drop the boom to maintain the desired predetermined grade. This can only be achieved by using information provided to the unit by either GPS or laser. Laser control has been used in the drainage industry for over 35 years. Laser control is still widely used today, although GPS is becoming more popular. Laser systems use a light emitter on a field based tripod that the receiver, mounted on the drainage machine, captures. The emitter determines the grade and depth of pipe installation and the receiver controls the hydraulics on the drainage machine. If in undulating ground, multiple grades will need to be calculated ensuring not to have a negative grade. This reduces the risk of pipe silting and, worst case, drainage failure.

GPS, on the other hand, offers a fully integrated system with its calculating power. It provides complex surveying information, design technology and accurate machine control. By setting parameters such as optimal depth, minimum grade and outlet depth, the drainage plough or trencher varies the grade to suit during installation. This enables the tile pipe to be installed in the best position possible. An Ontario contractor states that pipe installation output has risen by 20% since moving from laser to GPS (Wielgut, 2011).

3.2.4 Drainage Machinery

There are distinct differences in pipe installing machinery:

Trencher

Chain trenchers cut an open style trench and are used to install drainage pipe in-field. This style of trenching is very popular in the UK as it facilitates integration of older field drains into new drainage systems; that is to say, as the trench opens, old drainage lines can be seen. This type of machine is quite often lighter than the trenchless style, reducing compaction while draining. Bucket wheel machines are used to dig large trenches to install main drainage lines that carry the water from the field. The flexibility of a trenching machine is that it can be used in other industries, such as construction and mining, for installation of non-agricultural pipe or cables (Burtonshaw, personal communication, 2014).

Figure 10: Mastenbroek chain trencher.

Source: G. Gibson, Bury St Edmunds, UK (2014).

Trenchless

Trenchless machines use a single tine ripper or "V" style leg to install pipe. The advantage is the speed that pipe can be placed in the ground compared to a trencher. The tine is pulled through the soil shattering the profile to provide fissures to enhance water filtration. The tine design creates a lifting action in the soil that reduces the draft required. Trenchless machines require more weight and horsepower than trenching machines to maintain the draft required to pull the plough.

Figure 11: Inter-Drain trenchless plough.

Source: G. Gibson, Indiana, USA (August, 2014).

Add-on Drainage Ploughs

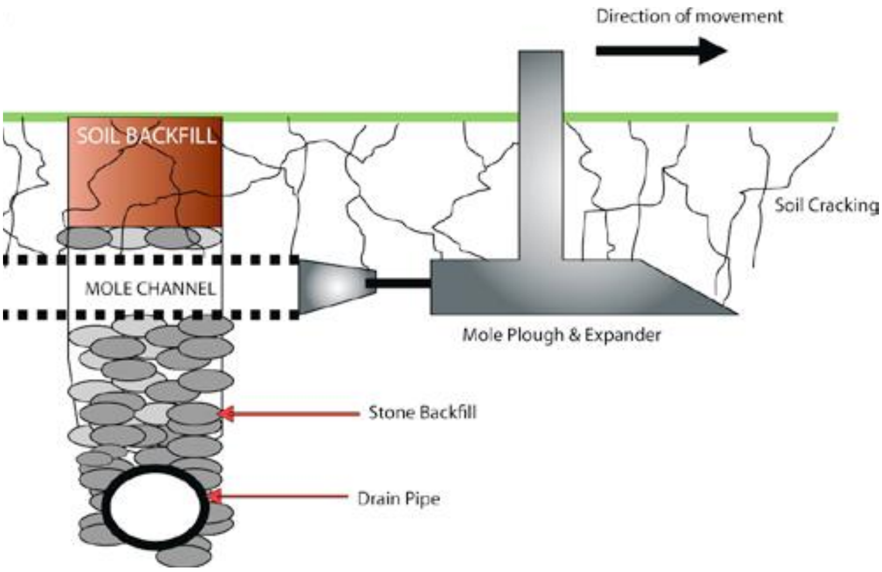
Add-on ploughs and trenchers can be attached to a tractor or bulldozer. There are many manufacturers in this market. The units range from small chain trenching and trenchless machines to very large implements. The advantages of these units are that they are inexpensive and easy to use. In addition, a large percentage of farm tractors now have GPS for auto steer and a software upgrade can offer the capacity to survey and install pipe. Also, growers can install pipe in a quieter part of the season utilising their own equipment. It is critical that professional advice is sought prior to any pipe installation.

Mole Plough

Mole draining utilises a tine leg with a 50 – 60mm diameter bullet or torpedo shaped foot attached. Behind the bullet is an expander or plug (100mm diameter) that is attached by a chain. It is used to help create a round compacted channel to allow water flow (see Figure 12). Mole drains are best suited to heavy clay soils (30-35% and above clay content), and are used to expand the capacity of normal tile drains. This is done by crossing the tile lines containing an aggregate on a level or preferably falling grade. The mole goes through the aggregate and water then disperses into tile lines. Moles are usually installed approximately two metres apart and renewed every four to five years.

It is critical to dig down into the subsoil to check on soil moisture before mole draining. The soil moisture at the mole depth, usually 500mm-600mm, should be able to be rolled into a pencil thick rod and formed into a 40-50mm diameter circle (Department of Environment and Primary Industries, 2010). This is to test that the soil is moist enough to form a good mole that will hold its shape over that period of time. The mole drainage plough is towed at a maximum speed of four kilometres per hour. If speed is any higher, the expander can tear the walls of the channel resulting in failure within one to two years (Beeby, 2014).

Figure 12: Mole plough and channel through permeable fill.



Source: Teagasc (2013).

Gravel Mole Plough

Gravel mole ploughs are similar but are able to fill the mole with aggregate. The mole is held in place in unstable soils unable to hold its shape for an extended period of time. The disadvantage is the added cost of the aggregate, as the narrow spacing of the mole drain make it very expensive.

3.2.5 Permeable Fill

Permeable fill can be used in situations where clay soil types are sub-surface drained. There are many aggregate options and these depend on what is available in the immediate area. The permeable fill can be placed around and above the pipe during installation, using either a gravel box mounted to the rear of the drainage machine, or a gravel sled towed by a gravel cart. The depth of the aggregate placement over the pipe should be to a point where it meets the permeable layer in the soil. Any aggregate above this point serves no advantage. Permeable soil backfilled above the aggregate acts as a natural protective layer minimising nutrient loss through the drainage system as demonstrated in Figure 12. If aggregate is not placed up to the permeable layer in heavy clay soils, water will be extremely slow accessing the drainage pipe (Tuohy, et al, 2013).

3.2.6 Drainage Control Structures

Drainage control structures are used to control water height in the soil profile by being placed at the outfall end of the pipe. In a meeting with Dr Chin Tan (personal communication, August, 2014) at the Greenhouse and Processing Crops Research Centre he explained that a drainage control structure is made up of a square box apparatus with removable stop logs to control water height. The stop logs are removed when the water table depth needs to be lowered. This can be done before a forecast large weather event to prevent the crop from being inundated with water. Likewise, when moving into a dryer part of the growing season, the water table can be raised higher to facilitate irrigation. To use this system to its full potential, a comprehensively drained field containing an even soil type with evenly spaced laterals is required.

Summary

Utilisation of a well-planned and executed drainage system can prove advantageous in the aim to achieve reduced waterlogging and, in turn, yield losses. Surface drainage aims at removing surface water utilising shallow field drains, land forming, open excavated drains, raised beds and hump and hollowing. Sub-surface drainage requires a good design and specialised machinery with precise grade control to achieve desired outcomes.

Chapter 4: Irrigation and soil aspects

4.1 Irrigation

Timeliness of watering is an integral part of plant growth and irrigation gives farmers significant control over this, and also over how much water is applied to maintain optimum conditions. As mentioned in Chapter 1, monitoring soil moisture when irrigating crops will reduce the risk of over-watering.

4.1.1 Irrigation Scheduling

It is important to consider the following when planning an irrigation schedule:

- Soil properties: texture, moisture, infiltration rate, Available Water-holding Capacity (AWC), wilting point and drainage capacity.
- Crop requirements: crop stage (emergence to critical growth period), depth of root zone and disease considerations.
- Irrigation capacity: source, pump, pipeline, machine and nozzles.
- Weather: evaporation rates and forecasts of large precipitation events.

When the data has been collated, a fully operational irrigation schedule can be finalised. Water is an expensive resource and requires careful management decisions. Adoption of a system that suits the particular farm and crops grown will be beneficial to plant growth and, in turn, profit. Data from soil moisture sensors, NDVI and visual inspections provide ongoing information to build watering schedules.

4.1.2 Control Systems

Control systems are mechanisms used to regulate irrigation. There are many differing irrigation control units on the market. They range from simply being able to switch irrigators and pumps off to units that can be fully monitored and controlled on a smartphone. Units can control all kinds of irrigation systems including pivots and laterals with end guns, drip control valves, pumps and injection equipment. They can monitor and record water usage, energy, and also dam levels. Integration between pumps and irrigators provides a system that can be managed simultaneously for efficient performance. Being able to monitor and record water application when using fertiliser injection or when applying effluent provides another layer of environmental protection. Weather information can also be monitored and recorded including temperature, rainfall, humidity, evaporation, soil moisture and wind speed. The attributes that an irrigation control system provides allows for irrigation scheduling, data recording and machine control that saves time. It adds another level of control to managing water efficiently and effectively reduces the likelihood of waterlogging.

4.1.3 Variable Rate Irrigation

Variable Rate Irrigation (VRI) is a control system that enables an irrigation system to supply water in rates relative to the needs of individual areas within fields (Perry and Pocknee, 2003). VRI is used as a method of improving Water Use Efficiency (WUE). It can be linked to irrigation control units to provide a complete package in water management. VRI can prevent waterlogging by limiting watering on wetter parts of a field. It is achieved by either controlling the speed of the irrigator or controlling individual nozzles. Nozzles are computer controlled to switch on and off at set intervals. Multiple irrigation zones can be set up across the field applying differing amounts per zone. Zones can be designed using a hand held GPS and driving or walking around a desired area or it can be done on a desktop computer. Data such as that collected in the survey phase (Chapter 1) of this report can be used to determine zones. Research has shown irrigation water and energy savings of 9 – 19% using VRI as well as reducing runoff and drainage by up to 29% (Hedly et al, 2009).

4.2 Soil Aspects

The discussion in Chapter One focuses on monitoring waterlogging in soils. This section will highlight the methods that can be used to reduce the effects of waterlogging. One of the major causes is compaction. Crop yield reductions of more than 35% have been measured (Houskova, 2014). Reduced crop yields and reduced nitrogen content in crops were detected 17 years after a single compaction event with wheel loads of 5 000 kg (Houskova, 2014). Livestock and heavy machinery operating on fields create hard pans that plant roots are not able to penetrate leaving the plant at risk of reduced growth. Farming practices can determine how healthy the soil is. Staying off wet fields until dry enough to plough, cultivate, plant and harvest can have a beneficial effect on the soil quality and reduce compaction. Unfortunately, it is not always practical and some company harvest schedules, particularly in the vegetable industry, require the crop to be harvested even when field conditions are unsuitable. Damage to fields in these circumstances can take many years to repair. Sub-soiling, Controlled Traffic Farming (CTF) and minimum tillage can reverse and minimise the effects of soil compaction.

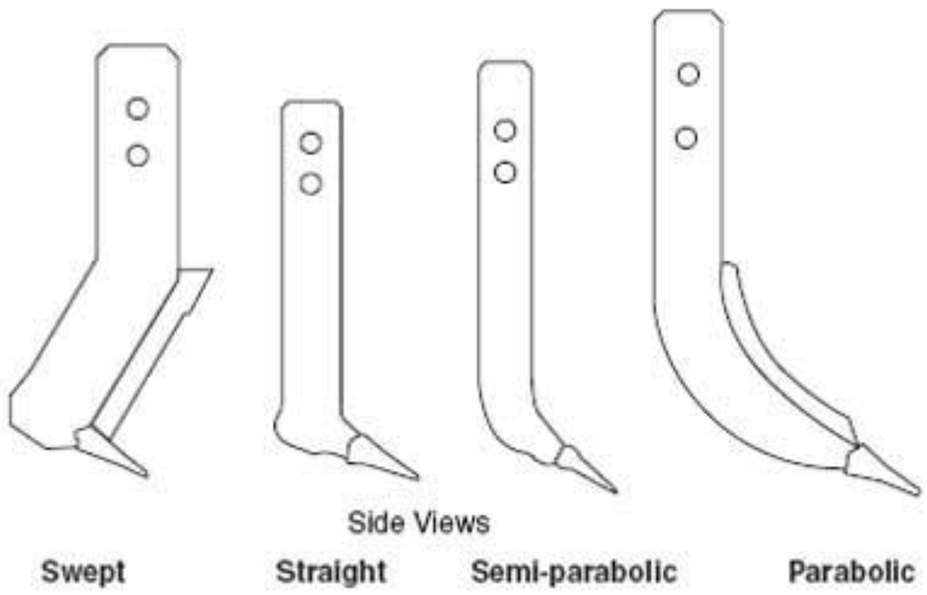
4.2.1 Sub-soiling

Sub-soiling, or deep ripping, is used to break up compacted hard pans created by ploughing or cultivating at a repeated depth. If the compacted layer is hard enough, plant roots are unable to penetrate, leaving the plant with a stunted root system. "Fracturing compacted soil promotes root penetration by reducing soil density and strength, improving moisture infiltration and retention, and increasing air spaces in the soil" (Keys, 2008). Research has shown that depth management is of critical importance. Subsoiling at insufficient depth will not fully eliminate the compaction layer (Cotching & Davies, 2015). Subsoiling at a depth deeper than necessary wastes energy and unnecessarily disturbs excessive amounts of soil. Deciding on depth can be achieved by using a pocket penetrometer or by digging a small test hole 400mm deep and running a knife or screw driver up the wall of the test hole feeling for resistance (Cotching & Davies, 2015). Resistance should be felt at the compaction layer. Subsoiling just below this depth will break up the compacted layer. Attention should also be paid to plant root structure. If roots track vertically through the soil profile and suddenly take a horizontal turn, closer inspection will usually reveal a hard pan.

The benefits of subsoiling can give yield responses due to root development, which aids the plant to capture greater soil moisture and absorb more nutrients. The benefits, however, can quickly recede with re-compaction by traffic, natural soil settling and cementation. To avoid this, subsoiling can be done as the last working of a cultivation program (Chilvers, 1996) or preferably by using a controlled traffic system (discussed below). Subsoiling is best done in summer when dry conditions allow for maximum soil fracturing. Some moisture should be present to limit clods or blocking but conditions should not be too wet to smear the soil (Cotching & Davies, 2015). A gauge to check if soil is at the correct consistency is to roll subsoil in fingers, if a ribbon can be formed, sub-soiling should not be undertaken (Armstrong, Kirkegaard et al, 2009).

There are different shanks available for subsoiling - including straight, parabolic, swept, wing tipped and non-winged. The biggest difference with these shanks is the way they move through the soil and the draft required to obtain the desired outcome.

Figure 13: Subsoiling shank designs.



Source: USDA Forest Service, Technology and Development Program (2008).

The action of not mixing layers is important to keep the soil profile intact. Choosing the correct shank for the soil type will aid in achieving the ideal outcome. For example, if sub-soiling ground with a shallow top soil, low disturbance straight shanks are best used. This prevents mixing unstable clay with high quality topsoil as this dilutes its natural texture (Bastick, personal communication, May 2015). Another example is when sub-soiling deep top soil that requires lifting and mixing to incorporate residues, parabolic shanks are best used.

4.2.2 Controlled Traffic Farming

"Controlled Traffic Farming (CTF) is a farming system built on permanent wheel tracks where the crop zone and traffic lanes are permanently separated. It can improve profitability and sustainability, and adoption of CTF need not be a daunting proposition." (Grains Research and Development Corporation (GRDC), 2013). The idea of CTF is to keep all field traffic on the same tramlines; this is done by matching up seeding, spraying and harvest equipment utilising corresponding or multiple widths.

Matching seeding and harvesting equipment is usually done first. For example, a 12 metre seeding bar and 12 metre harvester front will suit a multiple of three in a 36 metre sprayer (3:1 Ratio) (GRDC, 2013). Some farmers use other ratios but this will mean overlap runs on fence lines and extra runs to match up. Common wheel track width in Australia is set at three metres. Changes to existing equipment include wheel width adjustment on seeding tractors and pull type spray rigs and tractors. With self-propelled spray rigs becoming more common, most machines are capable of three metre centres. Harvester wheel widths are usually at three metres but will sometimes require an auger extension to reach the chaser bin so it can remain on the tramline while being unloaded. As wheel tracks are used for all field traffic they become hard and compacted providing good traction, all weather use and efficiency gains.

The advantages of CTF are many. The GRDC (2013) quote figures up to 16% increase in grain yield in the first year, with averages of 10% being very common. Increased soil health, less erosion and less compaction are high on the list of advantages. In a CTF model, compaction is kept on the tram lines while leaving the field untouched.

A modelled Western Australian farm showed a $47 AUD/ha increase in profit across 1000 hectares - half from yield and half from grain quality (GRDC, 2013). Fuel usage has also been highlighted as a big saving with up to 12% reduction in seasonal use. Infiltration rates compared to conventional farming is also greater. McPhee (2013) showed that, in a CTF system, there was no water run off recorded compared to it only taking four minutes of precipitation to show runoff in a conventional program.

In a Tasmanian high rainfall context, a fully utilised CTF system struggles to match the diverse range of crops grown. Seasonal CTF, using as many options as possible, is still better than nothing (McPhee, 2013). A range of vegetables, opium poppies and cereal crops are all commonly grown in a rotation. Most equipment is on many different wheel centres and matching a single system is very difficult. In a conventional intensive vegetable rotation, McPhee (2013) quoted field track coverage can be from 300 – 500% compared with CTF at 10-20%. The outcome of this is reduced compaction, water runoff, decreased costs and a gain in yield.

4.2.3 Minimum/No Tillage

"The first principle of healthy soil is to minimise the amount of disturbance you're causing to the billions of busy inhabitants of the soil. One of my favourite facts is that there can be more living things in a handful of healthy soil than there are people on Earth" (O'Connor, 2015).

Minimum tillage (no-till) is minimising the amount of soil disturbance. Crops are simply sown using one-pass methods to retain stubble and moisture and to lessen disruption of soil inhabitants.

"Why move several thousand tonnes of soil repeatedly each year to control several hundred kilograms of weeds?" (Land and Water Conservation, 1978).

In a system where the aim is to reduce waterlogging, minimum-till is another tool to assist. As stated above, soil health is critical to the soil's capacity to hold more water and maintain healthy crops. Minimum-till can help through less traffic on the field, increased organic matter, less compaction and improved yields.

The following advantages and disadvantages of minimum tillage/no-till systems have been resourced from SANTFA, WANTFA and GRDC (2009).

Advantages:

- significantly less soil erosion;
- reduction in fuel and labour cost;
- increase in soil structure and health including building organic matter and microbial activity;
- less compaction;
- more timely crop sowing;
- improved yields; and
- improved water use efficiency and moisture conservation.

Disadvantages:

- the reliance of herbicides and the risk of resistance;
- high initial capital outlay for no-till machinery;
- limited crop diversity;
- pre-emergent herbicide efficacy; and
- insufficient crop residue left on the soil surface.

4.2.4 Salinity

Salinity in soil is the presence of soluble salt. When rainfall evaporates, salts accumulate in the soil and in ground water. Salinity affects large areas of irrigated land. Estimates for India range from 27% to 60% of the irrigated land, Australia 20%, Pakistan 14%, Israel 13%, China 15%, Iraq 50% and Egypt 30% (Stockle, 2001). Salt-affected private land in Tasmania is estimated to total 74,000 ha or approximately 4% of the arable land area (Department of Primary Industries Water and Environment (DPIWE), 2007). Land practice changes such as moving from a long pasture phase into intensive cropping using irrigation can increase the risk of accelerated salt build up. Increased water from irrigation moving through the root zone potentially could mobilise salt. A robust monitoring program needs to be in place to maintain a balanced system. An example of salinity risk in Tasmania is an application of saline water of 1dS/m (600 ppm) via irrigation at a typical two megalitres per hectare on a poppy crop adds approximately 1,200 kilograms of salt annually (Bastick, 2001). Risks of salinity can be reduced by controlling the water table depth and maintaining good irrigation management techniques.

Summary

World's best technology enables utilisation of irrigation through scheduling and control systems. This, combined with soil conservation by way of sub-soiling, CTF, minimum tillage and salinity consideration plays an integral role in the systematic approach to reducing waterlogging.

Conclusion

Waterlogging affects large portions of unirrigated and irrigated farmland globally. Reducing waterlogging to minimise yield loss is critically important when responsible for feeding and clothing the expanding world population.

It is imperative for the Tasmanian agricultural community to understand how much waterlogging really costs the industry. With high value crops being commonly grown in Tasmania, minimising crop losses is especially critical. Crops have high inputs therefore any yield loss is extremely costly.

Reducing waterlogging is rarely achieved using a singular tool. This study has presented the multiple options available to reduce waterlogging and, in turn, mitigate crop losses, using an integrated systematic approach.

The causes of waterlogging need to be determined before action can be taken. The use of technologically advanced monitoring tools highlight where, and to what extent, crop losses are likely to occur. A single piece of data offers a very narrow window of information. However, when soil scanning, compaction testing, NDVI and yield information is collated in a layered format, it extends that information base. Add to this multi-year data and the information becomes a very powerful tool. From this, informed decisions can be made about what action to undertake to alleviate ensuing losses before they can arise. Using advanced farming practices and cutting edge technology can give growers an advantage in improving non-performing ground. Suitable drainage techniques, irrigation management and healthy soil are critical when targeting reduction in waterlogging and yield losses.

The importance of understanding how much waterlogging really costs the Australian agricultural industry cannot be over-emphasised. Currently, federal and state governments, and the agricultural industry in Tasmania, are focusing on irrigation systems. Monitoring for unforeseen water management issues also needs to be a priority. There is little up-to-date data available highlighting yield loss statistics due to waterlogging in Tasmania. This information would be beneficial to Tasmanian growers when determining water management programs.

Recommendations

As a result of this study, the key recommendation is that an integrated systematic approach to reducing waterlogging be adopted. Growers, service providers and commodity based companies each have a part to play to ensure that water management systems are sustainable, economically sound and environmentally friendly.

Today's technology provides uncomplicated ways of monitoring soil, water, plant and weather. This enables growers to make more informed water management decisions. The role of the farmer is to:

- Understand the true cost associated with waterlogging;
- View waterlogging as a threat to their income;
- Know what the potential productivity of the farm is without waterlogging;
- Seek the right advice for monitoring programs;
- Understand that advice is expensive, but the right advice is cheap;
- Use techniques and tools suitable to conditions to reduce losses associated with waterlogging; and
- Continually review and address water management systems.

Service providers can also play a role in the adoption of an integrated water management system with increased consultation with growers.

The role of the service provider is to:

- Know that primary producers can be very good at adopting new ideas if it is of benefit to them.
- Increase involvement in crop planning.
- Provide more intense crop monitoring.
- Be proactive with in-season advice to growers.
- Expand knowledge of in-season crop requirements including irrigation scheduling.

- Be up-to-date with the technologies available to facilitate growth.
- Increase involvement with post-harvest reviews.

It would be advantageous for Australian farmers if the agricultural industry encouraged investment in yield mapping facilities in harvesting machinery. In a Tasmanian context this includes machinery used by vegetable and poppy companies.

The role of vegetable and poppy companies is to:

- Provide the option of yield mapping data collection, and
- Analyse the results with growers to help make decisions for future seasons.

Appendices

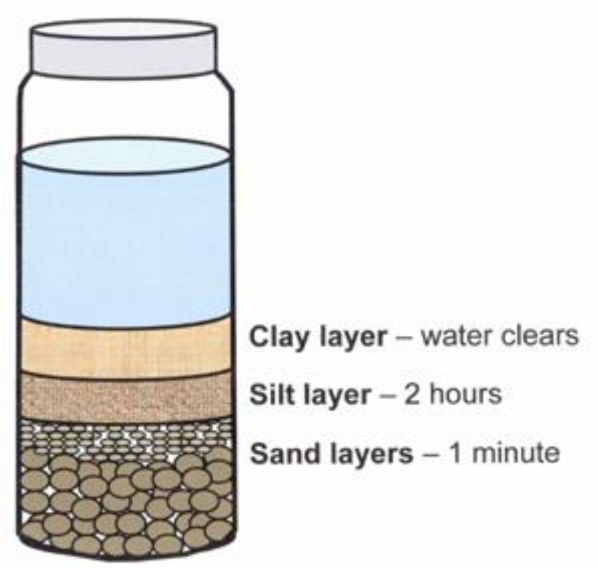
Appendix 1

How to determine soil texture

1. Spread soil on a newspaper to dry. Remove all rocks, trash, roots, etc. Crush lumps and clods.
2. Finely pulverize the soil.
3. Fill a tall, slender jar (like a quart canning jar) 1/4 full of soil.
4. Add water until the just is 3/4 full
5. Add a teaspoon of non-foaming dishwasher detergent.
6. Put on a tight fitting lid and shake hard for 10 to 15 minutes. This shaking breaks apart the soil aggregates and separates the soil into individual mineral particles.
7. Set the jar where it will not be disturbed for 2-3 days.
8. Soil particles will settle out according to size. **After 1 minute,** mark on the jar the depth of the sand.
9. **After 2 hours,** mark on the jar the depth of the silt.
10. **When the water clears** mark on the jar the clay level. This typically takes 1 to 3 days, but some soils may take weeks.
11. Measure the thickness of the sand, silt, and clay layers.
    a. Thickness of sand deposit ____
    b. Thickness of silt deposit ____
    c. Thickness of clay deposit ____
    d. Thickness of total deposit ____
12. Calculate the percentage of sand, silt, and clay.
    a. [clay thickness] / total thickness] = ___ percent clay
    b. [silt thickness] / total thickness] = ___ percent clay
    c. [sand thickness] / [total thickness] = ___ percent sand
13. Turn to the soil texture triangle and look up the soil texture class

(Colorado State University Extension, 2014)

Figure 14: Texture by measurement.



Source: Colorado State University Extension (2011).

Appendix 2

Elements to be considered before undertaking a drainage program:

- Why is the field waterlogged and where is the water coming from? Determination of the cause is the most critical element to rectifying waterlogging. Is it caused by over irrigation, rainfall or flooding?
- Weather patterns/rainfall events.
- Size of the area to be drained.
- Physical attributes of field (examples: topography, soil type, water table depth).
- What is the frequency of waterlogging – a one-off event or a regular occurrence?
- Where can the water exit the field and can all of the surface water exit the field from this point?
- What capacity does the drain need to be?
- What kind of drainage system is most suitable – surface, subsurface or both?
- What are the environmental impacts? Is there a need to do an environmental impact study?
- Are there any government restrictions?

- Will the drainage system correct the issue?
- How long will the drain last - short or long term?
- What is the cost?
- Is it cost efficient?
- Do I need assistance to develop the plan?

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Plain English Compendium Summary

Project Title:	**Utilising Innovative Management Techniques to Reduce Waterlogging**
Nuffield Australia Project No.:	1414
Scholar:	Greg Gibson
Organisation:	Gibson Ag Pty Ltd Hagley, Tasmania Australia
Phone:	+61419528165
Email:	gibsonag@bigpond.com
Objectives	To research monitoring tools available for determining the causes of waterlogging, explore the world's best techniques in reducing waterlogging and implement an integrated systematic approach to reducing waterlogging and, in turn, yield losses.
Background	Waterlogging affects large portions of unirrigated and irrigated farmland globally. Reducing waterlogging to minimise yield loss is critically important when responsible for feeding and clothing the expanding world population.
Research	Meetings with university professors and students studying water management techniques and technologies. Farmers offered important insights into individual strategies to reduce waterlogging and increase yield and profit with sustainable outcomes. Drainage contractors, manufacturers and service providers raised many different views of world's best water management practices. Countries travelled to were USA, Canada, UK, Ireland and the Netherlands.
Outcomes	There are multiple options available to reduce waterlogging and mitigate crop losses. Using advanced farming practices and cutting edge technology can give growers an advantage in improving non-performing ground. This can be best achieved by implementing an integrated systematic approach to reduce waterlogging. The use of monitoring tools highlight where waterlogging has caused crop losses. Informed decisions can then be made to plan an effective water management strategy.
Implications	Growers, service providers, commodity companies and the government each have a part to play to ensure that water management systems used to reduce waterlogging are sustainable, economically sound and environmentally friendly.