Improving productivity of rice farming systems with better layouts

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- The average time to water and drain bays in lasered, side-ditch (or bankless channel) layouts is 40–50 hours. Furthermore, it takes around 60 hours after bays have drained for surface soils to dry/drain to field capacity and allow air back into the profile, resulting in over 100 hours before soil oxygen levels begin to recover.
- Waterlogging following irrigation in contour layouts is considered the single greatest production limiting factor in the rice-based farming systems of the southern Murray-Darling Basin. Minimising the time water is ponded on the soil offers the greatest scope for improving productivity and cropping flexibility.
- To minimise waterlogging, design and operate bays so they can be watered and drained in 10 hours.
- For sodic soils, surface irrigation will almost inevitably cause waterlogging losses. Strategies to reduce waterlogging include individually supplying and draining bays, reducing compaction, increasing organic matter and/or applying gypsum.

Waterlogging has been the major constraint to the productivity of irrigated crops and pastures in the southern Murray-Darling Basin (MDB) since the opening of the irrigation schemes. Annual losses are estimated to be in the order of $80 million in wetter years.

Fine textured soils, sodicity at depth, low saturated conductivity and flat slopes pre-dispose much of the Riverine Plain to waterlogging in winter. We may have forgotten about this problem after nearly a decade of drought, but one of the main causes of lost productivity in contour (or basin) layouts is waterlogging of non-rice crops during and after surface irrigation.

Water ponded for only four hours on a red-brown earth causes waterlogging stress in white clover–perennial ryegrass pasture and yields have been shown to be reduced after 10 hours ponding. Similarly, wheat yields are reduced when ponding times exceed 12 hours. Research at Griffith showed wheat yield declined by 69 kg/ha for each day that water was ponded on the surface of a transitional red-brown earth; equating to a crop loss of 1.0 t/ha from a fortnight's worth of ponding.

Opportunity time

Opportunity time is the time between the arrival of the irrigation wetting front at a point in the bay and the recession of the water following draining. Effectively, it is the time that water is ponded on the soil surface and able to infiltrate the soil profile.

Surface irrigation systems should be designed so that a target depth of water is applied in the minimum practicable opportunity time, to minimise deep drainage losses and waterlogging.

A scoping study conducted in 2007 found wide variation in recommended opportunity times (8 to 15 hours) and an almost complete lack of basic data to support the design of bay sizes for surface irrigation systems in the southern MDB.

Almost no agronomic data was found to support recommended opportunity times and there was evidence that these times may differ between soil types. Furthermore, irrigators who were interviewed reported opportunity times in contour systems that were often more than double the recommended times (i.e. 24 to 48 hours).

In order to address this issue, Industry and Investment NSW, supported by the Murray Land and Water Management Plans and CRC for Irrigation Futures, investigated ways to improve the design and performance of contour systems from an engineering, agronomic and economic perspective. This article summarises part of this study.

Experiments were conducted over the three years (2008–2010) to:

1. determine the duration of waterlogging after irrigation in typical contour layouts and soil types in the southern MDB.
2. determine the length of time that typical Riverina soils can be waterlogged in spring before wheat growth is reduced, with waterlogging timed to correspond with a first spring irrigation at full ear emergence.

These experiments involved a combination of measurements in farmers' paddocks during and after spring irrigations, comparative field trials and a glasshouse pot trial.

How does irrigation affect soil oxygen?

When water arrives on the soil surface during an irrigation event, it cuts soil pores off from the atmosphere and displaces the air within them, causing the oxygen level of the soil to fall. Soil oxygen levels continue to fall, even after the bays have been drained and water is no longer ponded, until all gaseous oxygen has been depleted or until field capacity is reached (i.e. the water content of the soil at which macropores have drained enough for air to enter).

Once field capacity is reached, soil oxygen increases as the soil dries/drains, until oxygen levels come to equilibrium with the air above the soil. At this point, soil oxygen levels plateau, even if soil drying continues.

If rain or another irrigation occurs before oxygen levels in the soil recover, then the depression of oxygen levels caused by the second event will push the oxygen content below that reached after the first event. Consequently, more time is needed for soil oxygen to recover.

Are there differences between soil types?

This pattern of response by soil oxygen to surface irrigation occurred in all the soils examined in the study: red-brown earths (RBE), transitional red-brown earths (TRBE), non self-mulching clays (NSMC) and self-mulching clays (SMC).

Furthermore, despite the number of factors that can influence soil oxygen, the rates of decrease in soil oxygen when the soil was saturated, and the rates of recovery once it became drier than field capacity, were remarkably similar across all the field sites. There were, however, three exceptions:

1. Soil oxygen did not return to pre-irrigation levels if wetting caused a loss of soil structure. This occurred in a RBE and a SMC which had been cultivated and formed into raised beds.
2. Soil oxygen levels in the RBE soils decreased at a similar rate as in the SMCs when irrigated, but they recovered at a rate that was nearly four times faster.
3. Soil oxygen levels were low in the sodic (NSMC) soils prior to any irrigation and following irrigation, and they decreased nearly twice as fast as in other soils.

How long are soils waterlogged after irrigation?

These findings showed that the potential duration of waterlogging stress during surface irrigation does not just equate to the duration of ponding (i.e. the opportunity time).

The extent of the problem in all the rice layouts we investigated is best illustrated by measurements made during the first flush for rice establishment in the second bay of a six-bay, side-ditch delivery, lasered contour layout. The bays were 3.85 ha (350 m by 110 m) with a 1:1500 slope. Flow rate into the block was 17 ML/day.

Although it only took four hours to fill the bay, water was ponded for 44 hours and it took another 59 hours for the soil to dry/drain to field capacity. Soil oxygen levels would have been decreasing for a total of 103 hours.

Water depth loggers and soil waterlogging sensors in one of the bays monitored during the study. Although the bay only took four hours to fill, water was on the bay for 44 hours and it took another 59 hours for the soil to drain. So oxygen levels in the soil were decreasing for over 100 hours.

Effect of waterlogging on wheat

In order to derive recommendations for designing an irrigation system, we need to select a design "event". The most common crop grown in rotation with rice in the southern MDB is wheat, and the highest waterlogging risk to wheat yields occurs with the first spring irrigation.

A glasshouse experiment was designed to simulate waterlogged conditions in wheat at heading.

The results showed that wheat growth between heading and flowering was only affected by ponding after gaseous oxygen in the soil had been depleted for 36 hours.

After 36 hours, wheat growth, relative to the non-waterlogged control, was reduced by 0.19 g/plant for each day that the soil had low oxygen levels. Assuming a density of 200 plants/m^2 and a harvest index of 0.35 to 0.40, this result is similar to the findings at Griffith of 69 kg/ha grain loss per day of ponding.

Maximum irrigation opportunity times

The field trials and glasshouse experiment gave us the information we needed to determine a maximum opportunity time for surface irrigation systems on the Riverine Plain.

The general case

The average time between the end of ponding and drying to field capacity across all soil types was found to be the time it takes for 12.4 ± 1.7 mm of crop evapotranspiration (ETo) to occur. This equates to about 63 hours (2.5 days) in the first the first week of October in the southern MDB when wheat is generally flowering and when it is first irrigated in spring.

Knowing this "duration of soil saturation" plus the response to waterlogging we observed in the wheat in the glasshouse, and assuming a "worst-case" scenario for soil oxygen levels prior to irrigating (i.e. coming out of a wet winter or a previous irrigation), we determined a maximum irrigation opportunity time of 10 hours for surface irrigation systems in the southern MDB.

Based on the soil type differences we observed, specific recommendations may be made for RBE and NSMC soil types.

For RBE soils

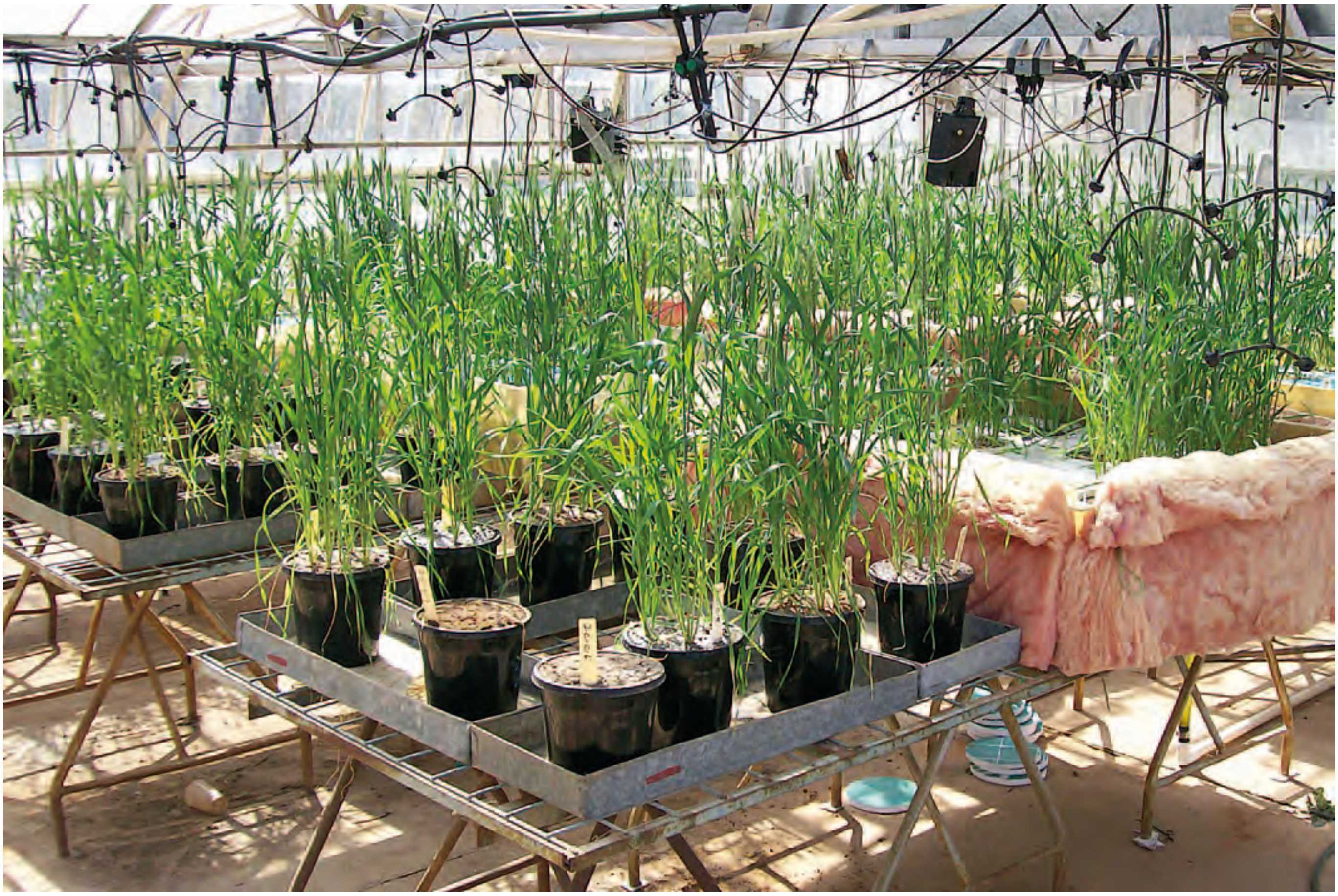
For better drained and non-swelling RBE soils, we used the shorter time to drain to field capacity that we observed (i.e. 55 hours) and determined a maximum irrigation opportunity time of 18 hours.

For sodic NSMC soils

For poorly drained and sodic NSMC soils, soil oxygen levels drop quickly when surface irrigated and they take longer to dry/drain to field capacity following removal of surface water (i.e. 82 hours). Our calculations showed that, if soil oxygen levels are low prior to an irrigation (as was assumed for the other scenarios), then waterlogging stress and production loss is almost inevitable following surface irrigation.

If irrigation opportunity time is 10 hours (as per the general case), then it is still possible to surface irrigate these "problem" soils without causing any waterlogging stress – if the soil is well aerated prior to irrigation.

Irrigators with problem sodic soils could manage their irrigations to ensure good aeration before irrigation starts (using irrigation scheduling, strategic irrigations), improve the structure and



Wheat grown in pots in a greenhouse where waterlogged conditions were simulated at heading. The glasshouse work and the field work enabled recommended irrigation opportunity times to be determined. Generally, bays should be watered and drained within 10 hours.

stability of soils (e.g. minimum-till, retain stubbles, controlled traffic, gypsum application if sodic), or change layouts to improve drainage (e.g. individual supply and drain to each bay, cropping on beds).

Recommendations

Our studies have shown that irrigation opportunity times are generally between 40 and 50 hours in the type of contour irrigation systems commonly used in the southern MDB. This is excessive and appears to be unnecessarily long, as shorter opportunity times are possible and were measured (i.e. 12–14 hours).

Reducing irrigation opportunity times in contour systems is essential if deep drainage losses are to be reduced and irrigation application efficiency improved, as well as if waterlogging induced production losses are to be avoided.

To increase cropping flexibility and ensure maximum production from as wide a range of crops and pastures as realistically feasible, it is recommended that contour systems in the southern MDB be designed to ensure they can be watered and drained within:

- 10 hours, as a general rule
- 18 hours, for non-swelling soils with better internal drainage, e.g. RBE and TRBE soils.

For sodic, NSMC soils, frequent irrigation will result in reduced productivity of waterlogging sensitive crops and pastures, no matter how short the opportunity time. Practices which improve soil porosity and structural stability need to be adopted with these soil types – e.g. soil monitoring to better inform irrigation scheduling; gypsum application; beds/hills, stubble retention, minimum tillage and controlled traffic.

The recommendations resulting from this work are comparable to the current recommendation of 12 hours for water to be on and off bays. However, they have the advantage of being based on experimental evidence which showed the effect of ponding time on soil aeration and the impact on crop growth in typical soil types found in surface irrigation systems of the southern MDB.

Achieving recommended opportunity times

There has been a push over the past few years for "fast watering", and the perceived need to increase flow rates has become a standard response in irrigators' efforts to improve contour irrigation performance.

Rice growers should note that "fast watering" comes from northern Victoria, where soils are lighter and supply flow rates are lower than most areas of southern NSW. Furthermore, without a proper understanding of the reasons for the under-performance of contour systems, higher flow rates may not be the most economically efficient solution for improving irrigation efficiency and providing greater cropping flexibility. It could in fact make matters worse.

In all bar one of the nine layouts that we examined, water was delivered to and drained from bays using a bankless channel (or side-ditch). In all of these systems, the problem was one of excessive drainage time, not slow inflow rate (i.e. supply), and the principle cause of this was the side-ditch.

Side-ditch delivery systems principally fail because of the loss of head that occurs in inlet/outlet structures when water backs up in the downstream bay. This causes a marked reduction in the delivery capacity of the structure, reducing the rate of outflow from the upstream bay.

What to do?

Unfortunately the situation is complex, as the optimal design is a combination of soil type, slope, bay size and delivery flow rate and further work is needed to determine design recommendation based on the multiple combinations of these factors. However, this work is unlikely to be able to produce a "one size fits all solution".

The best solution is to gain a better understanding of your own systems. This can be done simply and effectively by conducting a survey of levels and then measuring water depths and ponding durations near the inlet/outlet in the bottom corner of each bay in a block during an irrigation (i.e. measure water depth in each bay where it is first wet and last drained). This will show whether you have a supply or a drainage problem.

- If irrigation times (i.e. time to fill) are less than drainage times, then your focus should be on improving this aspect of your system (e.g. smaller bays, higher flow rates).
- If drainage times are greater than fill times, then your focus should be on improving drainage (clean toe furrows, steeper slopes, shorter distance to drainage outlets).

If you have a side-ditch system and your water depth measurements show that water is ponded to a greater depth than the side-fall in your bays, then you will be backing up water in your layout and you should consider installing a channel to individually supply each bay.

Further reading

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