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Water use and yields of wheat under centre pivot irrigation in the Murray Irrigation Districts

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Introduction

The number of centre pivot and linear move (CPLM) systems in the Murray Valley has been increasing over the past five years, driven in part by low irrigation allocations and the need to find irrigation systems that require less water. However, CPLM systems require a considerable capital investment and are not suited to all soil types, so objective information is needed when assessing their purchase. This information is currently not available for irrigators in the Southern Riverina and, in some cases, inappropriate and costly decisions have been made. By providing information on achievable yields and water use, those considering purchasing CPLM systems will have industry data for their region and their soils on which to base a decision. Furthermore, by benchmarking current practice, irrigators who currently own CPLM's will have objective data against which they can assess the performance of their systems and identify areas for improvement.

NSW Department of Primary Industries, in conjunction with RM Consulting Group, conducted a benchmarking study for the Murray Land & Water Management Plans (LWMP) in 2005 and 2006. The project had the following objectives:

1. Provide objective performance data on CPLM systems used to irrigate winter crops and lucerne for hay in the southern Riverina by:
    a. Quantifying actual yields of crops per ML of irrigation applied.
    b. Documenting farm practices that lead to these yields.
    c. Evaluating the cost of machine operation ($ per ML water applied).
2. Determine the financial implications of changing to or taking up CPLM pivot irrigation.

This paper summarises some of the findings with respect to just the first of these objectives for the wheat crops in the study. Financial data is yet to be fully analysed and is not discussed.

Methodology

Six co-operators with nine circles of wheat took part in the study in 2005. The amount of irrigation water applied to each crop was obtained from co-operator's records. Rainfall data came from district gauges. Final grain yield was obtained from weighbridge records and crop area or from header yield monitor data. Key data could not be obtained from two sites in 2005 so the methodology was changed in 2006 and these two sites were dropped for two new sites. Only six circles were monitored in 2006 and independent rainfall, irrigation and yield data was collected: the total amount of water applied to each crop was measured using two rain-gauges installed in each crop and the final grain yield obtained from strips harvested with a small plot harvester.

Of the six sites in each year, three were located in the east of the Murray LWMP area on red-brown earth (RBE) soils and three in the west: one on a RBE and two on non-self mulching grey clays (NSMC). In both years, crop growth was monitored from sowing to harvest, beginning with establishment counts and then biomass harvests roughly every 4-6 weeks. Soil water content (0-120 cm) and soil water potential (at 15 and 30 cm) were monitored at each site using a neutron moisture meter (NMM) and gypsum blocks respectively. These measurements did not commence until August/September in 2005, but encompassed the entire growing season from 1-2 weeks after sowing until physiological maturity in 2006.

Results and Discussion

Grain yields per ML water applied

Wheat grain yields across both years and all sites varied from 2 t/ha up to 6.9 t/ha. In general, yields of over 6 t/ha were achieved from fully irrigated crops grown on RBE soils. Crops that experienced some degree of water stress or which were grown on NSMC soils generally yielded around 4 t/ha.

It was found that the water requirement of well managed wheat crops grown under CPLM systems in the Murray Valley could be determined from the French & Schultz (1984) water use efficiency equation. This equation is described by the diagonal dashed line in Figure 1 which states that

$$\text{Total Water Requirement (mm)} = \frac{\text{Yield (kg/ha)}}{20} + 110 \quad \textbf{Equation 1}$$

A more accurate definition of the upper limit to crop water use was obtained in 2006 because the contribution of soil water was included. The diagonal solid line in Figure 1 shows the conversion of water to grain was the same in 2006 (i.e. 20 kg/ha/mm) but estimated direct soil evaporation was 80 mm rather than 110 mm. This suggests that the amount of water lost in direct soil evaporation will be greater if it is applied as pre-sowing irrigation rather than if it is used to water the crop up.

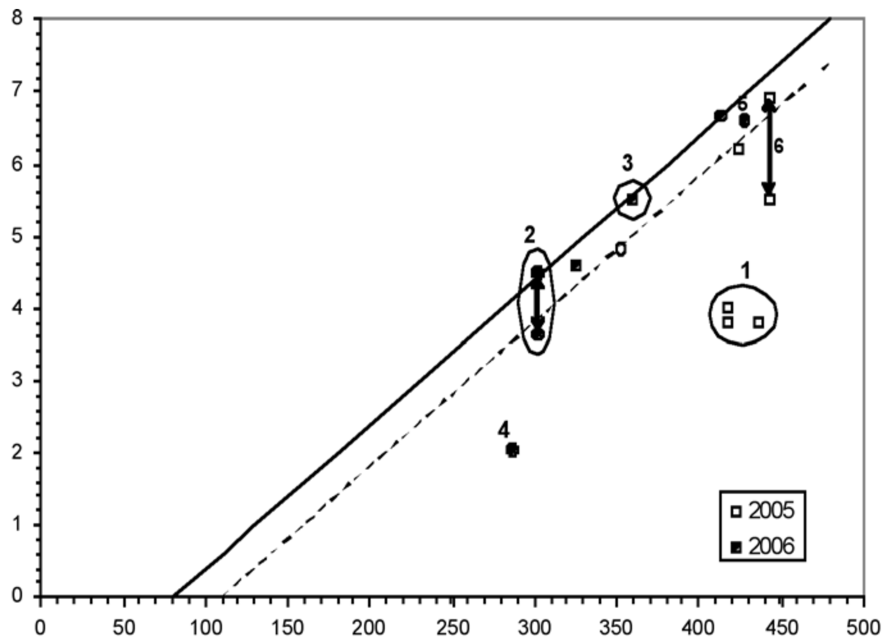

Figure 1. Graph showing the total amount of water applied as rainfall and irrigation to each of the wheat crops in 2005 and 2006 and the yields achieved. The dashed line (- - -) shows the French & Schulz (1984) relationship, with *Yield (kg/ha) = (mm rain + mm irrigation – 110) × 20*. The solid line shows the maximum potential yield when only in-crop water use is considered: *Yield (kg/ha) = (mm rain + mm irrigation – 80) × 20.* The circles and numbers are explained in the text below.

Estimating crop irrigation requirement

Using the findings from the study it is possible to estimate the amount of irrigation water required to grow a given yield. For example, if it is intended to grow a 6 t/ha crop, then approximately 410 mm of water will be needed (i.e. 6000/20 + 110 = 410). The irrigation requirement is then the difference between the total water requirement (i.e. 410 mm) and the amount of water supplied by rainfall. The average Southern Oscillation Index (SOI) for the autumn-winter period is a very good predictor of winter-spring rainfall in the Murray Valley so this can be used to estimate maximum irrigation requirements based on seasonal conditions and expected growing season rainfall.

Table 1 shows that in an average year (i.e. average May-Oct SOI -5 to +5) we can expect at least 158 mm in 80% of years. Under these conditions, the irrigation requirement for a 6 t/ha crop should therefore be no more than 250 mm (i.e. 2.5 ML/ha) in four years out of every five (i.e. 80% of years). If the SOI indicates dry conditions, then an extra 40 mm of irrigation water will probably be required and if a greater level of risk is acceptable, then the estimated irrigation water requirement can be reduced (e.g. by roughly 60 mm for a 50% probability).

Table 1. The minimum amount of growing season rainfall expected in the May to October period at Deniliquin with a 50% and 80% probability of occurrence in dry, average and wet years and for all years of record.

May to October Rainfall	Average May-Oct SOI			All Years
	< -5	-5 to +5	> +5	
In 50% of years, rainfall at least	172	223	256	216
In 80% of years, rainfall at least	115	158	200	155

Estimating on-farm storage requirement

River pumpers may not need on-farm storage if they have access to water all year round. However, irrigators on channel supply will need on-farm storage if they want to realise the full benefits of CPLM systems and irrigate in late autumn and early spring when the channel system may be empty. These benefits include being able to sow on time in autumn and water crops up as well as being able to irrigate early in spring and avoid water stress between ear emergence and flowering without the high risk of following rainfall causing significant yield losses from waterlogging.

If sown on time, wheat in the Murray Valley should flower around the first week of October. To avoid water stress between sowing in early May and flowering in early October, wheat in the central Murray Valley requires approximately 250 mm of water (Figure 2). In 80% of years (i.e. in 4 years out of 5), at least 100 mm of the total water requirement from sowing to flowering will be supplied by rainfall (Figure 3). Therefore, the on-farm storage required to ensure sufficient irrigation water is available to eliminate water stress in wheat between sowing and flowering in the central Murray Valley in 80% of years is 150 mm, or 1.5 ML/ha.

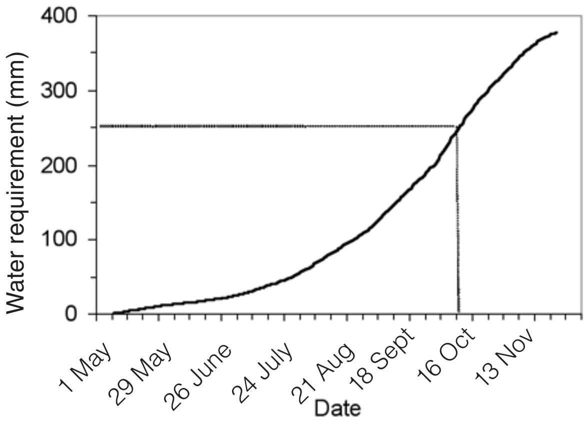

__Figure 2.__ Average potential crop water requirement during the growing season for wheat sown on 9th May at Deniliquin based on average ET_o at Deniliquin and local crop factors. The dotted lines indicate the depth of water (i.e. 250 mm) required to grow the crop through to flowering in early October without incurring water stress.

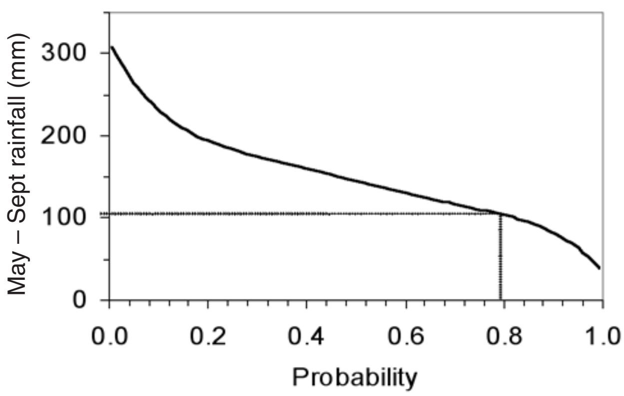

__Figure 3.__ The probability of receiving at least a given amount of rainfall in the period from May to September at Deniliquin. The dotted lines show that at least 100 mm of rain is expected 4 years in every 5 between May and the end of September.

Factors contributing to achievable yields

1) Heavy clay and sodic soils

The results circled and labelled "**1**" to "**3**" in Figure 1 are from crops grown on NSMC soils which have been classified as a Niemur clay (Smith ***et al.*** 1943). These are sodic, grey clays of heavy texture with a dense, poorly structured B horizon and their unstable surface structure, low permeability and poor surface drainage predisposes them to waterlogging. The crops inside the circle labelled "**1**" in Figure 1 were waterlogged after irrigation/rain in 2005 and this reduced their yield. Evidence of waterlogging is seen in the soil water potential data in Figure 4 which shows that it took 5-6 days for the NSMC to drain to an aerated condition at 15 cm depth following two large rainfall events in November 2005, whereas the RBE at the same depth drained to a similar condition after only two days. Waterlogging is not a yield limiting factor in a dry year such as 2006 and crop water use efficiency may be improved. This is illustrated by the crops from Site "**1**" and "**2**" in Figure 1 which had similar yields but markedly different water use.

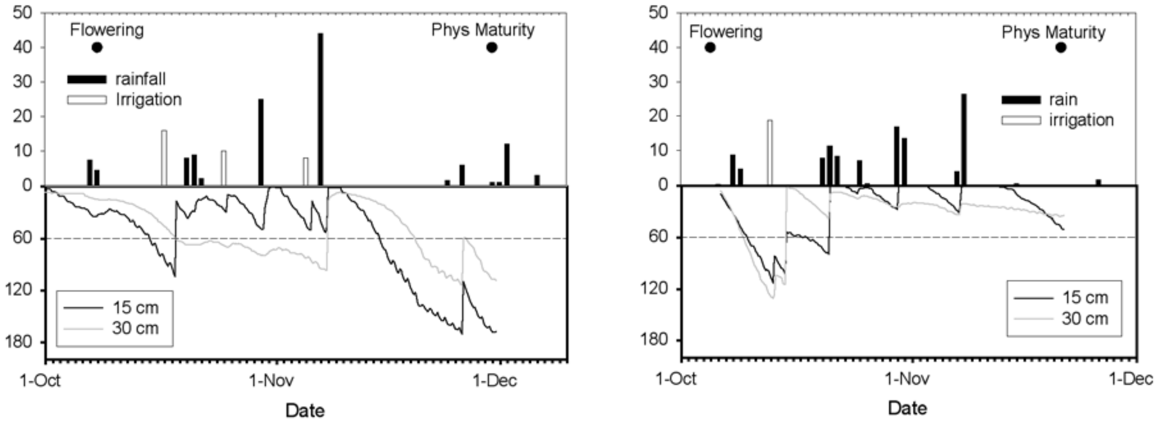

Figure 4. *Graphs showing rainfall (solid bars) and irrigation (hollow bars) and corresponding soil water potential at a depth of 15 and 30 cm at two sites in October and November 2005. The two sites had different soil types: RBE on the left and NSMC on the right*

It needs to be noted that *these soils are best suited to flood irrigation, particularly for rice*. Careful consideration is needed before installing a CPLM system on these soils. If the decision is made to site CPLM systems on NSMC soil, then management practices need to be adopted which improve soil structure and permeability and reduce the risk of waterlogging (e.g. stubble retention, direct drill, controlled traffic and gypsum if ESP is high). The results from Site "**3**" (see Figure 1) show that good yields are possible on NSMC soils under CPLM systems when these practices are implemented. However, management will always be more difficult and high yields under CPLM systems will be harder to obtain than on RBE and loam soils.

2) Timing of irrigations

The low yield from Site "**4**" in 2006 (Figure 1) highlighted the effect of excessive water stress in reducing crop water use efficiency. There was insufficient water to fully irrigate all crop circles on this property and winter rainfall did not wet the soil profile below 60 cm so there was only a limited soil water store for the crop to draw on in spring. This was possibly exacerbated by lucerne drying out the sub-soil in 2004 and then insufficient rainfall to replenish sub-soil water following its removal. Consequently, the 2006 wheat crop became increasingly water stressed from booting onwards (Figure 5 below). The dry subsoil and restricted root volume meant all crop water had to be supplied through the centre pivot and the hot, dry conditions and limited soil water availability made this impossible.

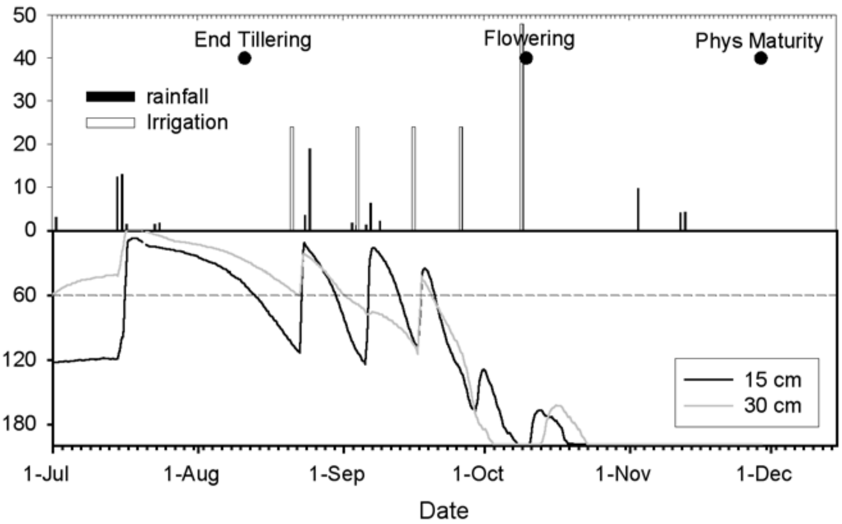

Figure 5. *Rainfall & irrigation (top) & soil water potential at 15 & 30 cm (bottom) in a RBE at Site "4" in 2006.*

The benefit of having a reserve of soil water deeper in the profile is illustrated by the results from the crop labelled "**2**" in Figure 1. This crop grew on a NSMC which had a wetter sub-soil so its roots were able to grow deeper (to 120 cm) and draw on an estimated 115 mm of plant available water, as opposed to only 75 mm at Site "**4**". The extra soil water reserve meant that water use from the top-soil at Site "**2**" occurred at a slower rate so that the irrigations at flowering and early grain fill were more effective and prevented the crop from becoming severely water stressed at this time (compare Figure 6 with Figure 5). The Site "**4**" crop was not fully irrigated because of the low irrigation allocation in 2006, but it had sufficient sub-soil moisture to finish filling the grain. As a result, the Site "**2**" crop used 35 mm less water than the Site "**4**" crop, yet produced roughly 1.5 t/ha more grain because it was able to use 50 mm more water from the soil.

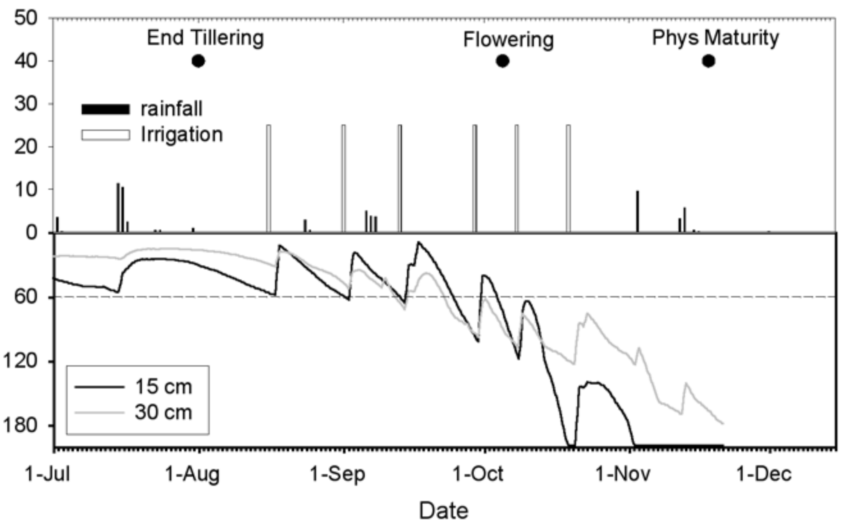

Figure 6. *Rain & irrigation (top) & soil water potential at 15 & 30 cm (bottom) in a NSMC at Site "2" in 2006.*

In contrast to the Site "**2"** and "**4**" crops, the crop at Site "**5**" (Figure 1) was fully irrigated to eliminate water stress until mid-way through grain filling (Figure 7) and, consequently, it yielded 6.6 t/ha. The gross margin for this crop was $1045/ha, clearly illustrating the benefits of irrigating to maximise crop yields under CLM systems. However, given the limited availability and high price of irrigation water in 2006 and the high prices being paid for fodder, the co-operator at this site felt it would have been better to cut this crop at flowering for fodder and thus avoid the cost of applying the last four irrigations which required 1 ML/ha.

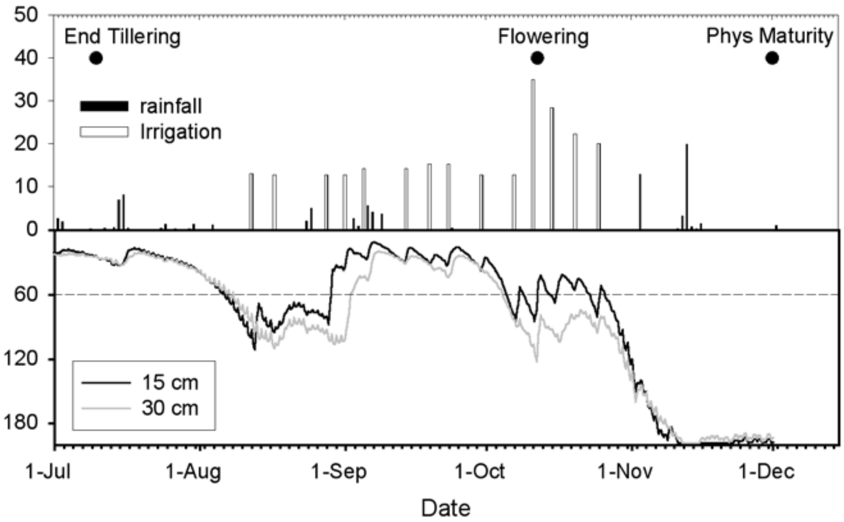

Figure 7. *Rainfall & irrigation (top) & soil water potential at 15 & 30 cm (bottom) in a RBE at Site "5" in 2006.*

3) Agronomic management

There were two sites where appreciable yield variation occurred (double headed arrows in Figure 1). In 2005, there was a 1.4 t/ha difference between the two varieties at Site "**6**". This was primarily due to lodging in the Ventura (5.5 t/ha), which grew taller and had larger heads than the adjacent crop of Wyalkatchem (6.9 t/ha). At Site "**2**" in 2006, the whole paddock yielded 3.6 t/ha whereas the yield from the header strips was 4.5 t/ha. This difference arose because the crop at this site had alternating strips of good and poor growth and the header strips were only taken from areas of good growth. The reasons for this variation are unknown, but the crop was sown dry and watered up and the heavy clay surface soil and lack of good follow up rain resulted in very patchy establishment.

The point here is that a greater level of crop management is required with CPLM systems because of their higher capital and operating costs compared to conventional flood irrigation systems. Adopting the same level of management and inputs as commonly used with flood systems and accepting yields of 4-5 t/ha will not maximise the benefits of CPLM systems or ensure a sufficient return to capital. Because the production function is a straight line, the profit maximising strategy for CPLM systems is to maximise yields (i.e. target 6-7 t/ha), even at quite high operating costs.

This is best illustrated by example. Assuming a return for wheat at the long term average price of $180/t, then the production function can be represented by the thick black line in Figure 8. If growing season rainfall is 250 mm and the dryland cost of production is $300/ha, then the profit from the rain-fed crop is the vertical distance between the production function (black line) and the cost function (grey line) at 250 mm on the x-axis in Figure 8. Irrigation with the CPLM increases yields by 20 kg/ha/mm (2 t/ML), so the vertical distance between the production and cost functions (i.e. profit) will also increase provided the cost of applying the water is less than $360/ML (i.e. 2 t/ML * $180/t).

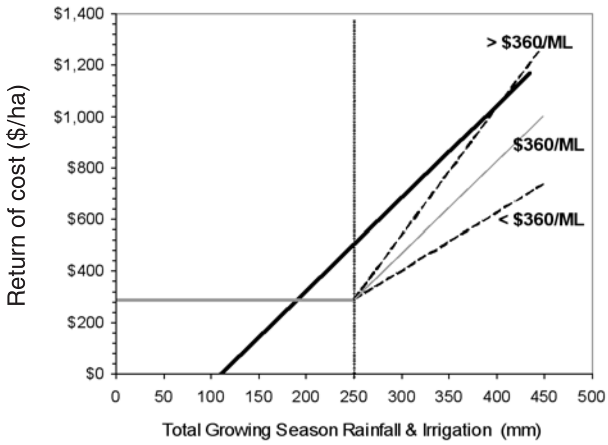

Figure 8. Production function (solid black line) for wheat at $180/t and an example cost function (grey line), illustrating the effect of increasing application costs on profit.

Summing Up

The key finding of the project is that the yield-water use production function for wheat under CPLM systems in the Murray Valley is a straight line equivalent to the French & Schulz potential water use efficiency equation (Equation 1). This is not surprising, given that irrigation losses through overhead pressure systems should be similar to those from rainfall (i.e. canopy interception and direct evaporation) and deep drainage losses, which occur with excess rainfall or surface irrigation, were non-existent in the crops monitored in 2005 and 2006.

Because the production function is a straight line for yields in the range 3.5 to 7 t/ha, then the profit maximising strategy is to apply sufficient water in order to maximise yield. A yield target of 6 to 7 t/ha appears realistic for well managed wheat grown under CPLM systems on RBE soils. However, a target yield of 4 t/ha may be more realistic for wheat under CPLM systems on (sodic) heavy clay soils, though this may be increased to closer to 6 t/ha with good soil management practices.

The total crop water requirement for a target yield can be estimated from Equation 1. Thus, a 6 t/ha crop will need 410 mm and a 7 t/ha crop will need 460 mm. There is a very high probability (i.e. 80%) of getting at least 155 mm of growing season rainfall at Deniliquin and, in 50% of years, at least 220 mm. Therefore, the irrigation requirement for a 6-7 t/ha wheat crop will generally be around 190 to 240 mm should only exceed 250 to 300 mm roughly one year in five.

Storage is required for those on district supply to allow best use of CPLM systems in autumn and early spring if conditions are dry and the channel system is empty. The most water sensitive period for wheat is the period from ear emergence to flowering and the crop water requirement up until flowering will be approximately 250 mm. In 80% of years, May-September rainfall will be at least 100 mm, so the estimated storage volume required to ensure wheat is not water stressed before flowering in four years out of five at Deniliquin is 150 mm (i.e. 1.5 ML/ha).

Storing this volume of water also provides an opportunity to maximise crop biomass at flowering in a dry year and suit it for fodder if insufficient water is available to finish filling grain.

CPLM systems have a number of advantages over flood systems:

- they allow crops to be sown on time, so yield potential is greater because flowering and grain fill takes place at a cooler time of the year;
- less water is needed to grow a given yield because losses to deep drainage are negligible if irrigations are properly scheduled;
- the potential for high yields is greater as the risk of waterlogging from slow irrigations or from rainfall following irrigation is much reduced;
- theoretically, they allow irrigators to stay in the market and compete for water at a higher price than irrigators with surface systems;
- they provide the ability to irrigate a larger area in a more timely fashion to avoid water stress
- they are well suited to RBE and sandy soils which may have excessive deep drainage losses if flood irrigated.

Their principle disadvantages over flood systems are:

- their high capital cost means it is important to attain high yields and to have them working every year to ensure a return to a sufficient capital;
- they are not ideally suited to heavy clay soils, as irrigation management becomes more difficult and yields and the return to capital can suffer and they should not be installed on sodic heavy clay soils which are best suited to growing rice;

- they may not be as well suited to irrigation of summer crops because of difficulties in keeping up with crop water demand and high water application costs and irrigators need to examine closely whether CPLM systems are justified for this on our heavy soils.

The key take home message from this study is that growers thinking of purchasing a CPLM system for winter cropping need to be confident of achieving wheat yields in the range of 6 to 7 t/ha. This requires a higher level of inputs and management than is common for flood irrigation systems in the irrigation districts of the Murray Valley. For example, given input costs of $400/ha, a water price of $50/ML and a pumping cost of $50/ML, then applying 2 ML/ha over 100 ha means break-even returns need be $600/ha. If the capital cost of the CPLM machine, installation and storage to irrigate 100 ha is $250,000, then a return of $850/ha is needed to obtain a 10% return on capital. If the CPLM system is used to irrigate one circle of summer crop, then the need to return 10% of its capital cost from the winter crop is reduced. However, returns to capital will decrease markedly if the machine is not used because of a lack of water, or because the price of water is too high.

References and further resources

Barron, G. (2005). Centre Pivot irrigation in the Riverina. *Primefact 98*. NSW DPI, Orange, NSW. http://www.dpi.nsw.gov.au/aboutus/resources/factsheets/primefacts/centre-pivot-irrigation

French RJ, Schultz JE (1984) Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. *Australian Journal of Agricultural Research. 35,* 742-764.

Smith R, Herriot RJ, and Johnstone EJ (1943) 'The soil and land-use survey of the Wakool Irrigation District, New South Wales.' (Council for Scientific and Industrial Research, Melbourne, Vic.)