Scheduling technologies to improve irrigated water use efficiency…
… a focus on centre pivots and lateral moves

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Take Home Messages

- Centre pivots and lateral moves are increasingly being adopted by broadacre farmers. However, machine performance is often lower than claimed and should be evaluated.
- Ensure the machine has an adequate capacity and high uniformity of application.
- Scheduling using centre pivots and lateral moves is more complex than other systems – tools are available to assist in assessing different strategies.
- Variable rate application systems provide an opportunity to respond to infield spatial variability
- The next generation of irrigation scheduling tools may involve automated adaptive control systems to maximise crop water use efficiency.

Key Words: irrigation, capacity, uniformity, scheduling, OVER*Sched*

1. Introduction

Broadacre farmers are increasing adopting centre pivots or lateral moves to improve on-farm water use efficiency. Advantages of these machines compared to other irrigation systems include labour, water application and fertiliser savings as well as the potential for increased agronomic responses leading to both improved crop yields and irrigated water use efficiencies. Disadvantages include the additional capital cost for conversion, maintenance requirements and the level of knowledge and management input required to obtain the benefits. The potential to apply small volumes on pre-season irrigations, improved germination of crops, better utilisation of in-season rainfall and the ability to utilise deficit irrigation strategies have all been cited as reasons for the lower irrigation water use and increased crop water use efficiencies obtained with centre pivots and lateral moves (CP&LMs). However, recent evaluations of machines have found that the performance and management of many machines is sub-optimal.

2. Machine Issues

Inadequate machine capacity will limit yield potentials

Inadequate system capacity is a major cause of low performance and yield potential. The system capacity is the maximum volume of water the machine is capable of supplying to a given area in a given time. It is expressed as mm/day not the depth applied per pass (mm). For example, a machine that has a system capacity of 12 mm/day does not mean that 12 mm is applied in each irrigation event. Rather, the machine would more likely be used to apply 25 to 50 mm per pass to minimise plant and soil surface evaporative losses common with smaller applications but the machine would take between 2 and 4 days to complete a full revolution. Machines which are used to irrigate summer crops require sufficient capacity to meet the peak irrigation demands (often 12-14 mm/day) during these periods. Machines with inadequate capacity (sometimes as low as 4 mm/day) will not be able to apply sufficient water during peak periods (Figure 1). These machines are also built to run 24 hours a day, seven days a week and should be operated in this manner during peak periods.

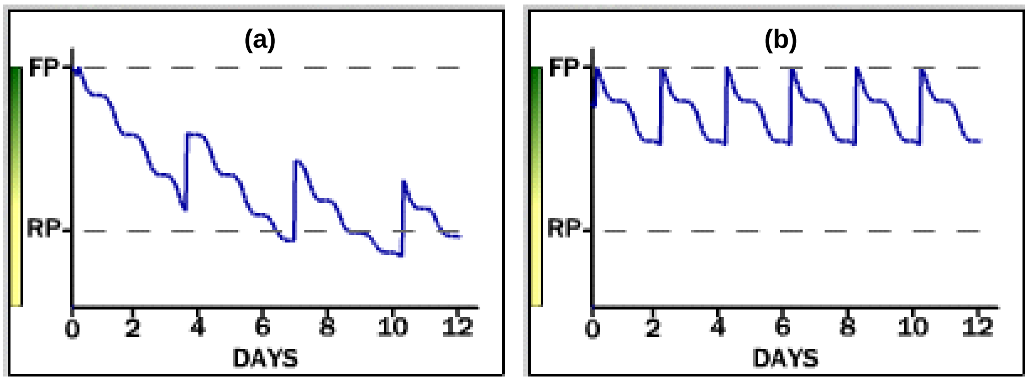


Figure 1 *Effect of (a) 6 mm/day and (b) 10 mm/day capacity of a centre pivot on the soil water deficit (machine application = 20 mm/pass, crop water use 10 mm/day, refill point = 40 mm)*

Uniformity of water application can be a major problem

The performance evaluation of in-field application systems can be divided into the two major components of water losses (ie. application efficiency) and uniformity of application. Although both components are influenced by system design and management practices, the losses are predominantly a function of management while the uniformity is predominantly a function of the system design characteristics. The ability of the irrigation system to apply water efficiently and uniformly to the irrigated area is a major factor influencing the agronomic and economic viability of the production system. The coefficient of uniformity (CU) for water application by well designed and maintained CP&LMs should be greater than 90%. The variation in water application increases rapidly with small decreases in CU. Figure 2 shows an example of a typical catch transect for a centre pivot with end gun showing the variation in the volume of water being applied along the machine. Typical problems include inadequate pipe sizes, incorrect sprinkler spacing or nozzle packages, sprinkler placement around the towers and operation of the end gun affecting the system hydraulics.

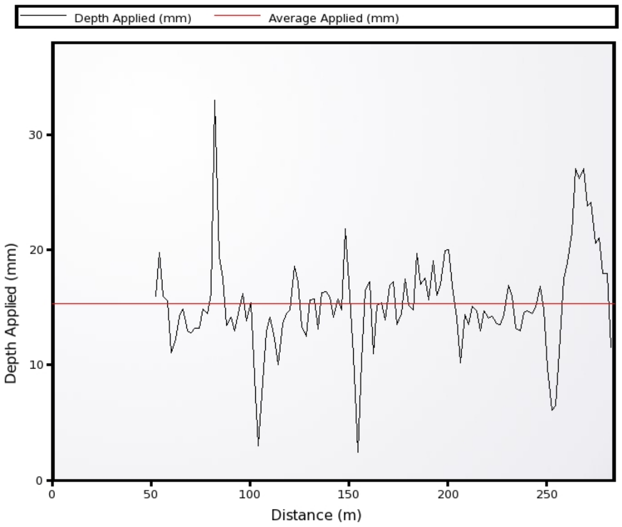


Figure 2. *Catch can measurements along a radial leg transect for a centre pivot (with end gun) (CU_{hh} = 80%)*

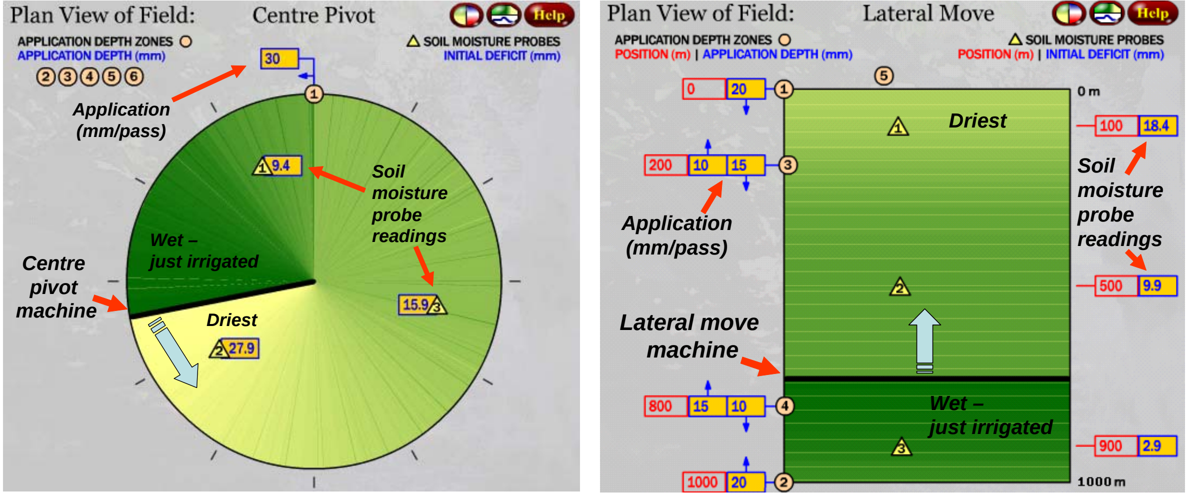
3. Scheduling for CP&LMs

CP&LM operation affects soil moisture variations within fields

CP&LMs are continuous move systems which enable frequent but relatively small irrigation applications to be applied. Appropriate irrigation scheduling (ie. both how much water to apply and when to apply the water) is important as it is closely related to crop yield potentials. Scheduling irrigations is necessary to maintain readily available water in the root zone. It is especially important to maintain adequate soil moisture levels during periods of critical crop growth (e.g. pre-flowering, grain filling). The risk of applying an inappropriate schedule is generally greatest during peak crop water demand periods.

The movement of CP&LMs produce significant soil moisture variations across the field. This may make it more difficult to interpret point source soil moisture or plant measurements. For centre pivots, the driest part of the field is typically immediately in front of the machine. However, for lateral move machines, the driest part of the field is typically at the opposite end of the field to the machine. There is also a need to consider ramping down the applied depth as the lateral move approaches the end of the field (and subsequently ramping up the applied depth as the machine moves away from the end of the field) to ensure that the field ends are not over watered.

While traditional approaches to scheduling irrigations are focused on minimising crop stress, there may be significant benefits associated with using regulated deficit irrigation strategies for some crops. However, managing the crop to ensure that excessive stress is not applied requires extra plant growth monitoring and a detailed understanding of the crop physiology. The visualisation tool OVER*Sched* (www.irrigationfutures.org.au/OVERsched/OverSchedv1-0.html) can be used to evaluate a range of scheduling strategies for CP&LMs (Figure 3).



(a) (b)

Figure 3. *OVERSched examples showing soil moisture variations across a field under (a) centre pivot and (b) lateral move machines.*

Starting irrigations after rainfall?

Rainfall events tend to even out infield differences in soil moisture. Large rainfall events will completely fill the rootzone across the field. Irrigations should be re-started well before all of the readily available water has been extracted and early enough to ensure that the machine has irrigated the whole field before the refill point is reached at any point. The amount applied when the machine is initially started should be no greater than the extracted water immediately in front of the machine. However, the application amount should be increased progressively until it reaches the normal application volume per pass.

Calculating appropriate irrigation schedules using evapotranspiration data

The most common method of developing an appropriate irrigation schedule involves the measurement of potential evapotranspiration (ET_o) and the volume of soil water able to be readily utilised by the crop (termed the “readily available water” or RAW). In this method, the daily crop water use (termed the “crop evapotranspiration” or ET_c) is calculated by multiplying a crop coefficient (K_c) and the ET_o obtained from atmospheric measurements. The RAW is estimated from texture-based soil water characteristic data, the maximum acceptable level of crop stress and the crop rooting volume (ie. depth). The maximum irrigation interval (in days) may then be calculated as the RAW (mm) / ET_c (mm/day). The volume of irrigation to be applied if the maximum irrigation interval is used is then equivalent to the RAW. For shorter irrigation intervals it is calculated as the ET_c multiplied by number of days since the last irrigation.

A major drawback of using evapotranspiration data for calculating irrigation schedules is that many growers do not (a) have access to a local weather station able to provide real-time ET_o data and (b) have difficulty relating variations in ET_o to a change in irrigation application. These issues are currently being addressed in several ways. Data from Bureau of Meteorology stations is now being interpolated to produce daily ET_o on 5 x 5 km grid resolution across the whole of Australia. This data is currently being provided directly to growers in a number of areas via web, email or SMS services. For fixed irrigation systems where information on the system capacity and crop has previously been recorded, it is also possible to provide the "hours of pumping" required to meet the crop water demands. For CP&LM systems, this data could be provided as a suggested application volume or possibly as a machine speed.

Soil moisture and plant monitoring sensors

Soil moisture sensors typically measure either soil moisture potential or content at a point in the field. Differences in soil properties within the field (e.g. depth, texture, salinity) should be considered when installing a soil moisture sensor. Electromagnetic (EM) surveys may be used to identify soil variations within fields (Figure 4). In some cases, EM measurements have been shown to be well correlated with plant available water content. Soil moisture sensors should be located to monitor either the most limiting soil in the field or to represent the dominant soil type. However, it should be noted that interpretation of soil moisture data requires careful consideration as there are significant moisture variations within fields due to machine operation and there is a need to consider the machine location relative to the sensor and the crop water demand since water application. Hence, soil moisture sensors under CP&LMs are often used to fine tune schedules calculated using ETo measurements (as above). In this case, the response of a soil moisture sensor located near the bottom of the active rootzone is used to identify either deep drainage (reduce application volumes) or crop stress (increase application volumes).

The plant water extraction depends on the potential (or energy) of the soil-water which is most commonly measured using tensiometers or matric (e.g. gypsum or ceramic) block devices. Measurements of potential are useful for identifying when to initiate irrigation. A benefit of these devices is that the threshold values for re-irrigation using soil-water potential are the same across soil types but vary between crops. They may also vary depending on stage of crop growth and management (ie. deficit) strategy. Accurate soil-water content measurements provide an indication of how much water to apply. While there are a wide range of soil-water content devices available, calibration of these instruments are rarely conducted under commercial conditions. Hence, these instruments (particularly those with multi-depth sensors) may be used to provide an indication of soil-water extraction patterns. Where soil moisture sensors are logged, temporal data can be used to assess crop stress and initiate irrigations.

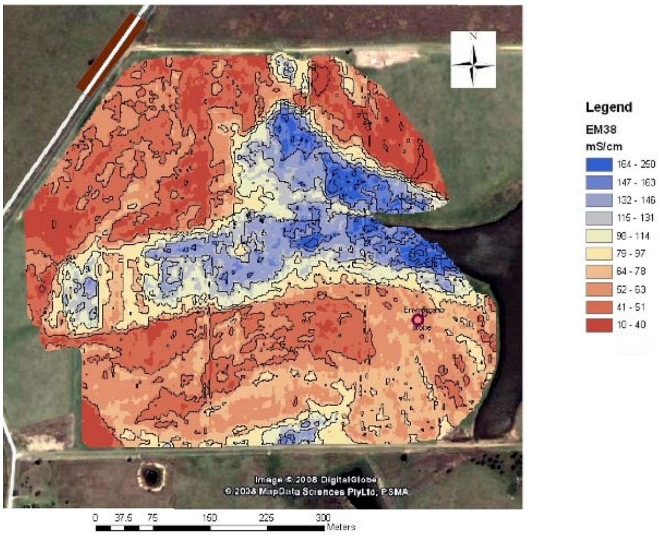


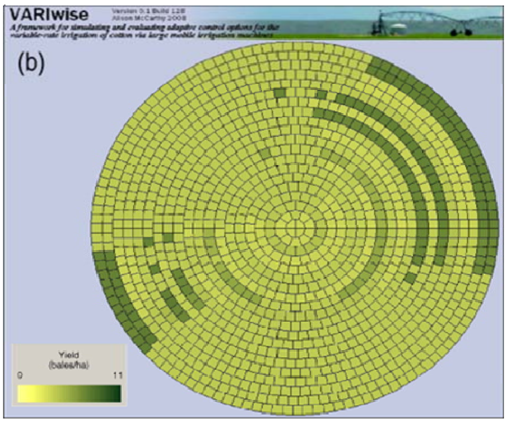
Figure 4. *Electromagnetic survey showing soil variations under a pivot*

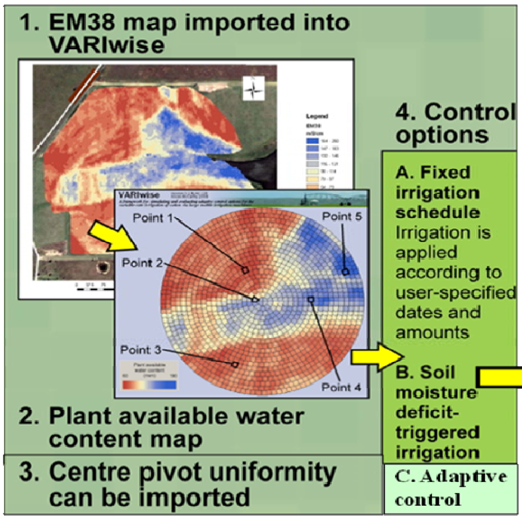
A limitation with using soil based scheduling is that these measurements do not provide a measure of plant water status. Crop growth and response to irrigation is a function of plant water status and depends on soil water status, evaporative demand, the rate of water flow through the plant and the corresponding hydraulic flow resistance between the bulk soil and the appropriate plant tissue. A wide range of plant monitoring sensors (PMS) are now commercially available. These sensors enable continual 'real-time' measurements of a variety of crop parameters including stem growth, leaf temperature and sap flow. Plant monitoring senors provide an insight into the 'real-time' crop water status and are particularly useful when coupled with both atmospheric and soil moisture data.

Proximal and remotely sensed net difference vegetation index (NDVI) and thermal infrared data have been used to identify field scale variations in crop stress and vigour both in dryland and irrigated crops. Similarly, dendrometers have been used, particularly in perennial crops, to develop an understanding of moisture stress responses. However, there is little information currently available which provides convincing evidence of significant benefits associated with using PMS for commercial irrigation scheduling of broadacre crops. A key limitation is the identification of appropriate PMS threshold values required to initiate irrigation applications under different crop, cultivar and/or atmospheric conditions.

4. The Future - Dealing with infield spatial variability

CP&LMs traditionally apply the same depth of irrigation over either the whole field or large sections of the field. However, not all plants in a crop may require the same amount of water due to the stochastic nature of the crop response and the spatial variability of environmental factors within the field. The variable speed controllers currently available on most machines enable the applied depth to be varied with machine speed. However, few environmental or crop management variables only vary perpendicular to the direction of machine travel. Consequently, current research is investigating automated control strategies using sensor input to effectively manage spatially and temporally varied irrigation applications under centre pivots and lateral moves in real-time. A framework to simulate adaptive control strategies has recently been developed (Figure 5) is currently being evaluated. This framework should provide a basis to assist growers identify the benefits and limitations of implementing variable rate irrigation strategies under different crop and environmental conditions. Components of the software are also expected to provide the basis for the commercial implementation of real-time adaptive controllers.





Sensor location	Variability in machine uniformity	Yield (bales/ha)	Irrigation water use efficiency (bales/ML)
Point 1	Low	7.0	0.7
	High	7.0	1.0
Point 2	Low	7.1	0.7
	High	7.0	1.0
Point 3	Low	7.1	0.8
	High	4.6	0.4
Point 4	Low	6.8	0.7
	High	7.0	1.0
Point 5	Low	7.4	0.9
	High	7.0	0.9

Figure 5. *Example of VARIwise operation for assessing the impact of in-field variations in soils and irrigation application on yields with different soil moisture probe locations*