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Water and Energy Efficiency of Centre Pivots on Dairies

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Introduction
As part of a Future Ready Dairy Systems project, field evaluations of 18 overhead irrigation systems were undertaken in 2011 and 2012 in the Hunter Valley and the Tamworth region. The purpose was to obtain measures of water and energy efficiency of centre pivot and lateral move irrigation systems in dairy farms, and establish the potential to improve water efficiency and to reduce energy costs.

This follows a similar project conducted in 2005 which examined water efficiency of overhead systems. With energy costs appreciating considerably, this project expanded the investigations to include energy measurements.

Field evaluations and calculations
The field tests were conducted on 17 centre pivot systems and one lateral move system on 11 properties. All except one enterprise were dairies, the other was a fodder production farm. Most systems were some years old, most in the order of 10 years. In each case, the uniformity tests were conducted in accordance with ISO 11545 *'Agricultural irrigation equipment – Centre-pivot and moving lateral irrigation machines with sprayer or sprinkler nozzles – Determination of uniformity of water distribution'*. Two lines of catch cans were laid out on the ground surface spaced 3 metres apart. The lines were a maximum of 50 metres apart at their outer end. They were placed sufficiently ahead of the system to avoid water entering on start up, except for the first span or two of the centre pivots where this was almost unavoidable. In many cases, catch cans were not placed under these spans as they would have had too much extra time to collect water, and the inner spans command a relatively small area compared to the remainder and hence contribute relatively little to the overall result.

The operating irrigator was passed over the cans until all, except perhaps for those under the inner span or two, were not collecting water. The volume in each catch can was measured and recorded.

To determine the speed of the irrigator, the time for the outermost tower to travel a measured distance was recorded.

The wetted width or diameter of the emitters at the outer end of the system was measured by inserting two pegs into the soil at either extremity of the wetted throw and measuring the distance after the irrigator had passed.

For most systems, the flow rates of at least one emitter per span were checked by timing how long each took to fill a container of known volume, usually a 10 litre bucket. These flow rates were compared to the supplier's specifications.

The pressure at the centre of the irrigator was measured for 12 of the systems using installed pressure gauges where fitted, and at the end of the system and sometimes in between using gauges fitted by the project team. These were compared to the manufacturer's specifications. A conventional minimum standard for flow rate variation is ±5%, and for pressure variation ±10%.[1]

The average application per pass was determined from the catch can measurements. These figures are reported in several ways:

- Measured Average Application per Pass, which for centre pivots uses weighted catch can readings
- Measured Application less Tower Cans where the catch can results from around the towers were deleted. Nearly all systems had a low-application sprinkler package at the towers, which is a designed non-uniformity. As this project was testing performance against specifications, the intentional non-uniformity was removed.
- Nominal Application per Pass which is determined from the volume applied by the pump divided by the irrigated area at the measured speed.

The Measured Applications were compared to the Nominal Applications and the applications specified on the Control Unit. The latter is of particular note as the system operators expect this figure to be applied at each irrigation event.

As the project proceeded, large differences were observed between the Nominal Application and Measured Application in some systems. This prompted a check of the irrigated area determined from the field observations compared to the nominal irrigated area.

Uniformity of the irrigation event was also determined from the catch can measurements, expressed as Distribution Uniformity (DU) and Coefficient of Uniformity (CU for lateral moves, CU Heerman & Hein for centre pivots) for all catch cans. For the centre pivots, both measures were determined using weighted catch can readings. To compare the effect of the low-application sprinkler packages around the towers and the effect of end guns on the system performance, the DU was also calculated with the relevant catch readings deleted.

The conventional benchmark for both DU and CU for these systems is 0.90 or 90%[2] although the following guide for DU from Page Bloomer Associates is useful[3]:

> 0.9 excellent
0.9 – 0.8 good
0.8 – 0.7 adequate
0.7 – 0.6 fair
< 0.6 poor

[1] NSW DPI 'Introduction to Irrigation Management' Day 2 course notes
[2] Foley and Raine p.14, Nelson Australia p.13
[3] Page Bloomer 'Irrigation Performance Quick Test – Guidelines for Centre Pivot Irrigators'

Pump flow rate was measured using the water meters fitted to the system and/or a portable ultrasonic flow meter. The pump flow rates were compared to the system specifications.

The pressure at the pump was recorded to give a measure of Delivery Head, and the Suction Lift was measured or estimated for each site.

Power measurements were taken from electricity authority power meters recorded over a measured period of time. In a couple of cases, power consumption at the time of testing was obtained from the electricity company.

From these figures, the pump efficiency was calculated, and this was compared to the theoretical efficiency indicated on the pump performance curve. From this, the potential for energy savings was calculated.

All of the systems had pressure regulators fitted to all sprinklers.

Where the crop and the proportion of time per week that system was used were known, the Managed System Capacity was calculated and compared to the peak crop water demand.

All of the measurements obtained from the field data were compared with the system specifications or recognised benchmarks to make conclusions on how well the systems were performing. A written report detailing the field measurements, calculations, findings and recommendations for improvement for each system was given to the farm manager or owner.

Results and discussion

The DU using all catch can readings ranged from 40% to 79% and the average was 56%. The 2005 average was 68%. With the low-application sprinkler package catch can measurements removed from the calculations, the DU improved to an average of 67% and a range from 46% to 88%. The 2005 average was 74%.

Eleven of the 18 systems had end guns fitted. The DU for these 11 systems using all catch can data ranged from 40% to 67% and the average was 57%. With the low-application sprinkler package catch can measurements removed from the calculations for these systems, the average DU was 65% with a range from 46% to 73%. With the low-application sprinkler package and the end-gun catch can measurements removed from the calculations, the DU improved to an average of 75% and the range was 67% to 81%. The end guns caused an average decline in DU of 10% ranging from 9% to 22%. For four systems, the decline was 6% or less, which shows that it is possible for end guns to provide uniformity of application with the rest of the system, but in most cases they significantly under-perform the sprinkler package.

The CU using all catch can readings ranged from 62% to 83% and the average was 75%. No comparison was made with the CU values from the 2005 project because they were adjusted for low-application sprinkler packages while for this project they were not.

Table 1: Summary of uniformity measures

	Average	Range	Average 2005
DU – all catch can data	56%	40-79%	68%
DU – all catch can data, end-gun systems only	57%	40-67%	-
DU – no tower catch can data	65%	46-73%	74%
DU – no tower or end-gun catch can data	75%	67-81%	-
CU – all catch can data	75%	62-83%	-

In no case did the DU or CU reach the benchmark of 90%. Allowing for low-application sprinkler packages around towers, one system attained over 85% DU which is 'good' on the Page Bloomer guide, and six attained CU of 80%.

Application per pass varied a lot from expected. For 15 systems, the application per pass was indicated on the control panel. Nine of the Measured Applications per Pass were lower than that indicated on the control panel, and 6 were higher. The range was from -59% to +27%, average -9%. This was an improvement from the 2005 results where the Measured Applications were lower than the control panel for all systems, with an average of -17%.

The emitter flow measurements, excluding the first one or two inner spans, had a range of -32% to +53% from specification with an average variation of +13%. Only two systems met the conventional benchmark of ±5%, five were close to it, and 10 did not meet it.

As in 2005, these results are alarming given that all 18 systems were pressure regulated. Possible reasons for the variations are components fitted to incorrect positions or wrongly selected, insufficient flow to the centre pivot, blockages, damage or wear to emitters and regulators, and poor hydraulic design.

The Average Application Rate (AAR) was calculated for each system from the measured wetted width, the measured emitter flow rate and the emitter spacing using the following equation:

AAR (mm/h) = emitter flow (L/h) ÷ [wetted width (m) x emitter spacing (m)]

The AAR was compared to the soil type and its likely infiltration rate. Ideally, the application rate of any irrigation system should not exceed the infiltration rate of the soil. If it does, water will pond and move on the surface, creating non-uniformity and patches of under and over watering. For CP/LM systems, the AAR usually considerably exceeds the soil infiltration rate. However, the initial infiltration rate of nearly all soils is significantly higher than after water has been applied for some time, and CP/LM systems apply the water for a relatively short time. This, combined with each application being relatively few millimetres and the retention caused by the micro-topography, means ponding and movement may not be a significant issue.

The AAR ranged from 21 to 97 mm/hr with an average of 46 mm/h and median of 40 mm/h. The soils were predominantly loam which means there is little likelihood of significant issues. Three systems had AAR above 70 mm/h so these systems may need to monitor the water movement at the outer end of the system and undertake remedial actions if necessary eg. install spreader bars and split emitters, build surface soil structure, gentle surface tillage, mulching, etc.

The pressure measurements at the centre ranged from -12% to +196% from specification, well in excess of the usual benchmark of ±10%. None of the 12 measured irrigators met the benchmark, 11 were higher and one was lower. Two systems with extreme highs of +103% and +196% gave emitter flow variations that almost met the benchmark, highlighting that excessive pressure may have little effect on performance but it increases operating costs, substantially in these extreme cases. The low of -12% also had emitter flow variations that almost met the benchmark.

Pressures measured at the end of the systems showed the same pattern. They ranged from -16% to +257% from specification, also well in excess of the usual benchmark of ±10%. Two of the 12 measured irrigators met the benchmark, nine were higher and one was lower.

Pump flow rate was compared to the specifications for nine of the systems. Five were operating as specified or within 5%, two were supplying 11% and 13% less than specified, and the other two were supplying 10% and 21% more than specified. The average variation was +2%.

Pump efficiency was calculated for 11 systems. The average efficiency was 52% and the range was 32% to 77%. Compared to the theoretical efficiency from the pump performance curves for 10 of the systems, there is a possible reduction of energy consumption of an average 37%, ranging from 15% to 80%, assuming the performance can be restored to theoretical efficiency. This represents an enormous cost saving especially for irrigators that pump a lot of water, and in nearly all cases, the cost of pump repair or replacement will be recovered in one season.

The area irrigated was determined from the field data ie. the number of catch cans that collected water, for 10 systems. Comparing these figures to the nominal area, the systems were on average irrigating 5% more area than specified, ranging from 10% less than specified to 29% more than specified. For irrigation managers, these variations are significant as if a known volume of water is applied over more area than expected, the average depth applied will be less than expected, and if the area is less than expected they may be applying excess water and/or obtaining less production than expected.

The Managed System Capacity was calculated for 10 systems and compared to the peak crop water demand. Managed System Capacity is determined from the following calculation:

Managed System Capacity = (Pump flow rate x 100 ÷ Irrigated area) x PUR x Ea

Where:

Managed System Capacity is in mm per day
Pump flow rate is in ML per day
Irrigated area is in ha
PUR = Pump Utilisation Ratio, the proportion of time the system is operating in a week during peak time, expressed as a decimal

Ea = field application efficiency expressed as a decimal

Peak daily crop water demand was determined by obtaining the Peak Potential Evapo-transpiration figure for the hottest month from the Bureau of Meteorology web site[4] and multiplying by the relevant Penman-Monteith crop coefficient (Kc)[5].

In nearly all cases, the Managed System Capacity was well below the peak crop water demand, mainly due to limited watering time (low PUR). The average was -29% and the range was -64% to +10%. This means that the pasture production would be seriously reduced during the summer months for nearly all systems tested. The many and varied tasks of operating a dairy is usually the reason for limited irrigation time. Investigating how to re-arrange or improve the efficiency of tasks to allow more time for irrigation to take place is recommended.

Conclusion

There is room for considerable improvement in both water and energy efficiency in irrigation on dairy and fodder farms.

The measures of water efficiency in this project were uniformity, amount of water applied, irrigated area and Managed System Capacity.

No system reached the benchmark of 90% for either DU or CU whereas in 2005 a couple of systems did. The average DU at 67% is worse than the average DU in 2005 of 74%. This is likely to result in uneven, sub-optimal productivity, especially where the soils are light texture. All systems should be investigated further to ascertain the reasons for the low uniformity.

On average, the amount of water applied was 9% lower than the control units indicated. However, the range of variation was wide, from -59% to +27%. This means some managers were applying almost 60% less than they expected for each irrigation while others were applying about 25% more than they expected. Both of these reduce water efficiency, as one severely stresses the crop resulting in reduced yield, and the other applies water that the crop cannot use which must end up as deep drainage, runoff or evaporation. This range is disappointingly greater than the 2005 results of -5% to -34%. The emitter flow measurements from this project show the same pattern with a range of -32% to +53% from specification and an average variation of +13%. It is recommended that the control units be re-calibrated for those systems with high variation.

Managed System Capacity appears to be chronically low. This is likely to have more impact on water efficiency than the other measures as inability to keep up with crop water demand often results in cumulative soil moisture deficit, which requires substantial rainfall or an extended period of mild weather to overcome. That is, the effect in suppressed productivity is likely to be felt for a long period through the warmer months. Irrigation managers should address the low Managed System Capacity as a matter of urgency.

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[4] www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp?maptype=6&period=an#maps

[5] FAO Irrigation and Drainage Paper 56

As part of this, the area irrigated by each system should be accurately measured. The results show that some systems are irrigating areas much less or much more than specified, probably with the managers unaware. As irrigated area affects the performance of the system in a number of ways, the area should be adjusted where necessary.

The measures of energy efficiency in this project were operating pressure and pump efficiency.

Operating pressure measured at the centre and along the system showed the tendency for irrigation managers to operate with excess pressure. A small amount of excess pressure, say 15%, is appropriate to allow for wear of components, build up in pipes, etc. but more than this means energy is being consumed for no performance benefit. Pressure is a much more significant factor for energy consumption than flow rate – a small increase in pressure leads to an increase in energy consumption several times more than a small increase in flow rate. The average centre pressure was 74% higher than specified, indicating considerable opportunity to reduce energy consumption and costs.

Pump efficiency was poor for most systems. The average efficiency was 52%. If performance could be restored to specification, an average reduction of energy consumption of 37% is possible. If both the operating pressure and pump performance were improved, the reduction in energy consumption would be substantial, probably sufficient to pay for an entirely new, better suited pump installation in a season or two.

The results of this project show that performance of overhead systems is generally well below specifications for both water and energy efficiency and, by some measures, has deteriorated since 2005. Monitoring of system performance appears to be lacking, and with water availability becoming less certain and energy costs likely to continue appreciating, comprehensive performance tests should be adopted as normal practice at system commissioning and at regular intervals thereafter.

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Summary of Results 2011-12 – 18 CP/LM System evaluations

	Appln Control unit (mm)	Measured Average Appln (mm)	Variation: control v measured	Measured Appln less tower cans (mm)	Variation: control v measured less towers	Nominal Appln (mm)	Variation: control v nominal	DU	DU less tower cans	DU less tower & end gun	CU	Centre pressure variation from spec	Pump flow variation from spec	Pump eff	Pot energy saving	Area variation from spec	Managed System Capacity
	14.6	12	-18%	12.5	-14%	13.2	-10%	79%	88%		83%	17%	13%	64%	44%		-12%
	17.8	15.2	-15%	15.7	-12%	17.3	-3%	55%	58%	80%	83%	37%	0%	64%	18%	4%	10%
	15.2	16.1	6%	17.2	13%	17.3	14%	47%	64%	78%	76%	68%	0%	61%	22%	0%	-19%
	10.1	7.5	-26%	7.9	-22%	9.6	-5%	59%	68%	77%	77%	-12%	3%	60%	15%	12%	4%
	10.1	9.4	-7%	9.6	-5%	9.1	-10%	42%	46%	67%	65%			55%	27%	-6%	-20%
		9.5		10		9.5		62%	69%	78%	76%	47%	0%	43%	34%	9%	-41%
	6	7.6	27%	8	33%	7.1	18%	62%	71%	81%	80%		10%	32%	40%	3%	
	43	23.4	-46%	24.4	-43%	18.2	-58%	62%	64%	68%	73%					29%	
	33	34	3%			36	9%	47%			67%	103%	-11%	42%			-53%
	7	5.9	-16%	6.5	-7%	7	0%	52%	78%		78%		21%	56%	25%		
	7	7.4	6%	8.3	19%	4.9	-30%	40%	63%	66%	69%	43%				3%	-58%
	14	11.4	-19%	12.2	-13%	14	0%	50%	71%		80%	180%					
	12.5	15.6	25%	16	28%	12.6	1%	67%	73%	73%	75%	93%	5%	77%	27%	-10%	-64%
	5.6	2.3	-59%	2.5	-55%	3.9	-30%	41%	64%		70%	50%		41%	73%	9%	-35%
		1.8		1.9		1.9		49%	53%		67%	196%					
		12.4		12.7		8.3		64%	71%	77%	81%			33%	80%		
	12	9.6	-20%	10.2	-15%	11	-8%	63%	73%	81%	80%	85%					
	7.9	9.3	18%	9.9	25%	10.1	28%	59%	71%		62%						
Average:	**14.4**	**11.7**	**-9%**	**10.9**	**-5%**	**11.7**	**-6%**	**56%**	**67%**	**75%**	**75%**	**76%**	**5%**	**52%**	**37%**	**5%**	**-29%**

Summary of Results 2005 – 23 Centre Pivot evaluations

	Application Control Unit (mm)	**Measured Average Application (mm)**	**Variation: Control v Measured**	**Nominal Application (mm)**	**Variation: Control v Nominal**	**Weighted Av Appln (mm)**	**Variation: Control v Weighted Av**	**DU**	**CU (H)**	**Centre pressure variation from specification**	**pressure reg?**	**end gun?**
	12.1	11.7	-3%	11.4	-6%	10.4	-14%	85%	85%	16%	y	n
	16	13.5	-16%	13.7	-14%	13.2	-18%	67%	75%	0%	y	y
		5.6		5.57		5.6		78%	85%	32%	y	n
		14.2		16.5		12.7		82%	84%	-22%	y	n
	9.1	8.3	-9%	8.45	-7%	7.5	-18%	71%	79%	13%	y	y
	25.4	16.9	-33%	16.76	-34%	16.7	-34%	70%	84%	215%	y	y
		9.3						62%		n/a	y	y
	19.5	12.4	-36%	12.68	-35%	12	-38%	74%	84%	n/a	y	y
	15.2	11.2	-26%	12.4	-18%	11.2	-26%	70%	83%	-33%	y	y
	16.7	15.2	-9%	16.7	0%	14.6	-13%	75%	85%	-4%	y	y
	10.1	8.7	-14%	9.3	-8%	8	-21%	82%	81%	12%	y	y
	6.9	5	-28%	5.2	-25%	4.9	-29%	84%	90%	-6%	y	y
		7				7		58%	78%	100%	?	y
		6.5		10		6.5		64%	76%	33%	y	y
	10.1	8.9	-12%	9.6	-5%	8.9	-12%	68%	80%	26%	y	y
	10.1	7.2	-29%	7.8	-23%	7.2	-29%	54%	72%	-10%	y	y
	10.1	9	-11%	10.4	3%	9	-11%	78%	86%	-5%	y	y
	10.1	9.9	-2%	9	-11%	9.6	-5%	81%	86%	-1%	y	n
	15.9	13.6	-14%	14.9	-6%	11.3	-29%	82%	80%	16%	y	n
		20.7				20.7		79%	86%		?	y
		31.5				31.5		86%	91%		?	y
	31.8	28.3	-11%			28.3	-11%	82%	87%		?	y
		11.5		14.1		10.5		61%	73%		y	n
Average	**14.6**	**12.4**	**-17%**	**11.2**	**-14%**	**12.2**	**-20%**	**74%**	**82%**	**23%**		