Spray irrigation on dairy pastures – efficient or not?

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Abstract
Applying water efficiently is increasingly important for dairy farmers and other users of surface and groundwater resources to maintain sustainable production. However, irrigation is rarely monitored. We used a questionnaire survey and measurements of five spray irrigation systems working in normal farm conditions to make observations on how efficiently irrigation is being managed. Survey results from 93 dairy farmers showed that, although the farmers believe they know how much water is being applied during irrigation, only 60% make measurements, and about 18% measure irrigation uniformity. Catch-can measurement of irrigation application depth for the different spray systems indicated large variability in application depths during irrigation, and field distribution uniformity ranged greatly between the different systems, decreasing in the order of centre pivots >travelling irrigators> K-line. Changes in irrigation system settings were sometimes made without considering application depths or uniformity. If our five case studies are typical, they may explain the large range of seasonal irrigation amounts recorded in the survey. We recommend that farmers monitor irrigation application depths and uniformity to help manage irrigation water efficiently and to help them estimate the value of irrigation to their enterprise.
Keywords: distribution uniformity, water use efficiency, catch cans

Introduction
Improving the efficiency of water use is an objective for farmers to improve production and reduce irrigation costs. The management and performance of the irrigation system can have a great impact on how efficiently water is used on farm. Many studies have shown that irrigation scheduling and system distribution uniformity are key determinants of overall on-farm water use efficiency (e.g. Lincoln Environmental 1999; Pereira 1999).

There is a range of sources of information available to farmers to help manage irrigation, including manuals (e.g. Jarman 2001; Lincoln Environmental 1997), web resources (e.g. MAF Sustainable Management Fund) and consultant services. Scheduling is used to determine when and how much to irrigate, but many dairy farmers do not record the basic information needed (Martin *et al.* 2006). Although there is information on the potential efficiency of different irrigation system types (Edkins 2006), this is rarely verified in the field under normal operational conditions.

We investigated how well farmers monitor the amount of water they apply with irrigation, including the depth and evenness of irrigation, from a survey of dairy farmers. We used case studies to investigate how well water is applied by five individual irrigation systems operating under normal farm management conditions in Canterbury using protocols developed for measuring the performance of irrigation systems under New Zealand conditions.

Methods
Survey of farmers' practices
Data were extracted from responses from a survey on current farm practices focusing on irrigation and nitrogen management. The questionnaire was sent to about 450 dairy farmers in July 2005. Two questions were asked about monitoring of irrigation amounts and evenness:

1) Do you know how much water you apply at each time you irrigate? Yes/No

If answering "yes" further information was requested about the type of irrigation system, average amount or range applied per irrigation, average number of times of irrigations per season, and the amount applied measured, calculated, or assumed.

2) Do you ever measure/check the evenness of application of water by your irrigation system? Yes /No.

If answering "yes" further information was requested about the frequency and method of measurement. Typical amounts of irrigation applied per season were calculated from the average amounts that the respondents said were applied and the typical number of irrigations per season.

Measurement of irrigation application depth and application uniformity
The uniformity and application depths of five spray irrigation systems (two travelling boom irrigators (Rotorainers), two centre pivots and one multi-spray lateral – K-Line) were measured in January 2006. Farmers were asked to run their irrigation systems under their normal operating conditions. These measurement procedures were developed under SFF Project 02-051 for the Code of Practice for On-Site Irrigation Evaluation

2005 (Bloomer 2005). Catch cans (10-L plastic buckets) were used to measure application depth and distribution uniformity.

i) Travelling rotating boom irrigators: The two systems measured were Rotorainers. Distribution uniformity was measured using catch cans spaced at 2.5 m intervals along the wetted width perpendicular to the direction the irrigator travelled. Three lines (transects) were set out to measure the amounts applied at the beginning, mid-point and towards the end of the irrigation run.

ii) Centre pivots: Two different centre pivot systems were measured. The first had a radial length of 400 m with an additional 100 m covered when an extension corner arm operated. The second was 255 m long and had a gun at the end of the pivot extending the wetted radius to about 270 m.

Two radial lines of catch cans were spaced at 5 m along the wetted length of the pivot irrigator. For practical reasons the first span, which has very low application rates and covers a relatively small area, was not measured. Measurements were also made of distribution uniformity under a corner extension arm of one of the pivots and under an end gun of the other pivot.

iii) K-line: The distribution uniformity for three overlapping sprinklers (15 m spacing) was determined halfway along a sprinkler line (120 m long) using a grid of 96 catch cans with a 2 x 4 m spacing.

Irrigation application depths were determined from the volumes of water collected in the catch cans. For individual irrigation uniformity tests, the lower quartile distribution uniformity coefficient (DU_{lq}) was calculated by:

$$DU_{lq} = Z_{lq}/Z_{av}$$

where Z_{lq} is the average depth of irrigation (mm) applied in the lower quartile of line or grid of catch cans and Z_{av} is the average depth (mm) applied across the line or grid of catch cans.

Field distribution uniformity (DU_f) describes how evenly water is applied across a field. It was estimated using the combined data sets from each field (i.e. three tests for each field along the direction of travel for the travelling rotating boom, and two tests for the centre pivot). Maximum and average wind speed was recorded for each evaluation.

Results and Discussion

Survey results

There were 135 surveys returned, and 93 of these respondents spray-irrigated their properties. The results reported are for spray irrigation. All the respondents said that they knew how much water was applied, but only 55 (59%) reported that they measured the amounts applied; 32 (34%) measured the evenness of application, while 17 (18%) said that they used catch cans or rain gauges with a frequency ranging from 3 or 4 times per irrigation season to alternate seasons. There was little information supplied about the number of catch cans or

Figure 1 Box plot of typical seasonal irrigation amounts. The box spans the interquartile range of the seasonal irrigation values, so that the middle 50% of the data lie within the box and the line across the box is the median value. The error bars indicate the upper and lower quartile value. The number of respondents for each system type is recorded in parenthesis.

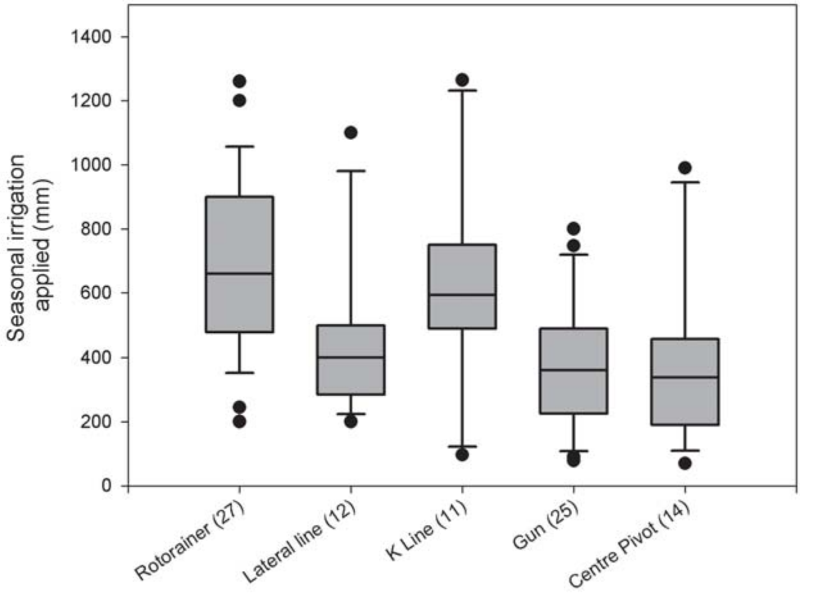


Table 1 Irrigation application and uniformity for five sprinkler irrigation systems on Canterbury dairy farms.

System Type	Test no.	Soil type	Average application depth(mm)[1]	DU_{lq} [2]	DU_f [3]
A Travelling rotating boom (Rotorainer)	1 2 3	Lismore silt loam	38.4 50.1 63.7	0.88 0.72 0.85	0.7
B Travelling rotating boom (Rotorainer)	1 2 3	Lismore silt loam	37.4 34.3 31.9	0.57 0.58 0.60	0.57
C Centre pivot	1 2 (corner arm extended)	Wakanui, Templeton, Paparoa silt loams	4.6 3.7	0.76 0.8	0.74
D Centre pivot		Waimakariri	11.6	0.67	
	sandy loam				
E K-line		Waimakariri	16.8	0.44	
	sandy loam				

[1]Average depths applied during tests.
[2]DU_{lq} – Lower quartile distribution uniformity coefficient for an individual test.
[3]DU_f – Field lower quartile distribution uniformity calculated from combined test results.

rain gauges used, and in some responses only one rain gauge appears to have been used.

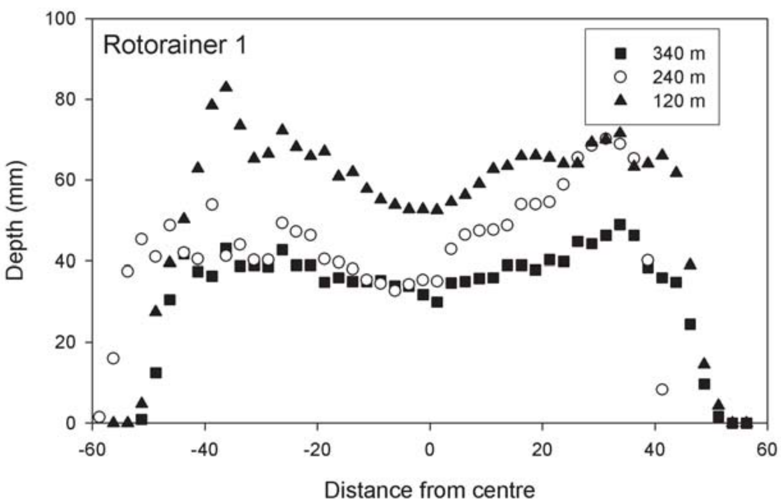
The amounts of irrigation typically applied per season varied greatly between and within the types of irrigation system (Fig. 1). We did not attempt to define a typical or average season; this was left to the farmers' judgement.

On-farm measurements

The maximum wind speed was 5.1 m/s, recorded during the measurement of one of the Rotorainers. For all the tests the average winds speeds ranged from <1 to 3 m/s. Wind speeds above 5 m/s are considered excessive for machine testing (Bloomer 2005). Irrigator performance was very variable. Measurements of DU_{lq} for individual tests ranged widely between systems and within the same type of irrigation system (Table 1). DU_f decreased in the order of centre pivots > travelling irrigators > K-line.

i) Travelling rotating boom irrigators: DU_{lq} measures for the three individual transect tests on one of the Rotorainers (System A, Table 1) appear to be good, but for the whole paddock the overall uniformity is much lower, as the average depth applied for the three transects varied greatly (Fig. 2). This occurred for three main reasons. First, changes in wind direction caused the distribution pattern to change. Second, increases in wind speed slowed the rotation of the boom. This in turn gave

Figure 2 Irrigation application depths for three transects (340 m, 240 m and 120 m from fixed end) along the direction of travel for a travelling rotating boom irrigator.



greater application depths, as the boom rotation speed governs the travelling speed of the irrigator. Third, the machine was slowed down overnight (Test 3) by the farm operator, to prevent the end of the irrigation run clashing with milking or other farm operations. This resulted in more water being applied during Test 3 at the end of the irrigation run. We estimated that the amount of water applied here would have been greater than the low water holding capacity of this shallow stony soil.

The second system monitored (B, Table 1) had poor distribution uniformity, mainly due to poor coverage towards the outside of the wetted width. The paddock was 100 m wide and only small amounts of water reached the paddock edge; approximately 10% of the paddock was not receiving any water. From the catch-can data, we estimated that reducing the paddock width to 90 m would increase the field DU_{lq} to 0.78. Water pressure measurements indicated that the machine was running below optimum pressure. Increasing the water pressure is likely to increase the wetted width, as typically a 100 m paddock width is appropriate for these machines, and this would also improve the DU_{lq} along a measurement transect. The farm staff were not fully opening the hydrant valve, resulting in reduced downstream pressure; lowering the pressure using the hydrant valve reduces pumping efficiency and increases pumping costs.

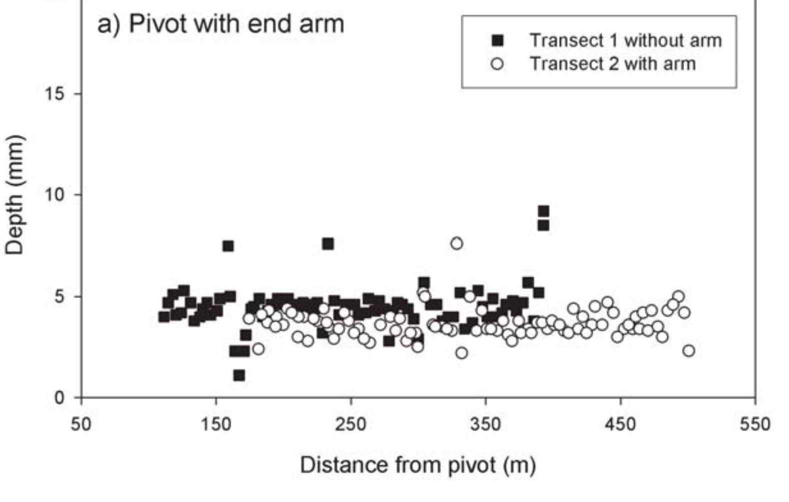
ii) Centre pivots: Distribution uniformity values for centre pivots ranged from 0.67 to 0.8 for the two systems. These values are lower than typical design expectations for a centre pivot of about 0.9. Values of DU_f above 0.75 for spray irrigation systems under typical weather conditions are still considered to be good, due to engineering limitations, but values greater than 0.95 are attainable (Bloomer 2005) .

Although the DU_{lq} for one of the centre pivots was relatively high for both uniformity tests (C, Table 1), when the data were combined the DU_f was reduced (0.74). Analysis of variance showed that the average depth of water applied when the corner arm was operating was significantly lower ($P<0.001$) than without the arm (Table 1, Fig. 3). The sprinkler pressure at the end of the arm was about 60% lower than the desired operating pressures for these sprinklers. The corner arm increases irrigated area by 56%, but the data suggest there are deficiencies in the design of this system, or its operation.

The second centre pivot system (D, Table 1), was much less uniform than the other system. For this system, there were some large variations of application depths. Beneath one malfunctioning sprinkler the application depth was 80 mm. Furthermore, the end gun was performing incorrectly and application rates were much lower than under the sprinklers along the pivot. Excluding these results, the DU_{lq} along the pivot (excluding the area covered by the gun) was much higher (0.87).

iii) K-line: The throw of the sprinklers was about 7.5 m each side of the irrigation line. Distribution uniformity was lowest for the K-line system (DU_{lq} = 0.44). Values of DU_f of less than 0.5 are considered unacceptable (Bloomer 2005). Visual checks showed problems with the sprinklers, including sprinklers blocked with debris, sprinklers not clearing the protection pods (i.e. spraying directly into the pod), and leakage from broken joints. An estimated 15% of the sprinklers were not working correctly. In some areas of the field this had led to severe water ponding around the sprinklers. Consequently, the field distribution uniformity could be much lower. The main factors that normally affect uniformity are sprinkler spacing, individual sprinkler throw and pattern characteristics that are also affected by system pressure,

Figure 3 Irrigation application depths along a centre pivot with and without an end corner arm extended.



and the effects of wind speed and direction.

Is spray irrigation on dairy farms efficient or not?

If our survey and the results from our measurements of the performance of five systems represent typical practices, this suggests that most farmers do not have an accurate idea of the amount, or the evenness, of irrigation they are applying to pasture. Without this information, a farmer does not know how efficiently irrigation water is being used. It may also explain the large range of seasonal irrigation amounts that farmers said that they typically applied.

An earlier survey of irrigators (Lincoln Environmental 2000b) showed that only 10% of farmers measured soil water or used evapotranspiration to schedule irrigation. If the amount of irrigation water applied is unknown, it is also difficult to schedule irrigation based on water balance methods. This strongly suggests that irrigation applications are not targeting crop or pasture demands. Our small sample of irrigators also indicates that changes in irrigation system settings (i.e. travelling speed and operating pressures) are routinely made without considering application depths or uniformity.

The uniformity of irrigation applied that we measured was lower than should be expected. Typical uniformity measurements for spray irrigation systems can be up to 0.9 and in some cases more (Lincoln Environmental 2000a). Some systems are inherently better than others. In all cases, simple changes to the management and maintenance of these systems could improve the field application uniformity. Poor uniformity makes it difficult to manage irrigation water efficiently for pasture production. Insufficient water will result in lower than optimum production, whereas excess application increases the cost of irrigating and increases the risk of production losses (and environmental costs) due to loss of nutrients through drainage or runoff.

Monitoring the evenness of water application will help show up deficiencies in the irrigation system. Regular system maintenance and good management practices that apply a known amount of water relatively evenly will reduce pumping costs. However, knowing how much water is applied needs to be combined with knowledge of the pasture water demand and water storage capacity of the soil to make the most cost-effective use of irrigation. More efficient irrigation will decrease energy use, and better irrigation scheduling could increase the opportunity to utilise cheaper off-peak electricity.

Quantifying the amount of water applied as irrigation can be used to determine pasture water use efficiency – the ratio of pasture dry matter production or milk solids to water applied. This will help farmers understand the economic value of water to their production system. However, one of the key remaining issues is why better irrigation water management practices are not adopted more widely

ACKNOWLEDGEMENTS

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