USING COMMERCIAL DISTRIBUTION UNIFORMITY AND YIELD DATA TO IMPROVE IRRIGATION MANAGEMENT

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ABSTRACT

In-field performance evaluations focusing on distribution uniformity and associated crop production responses has been the key to successful motivation of growers in spray irrigated horticultural areas of southern Queensland. In these analyses, the distribution uniformity patterns have been found to be closely correlated to a range of crop growth, quality and yield data. The provision of this farm specific production data has enabled irrigators to identify for themselves the potential benefits in crop yield and profitability available through simple system adjustments. However, this data has also been used to develop field (and farm) specific water use efficiency and crop production functions. The ability to link the crop production functions obtained with spray irrigation models which quantify the effect of spacing, layout, pressure and nozzle options has enabled the identification of cost-benefit relationships for alternative irrigation design and management practices. This data has successfully been used to stimulate grower interest in otherwise disinterested groups, encouraging grower measurements of the engineering aspects of irrigation performance and its effect on crop yield. In these cases, it appears that the irrigators prefer to discuss concrete examples involving the modification of their irrigation machinery in contrast to the more abstract topics typically associated with irrigated crop agronomy. It appears that system uniformity issues have started these irrigators on the road to better irrigation practices.

INTRODUCTION

Queensland Fruit and Vegetable Growers Ltd (QFVG) are implementing the Rural Water Use Efficiency Initiative (RWUEI) adoption program for the Queensland horticultural industry. While a traditional extension program focused principally on irrigation scheduling and the environmental benefits of improved irrigation management has been successful in some regions, this type of campaign has not been universally well received. Comments from some growers in the Queensland horticultural regions of the Lockyer Valley and the Granite Belt commonly reflect a widespread belief that “they have seen it all before”, that there is “nothing new” in the message being portrayed about irrigation management and that they “use less water than their neighbours so the program has little to offer them”. Motivation of these growers requires the demonstration of direct dollar benefits resulting from improved practices. One extension approach which is gaining irrigator support in these regions involves an analysis of the irrigation system performance (particularly with pressurised systems) which relates the results to crop yield. There has been strong irrigation uniformity and crop yield correlations in most of the conducted trials. Irrigators appear to have responded to this approach, preferring to discuss the mechanics of their irrigation rather than the more abstract concepts of soil moisture monitoring and scheduling. This paper provides an overview of the approach used to create grower interest and the implications of the data obtained for investigations of irrigation water use efficiency under commercial conditions.

MATERIALS AND METHODS

Distribution uniformity and crop yield uniformity data was collected at six properties in the Lockyer Valley, Granite Belt and Darling Downs regions (Table 1). Irrigation application volume data obtained at point scales during the catch can evaluations were correlated with point measurements of crop yield to demonstrate the effect of irrigation uniformity on crop performance and develop crop water use production functions. Options for improving irrigation system performance were identified using a two dimensional sprinkler irrigation model and the results combined with the crop water use production functions to determine the production and economic benefits of improved system performance.

The trials were principally conducted using solid set and drip irrigation systems so that the compounding influences of irrigator machine speed variation, variable supply hose hydraulic performance and variable elevation head were eliminated. However, two big gun traveling irrigators and the resultant crop yield responses were evaluated because these systems are popular in the Lockyer Valley. In all cases, growers were invited to be involved in the site selection and measurement process. Where possible, growers were also asked to record: dates and times of irrigation startup and shutoff; tensiometer readings at regular intervals, and catch can or rain gauge data at the site.

Table 1. Crops, irrigation systems and yield measures used to identify crop water use production functions.

Crop	Irrigation System	Region	Yield Measure
Cauliflower	Solid set[1]	Lockyer Valley	Head diameter
Sweet Corn	Big gun traveller[5]	Lockyer Valley	Stalk height
Potato	Solid set[1] Solid set[2] Solid set[3] Big gun travellor[5] Drip[6]	Lockyer Valley	Tuber grade (diameter) and quantity
Potato	Solid set[3] Drip[6]	Darling Downs	Tuber grade (diameter) and quantity
Lettuce	Solid set[4]	Lockyer Valley	Head diameter and quantity
Apple	Drip[7]	Granite Belt	Fruit diameter and quantity

[1]2" aluminium laterals spaced 14m apart with sprayheads 9m apart and 3/32" nozzles. [2]2" aluminium laterals spaced 11m apart with heads 9m apart and 3/32" nozzles. [3]2" aluminium laterals spaced 14m apart with and Nelson R2000 rotators spaced 9m apart along the lateral. [4]Lateral spacing changed from 16m to 14m after tuber initiation. [5]Trailco 2-250 with a bore nozzle. [6]T-systems 510-30-340 with 30cm spaced emitters discharging 340 L/100m nominally. [7]Netafim pressure compensated dripper with 1m spaced emitters discharging 8.5 L/hr nominally.

Catch can analyses

For each solid set irrigation system, the irrigation application depth was measured using a grid of catch cans (Figure 1). Irrigation uniformity is the evenness of irrigation applied to a crop and soil surface. There are many different measures of uniformity including distribution uniformity, emission uniformity, scheduling coefficient and the Christianson Uniformity. This study used distribution uniformity (DU) because this measure is comparatively simple to visualise and calculate (equation 1).

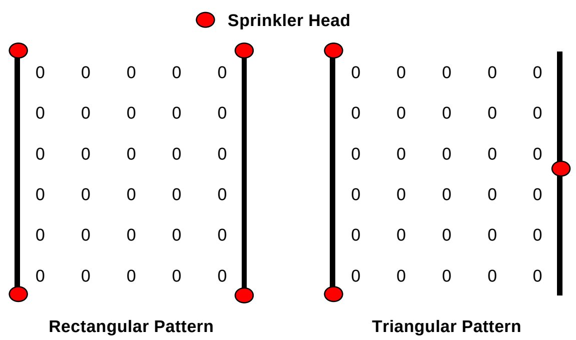

Figure 1. Catch can layout for DU calculation of a solid set system

$$\mathrm{DU}(\%) = \frac{\text{the average of the lowest quarter of catch can measurements}}{\text{the overall average of catch can measurements}} \times 100 \qquad \text{.........(1)}$$

The DU of drip laterals was measured by placing containers directly underneath emitters to catch irrigation discharge. Containers were placed under the drip lateral closest to the supply mainline and the drip lateral furthest from the mainline. The DU for the big gun travelling irrigator was measured by placing a single row of catch can across the travel path of the irrigator. The cans were located 2m apart and the row extended out past the wetted area of the machine to ensure all applied depths were recorded. The distance between the sacrificial laneways, colloquially known as 'tramlines', was measured. The overlap of the travellor was determined from the catch can data and distance between tramlines.

Crop sampling and subsequent analyses

The measured crop characteristics (Table 1) were selected to represent as closely as possible the market quantity/quality criteria for the respective crop. However, in some cases, alternative plant growth characteristics (eg. plant height, head size) were recorded as a surrogate measure of the plant response to irrigation. For example, the relationship between head diameter of cauliflowers and head weight was determined (Figure 2) so that the non-destructive and faster measurement of head diameter to be used to determine crop response. Where non-destructive sampling was able to be achieved, the characteristics were measured in the field.

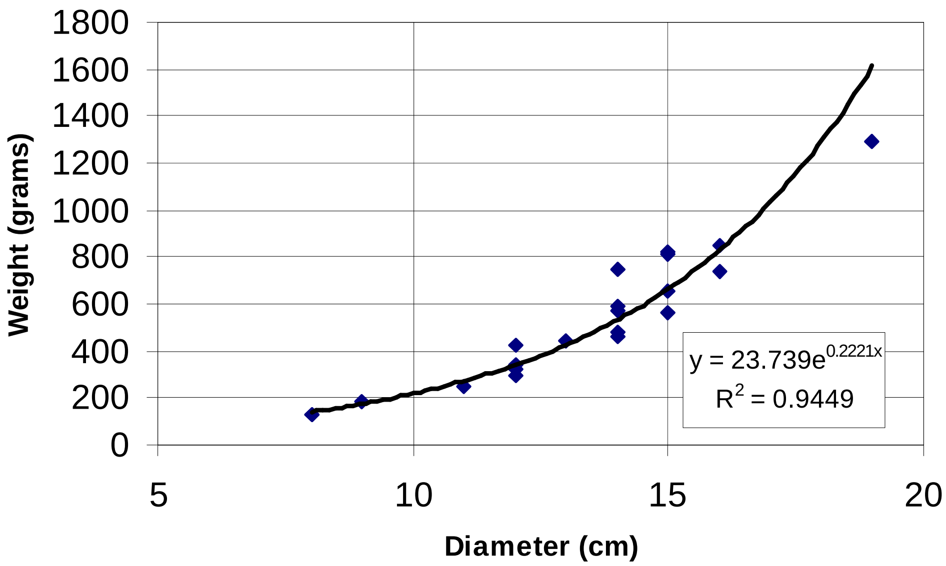

Figure 2. Cauliflower head diameter and weight relationship

For the spray irrigated row crops, the yield and application depth grid data were collected and averaged as a transect across the beds perpendicular to the laterals. At least four measurements were collected in each crop bed and used as replicates in the subsequent analysis. In selected trials, a transect parallel to the lateral direction was analysed to identify any relationship between the system's hydraulic performance and crop yield. For the apple crop irrigated by drip irrigation, individual tree yield data was simply plotted against seasonal emitter discharge for that tree. Where drip irrigated row crops were evaluated, yield data was collected for at least two drip laterals and crop yield data was plotted against the emitter discharge at the location of the crop sampling.

In each case, the crop production functions were developed based on a non-linear regression of the observed irrigation application volumes and the crop yield characteristic measured. While not specifically selected for this study, it should be noted that irrigation systems which perform poorly are better suited to the development of crop water use production functions because lower distribution uniformities provide a greater range of application volumes and crop production variability.

Options to improve the performance of the spray irrigation systems were investigated using the sprinkler design packages: Space Pro, Nelson Overlap and the Senninger Irrigation Profile Program. After initial evaluation of the various packages, Space Pro was selected for routine use as it allows for the input of both grid or radial data collected in the field. It also allows for the use of independently obtained radial leg distribution data for the range of sprinkler head/nozzle combinations found in the study area. The model outputs were used in conjunction with the crop water use production functions developed above to identify the potential production and economic gains associated with improved irrigation system performance.

RESULTS AND DISCUSSION

The performance of the irrigation systems investigated varied depending on the nature of the system and the management practices adopted (Table 2). Application efficiency was typically greater than 80% although two sites recorded lower values. The distribution uniformity ranged from 31 to 95%. While the two highest DU values were recorded on drip tape used to grow potatoes, the lowest value was measured on an ageing drip system used to grow apples. This data confirms that irrigation uniformity is one of the main reasons application efficiency (AE) is sometimes low as irrigators over-water sections of the crop to achieve a reasonable yield in the drier portions. In these cases, soil moisture monitoring can be rendered almost ineffective as the irrigation non-uniformity complicates the location of the sensor and raises questions applicability of the monitored data.

Table 2. Irrigation performance and potential agronomic gains through improved DU.

Crop	Irrigation System (refer to Table 1.)	Region	AE	Measured DU	Seasonal Irrigation ML/ha/yr	Potential agronomic gain if DU > 90 %
Cauliflower	Solid set	Lockyer Valley	60-80%	70%	2.5	7%
Sweet Corn	Big gun traveller	Lockyer Valley	-	72%	>3.0	14% (height)
Potato (0.8ML/ha Rain)	Solid set Solid set Solid set Big gun travellor Drip	Lockyer Valley	80-100% 80-100% 80-100% 80-100% 100%	71% 68% 81% 95%	1.2 1.6 1.2 1.7 0.95	21% 9% - - 0%
Potato	Solid set Drip	Darling Downs	80-100% 100%	64% 95%	4.5 2.5	14% 0%
Lettuce (0.4ML/ha Rain)	Solid set	Lockyer Valley	80-100%	70%	1.1	13%
Apple	Drip	Granite Belt	50%	31%	10	0%

Relationships between uniformity of application and yield.

For each of the systems and crops evaluated, the variation in water application appeared to be closely related to the variation observed in the crop yield parameter measured (eg. Figure 3). The measurements were typically all taken within a small area in an effort to ensure that water was the crop input factor which varied the greatest over the area. For the cauliflowers (Figure 3), seasonal irrigation volumes applied across the plot area varied from 1.3 to 1.7 ML/ha producing head diameters up to 30 mm in difference and equivalent yields which varied from 6.3 to 7.9 t/ha. For lettuce under solid set spray irrigation (Figure 4), the variation in application depth was 7.4-9.4 mm/irrigation. This comparatively small variation at each irrigation was equivalent to a range in seasonal irrigation application volumes from 0.6 to 0.83 ML/ha and a difference in lettuce head diameters from 118 to 155 mm.

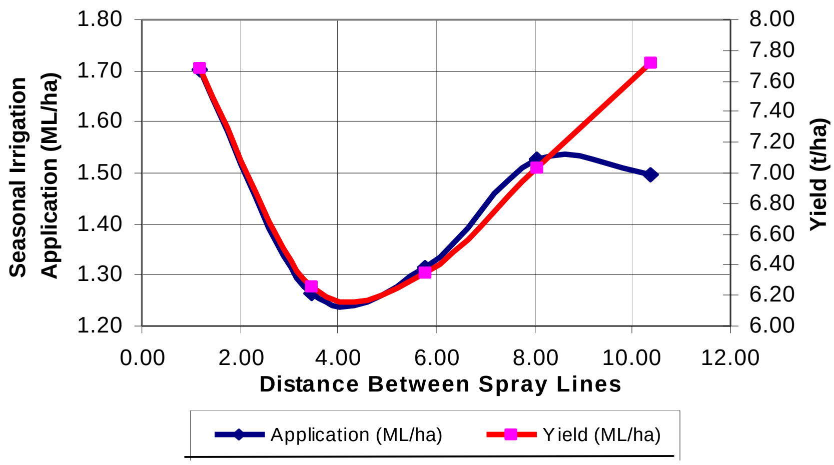

Figure 3. Variation in irrigation application and cauliflower yield between spray irrigation laterals

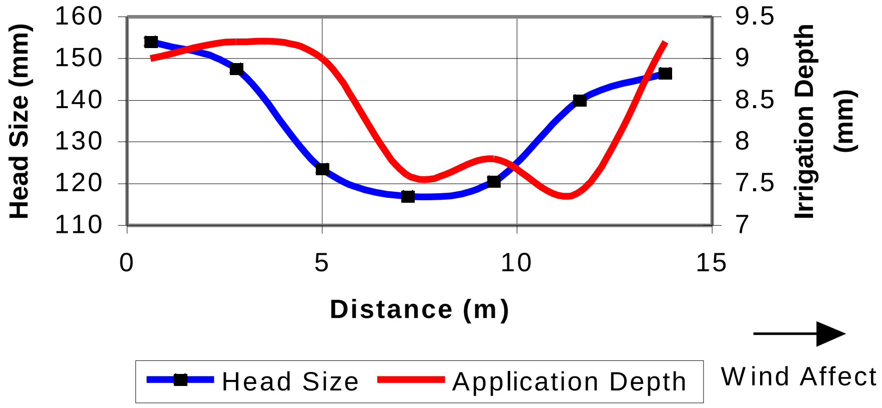

Figure 4. Lettuce Diameter and Irrigation Relationship with Wind Effects

Development of the crop production functions

The irrigation and yield data were used to identify crop water use production functions by regression analysis. In each case, crop response was significantly correlated (r^2 = 0.83-0.95) to the volume of seasonal irrigation water applied. However, the nature of the function varied between the crops with some producing a decreasing marginal benefit in yield with additional water application (eg Figure 5) while others displaying either a linear or increasing marginal benefit from additional irrigation water (eg Figure 6). While significant relationships were identified in each case undertaken in this work, it should also be noted that the relationship could be expected to be more difficult to identify in cases where:

- there has been substantial in-season rainfall (ie. the effect of irrigation uniformity on the crop tends to be evened out by the rainfall; or
- the crop has a deep and/or well established root zone (e.g. older tree crops) as the root distribution may tend to compensate for non-uniformities in irrigation application.

One of the characteristics of using the irrigation system non-uniformities to develop the crop water use functions is that it reduces the potential sources of variability that are present in broad scale data including:

- current and historic cultural practices (eg. tillage, crop rotations, crop varieties, traffic);
- pesticide/herbicide applications (eg. varieties, amounts and frequencies);
- fertiliser applications (eg. varieties, amounts and frequencies);
- soil types (eg. texture, compaction, fertility) and
- irrigation practices (eg. systems, scheduling, leaching).

The minimisation of these variations benefits the adoption of improved practices by those growers on whose farm the work has been conducted, as the results are more relevant. However, the transferability of these outcomes to other farms and across the region will be greatly influenced by the magnitude of the variation in the

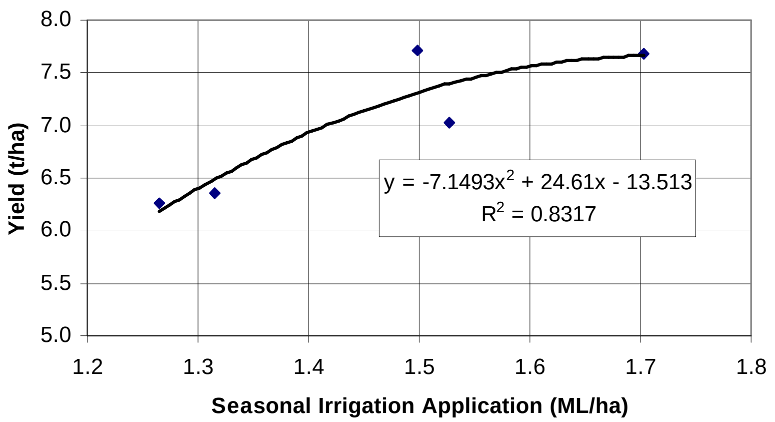

Figure 5: Irrigated Cauliflower Production Function

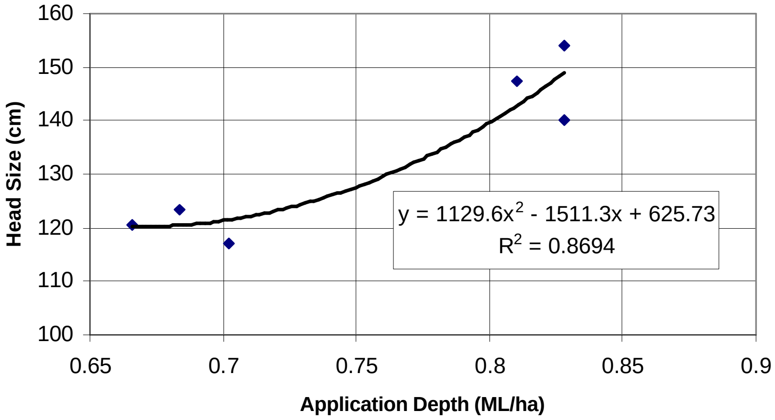

Figure 6: Irrigated Lettuce Head Performance Function

above factors between farms. Where substantial variation in environmental, cultural or management factors is suspected between farms within a region, it would be necessary to identify the effect of these differences on the crop water use functions prior to extrapolation across the region.

Irrigation modeling and identification of appropriate strategies

Modeling the performance of the alternative design and management strategies provided a mechanism to quantify the benefits associated with the various options. The generally accepted irrigation industry minimum acceptable DU is 75% but for higher value horticultural crops the DU should be even better, say 85-90%. Using the models, it has been possible to evaluate the effect of various sprinkler heads, nozzle sizes, operating pressures, sprinkler spacings and lateral spacings on the distribution uniformity. The potential agronomic benefit of improving DU from the existing measured levels to 90% were found to range from 0-21% for the systems evaluated (Table 2). However, the simulation of existing and alternative application systems also helps growers improve decision making through the identification of the benefits and limitations associated with the various options. Scenarios commonly investigated include:

- minimal cost option - effect of renewing nozzles only;
- maintenance of existing system spacing and layout – effect of changing spray heads or pressure only;
- prepared to change infield layout – effect of changing lateral and/or sprinkler spacing or type, pressure; and
- prepared to change distribution infrastructure and/or infield system – effect of system change.

For example, the effect on DU of varying solid set lateral spacings from 9m to 16m (Figure 7) suggests that for the specified equipment operating under optimal conditions (e.g. no wind), it is possible to achieve a DU in excess of 85% only if the lateral spacing is less than approximately 11m. This value decreases to approximately 75% if the lateral spacing is 14 m (Figure 7 & 8) which is the most common solid set configuration currently used in the Lockyer Valley.

Production and economic benefits of improved performance

The distribution uniformity and crop water use production functions have been used to estimate the potential yield gains available to commercial irrigators based on an improved system design, layout and operation of their existing systems. Some of the benefits typically associated with improved DU are shown in Table 3. The DU and yield relationship, irrigation schedule and AE are used to predict whether system improvements are financially feasible or not (Table 4). For the majority of systems studied in the Lockyer Valley, a number of simple and comparatively cheap system modifications have been found to significantly increase irrigation profitability (Table 5).

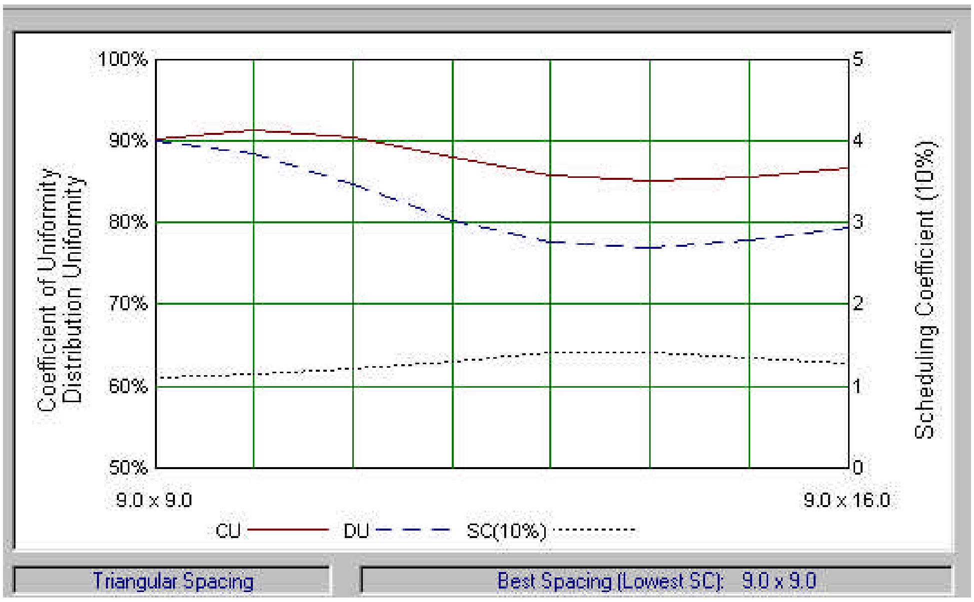

Figure 7: Effect of lateral spacing on uniformity (Space Pro Output -Nelson 20W sprinkler with a flow control nozzle at 50PSI, Triangular spacing, spray heads 9m apart)

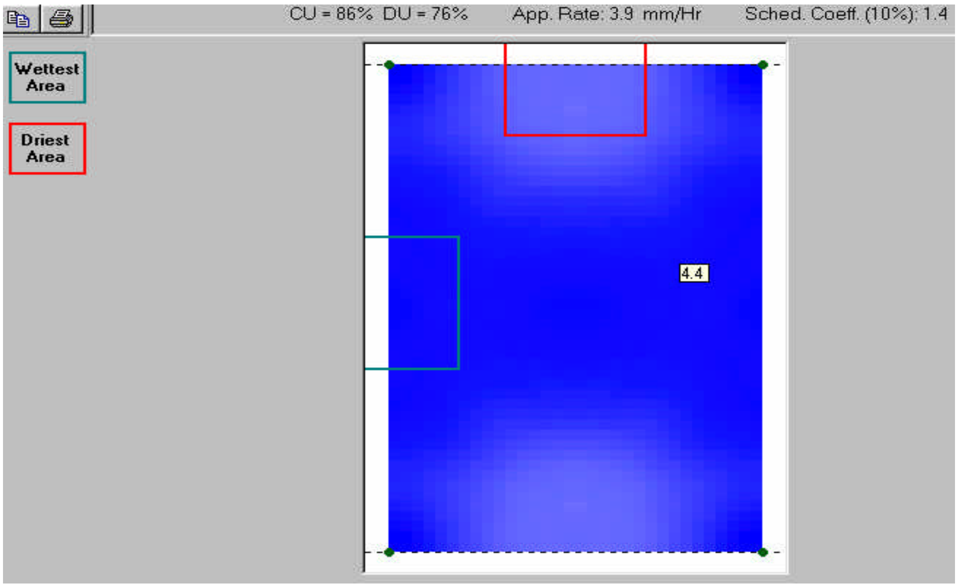

Figure 8: Densogram of irrigation application (Space Pro Output -Nelson 20W sprinkler with a flow control nozzle at 50PSI, rectangular spacing, spray heads 9m apart and spraylines 14m apart)

Table 3: Factors to increase irrigator profitability with improved DU and management

Increased Income	Decreased Costs
Increased consistency of produce size and quality Increased produce yield[1] Able to crop additional area under water limited conditions[1]	Reduced harvest and labour costs[2] Reduction in nutrient leaching and crop waterlogging Reduced water and pumping costs due to shorter pumping time and increased AE

[1] Assuming access to a market for the extra produce
[2] For crops that are harvested at a particular size such as cauliflower or broccoli based on more consistent produce size
[3] For improvement of existing system uniformity will typically result in decreased pump times

Table 4. Typical economic analysis to evaluate the gains from improved irrigation performance

Current Water Use	3ML/ha		
Market Price	$12.50	per 25kg Carton	
Potential Yield Gain	6.4%		
Current System Efficiency	80%		
Potential Efficiency	92%		
Potential Water Saving	0.45		
Pump Pressure	70		
Application Efficiency	60-80%		
Crops per year	3		
Direct Income Benefit			
	Minimum	*Average*	*Maximum*
Yield	6.3t/ha	7.2t/ha	7.7t/ha
Income	$3125/ha	$3605/ha	$3850/ha
Agronomic Production	2.1t/ML	2.4t/ML	2.6t/ML
Economic Production	$1042/ML	$1202/ML	$1283/ML
Indirect Income Benefit			
Power Savings	$11/ha		
Fertiliser Savings	$60/ha		
Total Income Increase			**$458/ha/year**
Costs Per Hectare	*Capital*	*Life Cycle*	*Cost*
Rubbers	$288	2	$144
Damaged Heads (20%)	$290	2	$145
Nozzles	$80	5	$16
Labour	$110	5	$22
	$768		
Total Cost to Improve DU			**$327/ha/year**

Table 5: Modifications commonly recommended to increase distribution uniformity in pressurised systems

System	Modifications
Solid Set and hand shift	Increased pressure, decreased spacing between spray lines, increased nozzle diameter, change from impact sprinklers to rotators
Boom, laterals, centre pivots	Pressure regulators at each nozzle, careful spray package selection
Travelling Guns	Closer run spacing, correct nozzle selection (ring, straight, tapered)

Extension and Benchmarking Benefits

The distribution uniformity and crop yield data was simple and quick to collect. The DU test typically takes less than 2 hours to setup and retrieve the catch cans. Similarly, the crop data is normally collected in less than 2 hours and it takes between 2 and 4 hours to analyse all the data. This is much quicker, simpler and cheaper than setting up either trial plots for crop water research or long term monitoring sites. While the statistical integrity of the in-field measurements could be further improved with replicate catch can layouts and additional yield measurements in the same irrigation block, it would seem to be more beneficial to increase the number of farm sites measured to improve our understanding of the “between-farm” variability and any subsequent estimate of the regional benefits of improved water use.

The horticultural sector is comparatively fragmented at the grower level due to local competition in the domestic fruit and vegetable markets. This competition has resulted in relatively little information being communicated between growers as there are often concerns over the dilution of any competitive advantage associated with new technology. However, the discussion of irrigation system machinery in general, and irrigation uniformity in particular, has been found to be a less threatening and mutually beneficial topic for these growers. This approach appears to be gaining enthusiasm from existing grower groups and seems to be analogous to attending a field day and discussing one brand of tractor in comparison to another. In these cases, the rapport and interest level generated through the irrigation performance evaluations has led to subsequent grower interest in the agronomic aspects of irrigation management.

CONCLUSION

Measuring crop performance under commercial practices has provided a useful approach to irrigation system evaluations, increased the relevance and interest of irrigators in water use efficiency. The linking of distribution uniformity and crop yield data with system performance models has also enabled substantial "value-adding" of the field data and improved the identification of irrigation production benchmarks (ML/ha, $/t, $/ha, t/ML, $/ML). This approach is directly relevant to irrigators and is simple enough for them to undertake with minimal assistance. The methodology deals with the irrigator's resultant profitability in conjunction with irrigation efficiency, provides direct environmental benefits and satisfies all parties interested in the irrigation industry from the irrigators to the environmentalists. Various crop management practices often complicate the comparisons of local irrigation regimes. Relating commercial distribution uniformity and yield data has highlighted the importance of irrigation as a fundamental production input that can often be managed more profitably.