The effect of irrigation non-uniformity on carrot production

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Abstract

Field trials were conducted at three field sites in the Fassifern Valley to determine the effect of irrigation non-uniformity on carrot production. Catch cans were used to measure the distribution uniformity. The total seasonal water at each catch can position over the entire growing period was calculated by summing the depths for each irrigation and rainfall. Yield samples were then taken at each catch can position prior to harvest and compared with the total seasonal water. Options to improve irrigation performance using simulation modelling were identified.

The distribution uniformities of the solid-set and travelling gun systems evaluated were found to be lower than the suggested industry standard of 85%. The sampled yield across the three trial sites did not show any correlation with the total seasonal water, implying that carrot yield did not vary significantly with varying irrigation uniformity. This may have been caused by the unusually high rainfall during the season. The SPACE program was used to in identify the optimal configuration of the solid-set system, while the TRAVGUN program was used to identify the optimal lane spacing and sector angles for the travelling guns.

Introduction

Carrot production is a significant horticultural activity in Queensland. The main growing areas are the Fassifern Valley, the Lockyer Valley and the Darling Downs. Due to insufficient and variable rainfall in these areas, carrot production is commonly irrigated using sprinkler systems.

The demand and competition for the scarce water resources in Australia is ever increasing. The efficiency with which this resource is being utilised is therefore of vital concern. It is against this background that the Queensland Government in partnership with the major rural irrigation industries established the Rural Water Use Efficiency Initiative (RWUEI) with the aim of improving on-farm water use efficiency. The adoption component of RWUEI in the horticultural industry was managed by the Queensland Fruit and Vegetable Growers (QFVG). This study was sponsored by QFVG's Water for Profit program to monitor the performance of carrot irrigators in the Fassifern Valley and to identify opportunities to increase their competitiveness.

Many studies have been undertaken to investigate the effect of uniformity of water applications on crop yield. Barber and Raine (2001) conducted a study of cauliflowers, potatoes, lettuce, apples and beans under drip and solid-set systems in the Lockyer Valley and found significant correlation between uniformity of applications and the resultant yields. King and Stark (1996) concluded that there is a general increase in potato yield with the increase in uniformity of applications. Conversely, Sanden (2002) found no statistical difference in yield with varying irrigation uniformity of sprinkler-irrigated carrots.

There is limited published data on the performance of Australian irrigation practices (Smith and Raine, 2000). The available data suggests this performance is highly variable. For instance Smith and Raine (2000) suggested that the application efficiency for irrigated agriculture in Australia ranged from 39 – 80%. Barber and Raine (2001) reported distribution uniformity of 31 – 95 % in the Lockyer Valley. However, the distribution uniformity standard suggested by QFVG (2003) was 85% for fixed sprinkler and travelling gun systems.

To the authors' knowledge, no data is available on the performance of the sprinkler irrigation systems used for commercial carrot production in Queensland. The specific objectives of this study were therefore to: (i) obtain the distribution uniformity (DU) data for sprinkler-irrigated carrots under commercial conditions; (ii) investigate the effect of irrigation non-uniformity on carrot production; and (iii) to evaluate the strategies that may be used to improve carrot yields through improved uniformity of applications.

Materials and methods

Field sites

Trials for this study were undertaken on three commercial carrot properties in the Fassifern Valley, a major carrot-producing region in Queensland (Table 1).

Table 1: Site characteristics

Site	Soils	Size (ha)	Application system
1	Clay loams	3.1	Solid set
2	Clay loams	3.0	Solid set[a] Travelling gun
3	Clay loams	2.0	Travelling gun

[a] solid-set used during crop establishment stage (one month)

A record of rainfall received in the vicinity of the three trial sites was required to determine the total amount of water supplied to the crop during the entire growing season. The rainfall data was obtained from the nearest meteorological station at less than 5 km from the field sites. The effective rainfall was assumed to be 80% of the recorded value.

Flow, pressure and calibration data measurement

Flow rate and operating pressure were monitored at all three sites to assist in the overall evaluation of the systems used. The data was also required to be used in the sprinkler simulation process and the calibration of the TRAVGUN simulation model.

The total flow of water through a single lateral (in the solid-set system) was measured using an electronic flow meter fitted on the lateral two metres from the sub main. Readings were recorded after each irrigation event. A Pitot tube was used to measure pressure at the sprinkler nozzles.

An electronic flow meter connected to a data logger was used on one occasion to record the supply flow rate delivered to the travelling gun. The flow meter was positioned at the water inlet connection to the machine, and the data logger recorded the flow rate at 5-minute intervals.

An automatic weather station with wind speed and direction measurement sensors was installed at the trial sites to obtain the wind speed and direction data for the calibration of TRAVGUN for the travelling gun irrigators. The machine travel speed, nozzle diameter, the trajectory angle and the sector angle were also measured. A pressure transducer connected to a data logger was fitted at the gun nozzle to record operating pressures at 5-minute intervals. However, there was a malfunction of either the transducer or the data logger (leading to loss of data) and as a result typical operating pressures of the two guns were obtained from the growers.

Measurement of application uniformity

Catch cans were used to estimate the evenness of water distribution at all three sites. The cans were installed at the trial sites one week before the carrots were planted, and were left in the same position throughout the carrot-growing period. The catch cans used were plastic containers with a capacity of one litre and opening diameter of 110 mm. The cans were attached to thin one-metre long steel rods using adhesive tape and installed slightly above the crop canopy.

The solid-set sprinkler system used at Site 1 had a lateral spacing of 9.75 m and the distance between the sprinklers was 9 m. The sprinklers were arranged in a triangular pattern. Two catch can grids of six rows and six columns were positioned between two laterals using a spacing of 1.80 by 1.63 m. At Site 2 where the solid-set system was used for the first month of crop establishment, the lateral spacing was 13 m and the distance between the sprinklers was 9 m. A triangular sprinkler pattern was also used at this site. Two catch can grids of six rows and seven columns with a catch can spacing of 1.5 by 2 m were established. These grids were dismantled just before the grower started irrigating using the travelling gun irrigator. A visual inspection of the sprinkler nozzles at Site 1 revealed that some were worn out.

In the trials conducted using the travelling gun irrigators, two rows of catch cans spaced at 2.4 m were placed at right angles to the direction of the machine travel. Site 2 had a lane spacing of 90 m and 20 catch cans on either side of the machine track. Site 3 had a lane spacing of 70.4 m and 16 catch cans on either side. In both cases, the distance between transects was 15 m and the width of the machine track was 4 m.

In the evaluation of each application system, the volume of water in each catch can was measured using a measuring cylinder immediately after irrigation to minimize losses due to evaporation, and the cans emptied. The cans were also emptied after each rainfall event. The catch can volumes were converted into depths of application by using the following expression:

$$\text{Depth of application} = \frac{\text{Volume of water in the can}}{\text{Cross-sectional area of the can opening}}$$

The distribution uniformity (DU) was calculated using the following formula:

$$\text{DU} = \frac{\text{mean of the lowest 25 \% of applied depths}}{\text{mean applied depths}}$$

The total depth of irrigation water applied to each catch can position over the entire growing period was calculated by summing up the depths for each irrigation. The total rainfall that occurred during the same period was added to the total irrigation applied to calculate the total seasonal water applied.

Crop sampling and analyses

The crop sampling process was undertaken in two stages at all three trial sites. The first crop measurements were undertaken approximately one month after the carrots were planted to determine the plant densities. Destructive yield sampling was conducted 1-4 weeks prior to harvest to estimate the carrot yield, and to relate it to the seasonal water applied.

Estimation of the average plant density simply involved counting all the plants established within a one-metre section of the carrot row at each site. This was done in five different locations of the sites. The average number of plants per metre and the row spacing was then used to calculate the total number of plants in one hectare.

Carrot yield was measured by pulling out between six and sixteen carrot roots within a distance of one metre of each catch can. A spade was used to loosen the soil around the carrot roots before pulling to minimize damage. The carrot roots were then weighed and the average weight of each carrot root determined. The following formula was then used to estimate the sampled yield for each catch can position:

Sampled Yield (kg/ha) = Average weight of carrot root (kg) x Number of plants/ha

The sampled yield was then plotted as a function of the total seasonal water applied at each catch can position.

Identifying options to improve irrigation performance using simulation models

The SPACE program (Oliphant 1999) was used to simulate the existing solid-set sprinkler system and to investigate strategies to optimise the irrigation uniformity. The options investigated included varying the spacing between the laterals, changing the layout, varying the pressure and changing the nozzles.

TRAVGUN (Smith et al. 2008) is a decision support tool which uses an empirical model to predict the performance of travelling gun irrigators under differing machine settings and wind conditions. The TRAVGUN simulation process involved altering gun configurations in order to achieve optimal irrigation uniformities. Also wind speed and direction, travel direction, sector angle, lane spacing, machine speed and target depth were varied and the application rates and the resultant uniformities calculated.

Results

Performance of the irrigation application systems

The irrigation performance of the solid-set system and travelling guns used at the trial sites are summarised in Table 2. The distribution uniformity of the solid-set system used at Site 1 ranged from 53-69%. The distribution uniformity of the travelling guns used at Sites 2 and 3 ranged from of 41-85% during the season. Total rainfall during the season ranged from 81-317 mm. The proportion of rainfall in the total seasonal water applied ranged from 47-79% at Site 1, 27-76% (transects) and 25-51% (grids) at Site 2, and 29-43% at Site 3. Rainfall across the trial plots was assumed to have been perfectly uniform.

Table 2: Irrigation performance of water application systems in the Fassifern Valley

Application system	Range in DU[a] (%)	Total water applied (mm)	Rainfall (mm)	Total seasonal water (mm)
Site 1-Solid-set	53-69	82-363	317	399-680
Site 2-Trav. gun	41-79	16-135	51	67-186
Solid-set	67-79	56-174	58	114-232
Site 3-Trav. gun	67-85	109-203	81	190-284

[a] DU values reported for travelling guns are for overlap patterns

The solid-set system used at Site 1 appeared to apply moderate application depths between the laterals, with the edges of the grids either receiving too much or too little application (Fig. 1). The solid set that was used at Site 2 appeared to have lower applications between the laterals and also between the sprinklers.

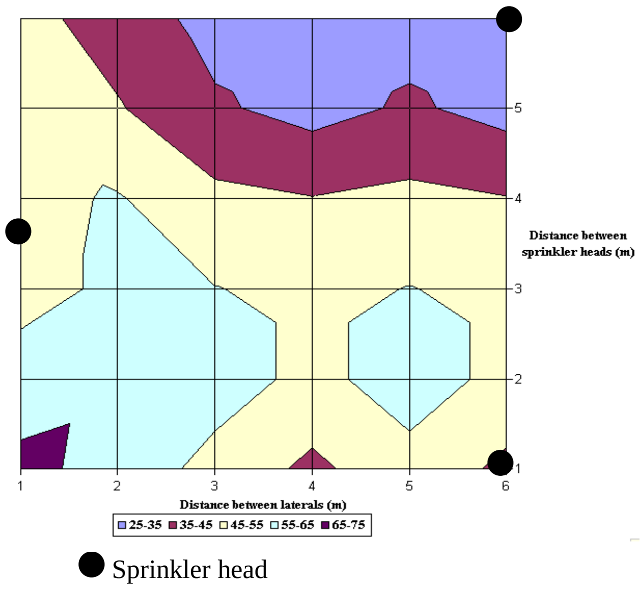

Fig. 1: Sample irrigation uniformity of the solid-set system at site 1

The uniformity of water applied by single runs of the travelling guns (Fig. 2) indicates that the application depths generally reduce as you move away from the machine. However when considering the overlapped pattern between two adjacent lanes, the area approximately midway between the laneways have application depths that are significantly less than the average application (Fig. 3).

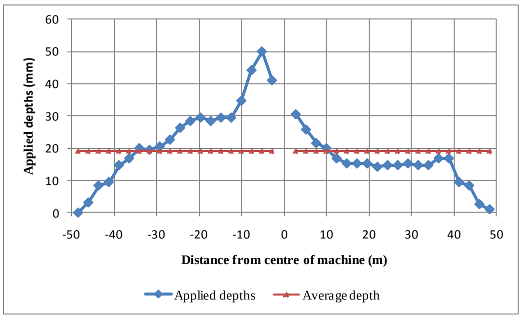

Fig. 2: Water distribution for a travelling gun (90 m lane spacing)

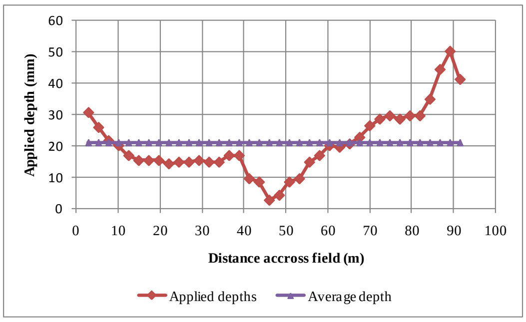

Fig. 3: Water distribution (overlap pattern, 90 m spacing) for a travelling gun

Crop response to uniformity of applications

There appeared to be no consistency in the response of total sampled crop yield at all three trial sites to the total seasonal water. However, yield generally tended to respond positively to total seasonal water at Site 2 (Fig. 4), but the response was not statistically significant (R^2 = 0.1057, Fig. 5).

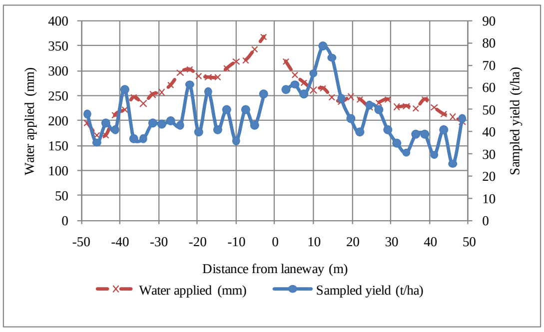

Fig. 4: Response of crop yield to water applied

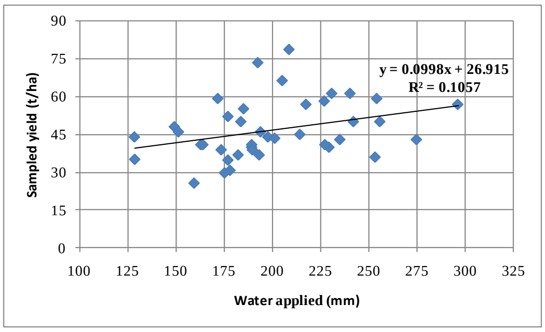

Fig. 5: Sampled yield versus water applied

Options for improving irrigation performance

Solid-set and hand shift systems

The SPACE computer program was used to predict the distribution uniformity (DU) of the solid-set system used by the grower at Site 1 (i.e. a triangular overlap pattern, a sprinkler head distance of 9 m and lateral spacing of 9.75 m). The output suggested a DU of 72 % operating in still conditions as opposed to the measured DU of 53-69 % (Table 1). The effect of varying the distance between the laterals from 7 to 12 m led to a decrease of DU from 78% to 63% over this range; with the optimal spacing being 9 x 9 m. Changing the layout of the sprinkler configuration was found to affect the performance with the rectangular layout pattern having the highest DU (75%).

Increasing the sprinkler pressure from 310-448 kPa was found to improve the sprinkler performance by 8% (Table 3). Increasing the pressure also resulted in an increase in the mean precipitation rate but a smaller variation over the mean values. Increase of nozzle size was also found to have a marginal increase in DU.

Table 3: Effect of pressure on uniformity of applications

Pressure (kPa)	DU (%)	Precipitation rate (mm/hr)		
		Mean	Minimum	Maximum
310.3	74	5.6	3.7	9.6
379.2	80	5.7	4.3	9.2
448.2	82	6.3	5.2	8.6

Travelling guns

The TRAVGUN simulations were used to investigate the effect of modifying gun (nozzle size 26 mm) characteristics on irrigation uniformities (Table 4). One parameter was varied at a time, with the wind speed and wind direction left constant at 1 m/s and 240° respectively. The machine speed was found to have no effect on DU while closer lane spacing resulted in deep drainage losses. The optimum lane spacing and nozzle sector angle for the gun operating at Site 2 were 46 m and 300° respectively. The program predicted that a lane spacing of 46 m would result in a DU of 86% and deep drainage loss of 42%. For the gun operating at Site 3, the optimal lane spacing and sector angle were 65 m and 240°.

Table 4: Effect of modifying gun operating characteristics on irrigation

Performance		DU (%)	Deep Drainage (%)	Minimum app. Depth (mm)	Average app. Depth (mm)	Maximum app. Depth (mm)
Lane Spacing (m)[a]	40	81.6	60.4	32.2	40.1	44.8
	46	86	42	26.5	35.5	52.3
	60	63.3	9.6	15.1	27.4	45
	80	69.1	0	13.4	20.6	44.8
	90	0	0	0	18.4	37.9
	100	0	0	0	16.5	44.8
Travel direction (°)[b]	0	63.9	0	13.7	24.8	44.8
	90	65.7	0	14.5	24.6	45
	180	63.7	0	13.7	24.5	44.8
	300	63.9	0	13.7	24.5	44.8
Sector Angle Deg (°)[c]	240	63.5	0	14.2	23.5	37.9
	300	70.3	0	15.9	23.5	37.9
	330	69.8	0	14.4	23.5	40.3
	360	63.9	0	13.2	23.5	43
Machine Speed (m/h)[d]	15	63.9	0	63.2	22.9	37.9
	20	63.9	63.2	22.4	17.2	74.6
	25	63.9	22.4	0	13.7	56
	30	63.9	0	0	11.4	44.8

[a] Machine speed 26 m/s, Target Depth 25 mm, Sector Angle 240°, Travel Direction 0°, Wind Direction 240° and Wind Speed 1 m/s

[b] Lane Spacing 70 m, Machine speed 26 m/s, Target Depth 25 mm, Sector Angle 240°, Wind Direction 240° and Wind Speed 1 m/s

[c] Lane Spacing 70 m, Machine speed 26 m/s, Target Depth 25 mm, Wind Direction 240° and Wind Speed 1 m/s, Travel Direction 0°

[d] Lane Spacing 70 m, Target Depth 25 mm, Wind Direction 240° and Wind Speed 1 m/s, Travel Direction 0°, Sector Angle 240°

Discussion

Performance of the irrigation application systems

The measured distribution uniformities of the solid-set and travelling guns used at the trial sites were lower than the suggested industry standards of 75% (Watson and Slugget 1984) and 85% (QFVG, 2003). However, the results are similar to those found by Barber and Raine (2001) in their trials conducted on the Darling Downs and the Lockyer Valley.

Wind and worn nozzles at Site 1 appear to have contributed to the low distribution uniformities. For instance at Site 1 one of the irrigations evaluated occurred during high wind speeds and resulted in a DU of 53 %. An inspection of the sprinkler nozzles around the catch can grids on one occasion revealed that some were worn out. The solid-set configuration at this site (9 by 9.75 m) was also closer than those commonly used in the Lockyer Valley (i.e. 9 by 14 m; Barber and Raine 2001).

The solid-set used for the first month of plant growth at Site 2 had a better DU than the system at Site 1, although it had a larger lane spacing (9 by 13 m). Site 2 was generally a low-wind zone (measured to be 0-1 m/s on one occasion and confirmed by the grower to be the typical wind speed) and this could have contributed to the better performance. The typical operating pressure of the gun used later in the season at this site (551 kPa) was in the recommended range of the Nelson 200 Series Big Gun (Newell *et al*. 2002). However, the lane spacing at this site (90 m) was 30 m more than the recommended spacing (Newell *et al*. 2002). The effect of this excess lane spacing on distribution uniformity is evident in the water distribution plots, with the area approximately midway between two consecutive laneways receiving less than 10% of the average application (Fig. 3). On average, the travelling gun used at Site 3 had a better DU than the one used at Site 2. This could be attributed to the narrower lane spacing (70 m) and higher operating pressure (655 kPa).

Options for improving irrigation performance

Solid-set and hand shift systems

The highest distribution uniformity measured at Site 1 (69%; Table 2) was 3% less than the distribution uniformity predicted by the SPACE program (72%). The predicted DU was expected to be greater than the measured DU as no wind conditions and no system wear are assumed in the modelling. The small variation in the predicted and the measured DU seems to suggest that the SPACE program may be a useful tool in predicting the performances of solid-set and hand shift designs before they are implemented.

The SPACE program is useful in the modification of the existing solid-set and hand shift systems to achieve optimum performance. Using the program to model the solid-set system at Site 1, it was possible to predict the expected irrigation performances at various lateral spacings in a triangular overlap pattern and therefore identify the optimum spacing. The model confirmed that DU increases with increase in operating pressure (Table 3) and nozzle size.

Travelling guns

The TRAVGUN simulation model suggested that lane spacing, travel direction and sector angle affect the distribution uniformity of the travelling gun while machine travel speed had no impact (Table 4) assuming constant wind conditions during the irrigation. This is in line with what other investigators have concluded (e.g. Gordon 2000). The program also rightly predicted that though closer lane spacing may have a higher uniformity, excessive deep drainage might result in some cases (Table 4).

Crop Response to uniformity of applications

The sampled carrot yield across the three trial sites did not show any correlation with the applied total seasonal water. This implies that carrot yield did not vary significantly with varying irrigation uniformity. This is in contrast with the findings of other studies for instance Barber and Raine (2001) on a study of potatoes, cauliflowers, lettuce and apples; and King and Stark (1996) on a study of potatoes. These results are however consistent with the conclusions made by Sanden (2002) on irrigated carrots.

Rainfall contributed significantly to the calculated seasonal water requirement at the three trial sites. For instance at Site 1 the effective rainfall accounted for between 46.6% to 79.4% of the total water applied (Table 2). It is thus possible that any potential impact of irrigation non-uniformity could have been evened out by this substantial rainfall. The studies that have suggested a strong relationship between crop yield and applied seasonal water unfortunately do not state the proportion of rainfall in the total seasonal water used in the analyses.

Conclusion

The distribution uniformities of the solid-set and travelling guns used at each trial site were generally lower than the irrigation industry standard of 85%. However, the values obtained appear close to what has been reported from the Lockyer Valley by other researchers (e.g. Barber and Raine 2001). Excessive lateral spacing, worn-out sprinkler nozzles and high wind speeds appear to have contributed to the low DU. Carrot yields across the three trials sites were found not to vary significantly with the amount of irrigation water applied. This implies that for the season investigated, the irrigation applications could have been reduced without either agronomic or economic loss. The high amount of rainfall during the season (especially at Site 1) was thought to have subdued the impact of the non-uniformity of applications on yields. A similar research in a low-rainfall season is desirable. The SPACE and TRAVGUN simulation models proved useful in improving the performance of existing sprinkler systems.

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