PRELIMINARY EVALUATION OF RELATIONSHIPS BETWEEN IRRIGATION NON-UNIFORMITY AND CROP RESPONSES IN LETTUCE

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ABSTRACT
Optimisation of irrigation management should aim to increase crop responses (yield and quality) to water application and reduce input (e.g. water and nutrients) losses. A key limitation to improving water use efficiency is the uniformity of irrigation application. To evaluate the impact of water application uniformity a trial was conducted using lettuce under a solid set irrigation system. Three weeks after transplanting, the sprinkler pressure was deliberately and asymmetrically reduced in one sprinkler grid (termed the Poor-1grid) producing an average water distribution uniformity (DU) of 53%. In a second grid (termed the Poor-2 grid) the uniformity was reduced by nozzle and sprinkler head changes to an average DU of 63% while in the Control grid the average DU was 75%. A significant variation in soil moisture tension (4 to 93 kPa) was observed between the high, medium and low water application areas of the Poor-1 grid while comparatively less variation (maximum 41 kPa) in soil tension was observed across the Control grid. No relationship was found between water application and lettuce canopy width. However, significantly lower harvest fresh weight, head size and head weight were found in the low and medium application areas compared to the high water application area of the Poor-1 grid. There were also substantial reductions in the number of marketable heads found in the Poor-1 (42% of total heads) and Poor-2 (58%) grids compared to the Control (71%). There was no indication that the marketability and/or production benefits of improving uniformity of application reached a plateau at the industry accepted levels for irrigation uniformity (ie. DU ≥75%, CU ≥80%). This work has quantified the relationships between irrigation uniformity, water application and production in lettuce. However, further work is required to incorporate the effect of environmental conditions (i.e. probability of in-season rainfall), crop production responses, water availability and price, as well as the cost of application system changes into a framework for the identification of optimal levels of application system uniformity.

1. INTRODUCTION

Soil-water availability is a major determinant of crop yield and is often highly correlated with the uniformity of irrigation application. Uneven watering has been found to affect crop growth for a range of crops including cauliflower and lettuce (Barber and Raine 2002), sugar beet (Ucan and Gencoglan 2004), citrus (Dagan 2002), corn and soybean (Kravchenko and Bullock 2000) and cotton (Elms et al. 2001). Improved water control using precision management (Sadler et al. 2005) has been found to significantly increase crop water use efficiency (Jin et al 1999).

Low uniformities of water application under sprinkler irrigation systems may be caused by a range of problems but most commonly are due to inappropriate sprinklers selection, sprinkler and lateral spacing, pressure differences along the laterals or operating the system under inappropriate conditions (e.g. high wind) (Raine 1999). However, optimal irrigation management not only requires the appropriate knowledge of the irrigation system but also needs environmental knowledge. For example, crop water requirements may be fulfilled during certain periods by rainfall.

Vegetables are a major contributor to irrigated agriculture production in Australia (ABS 2004) and the annual value of the lettuce industry is approximately $174 million (AUSVEG 2007). Solid set sprinkler irrigation systems are commonly used by lettuce growers in Australia (Barraclough and Co 1999). However, very little information is available on the spatial variability of irrigation application and its impact on lettuce growth. The main focus of this research was to evaluate the effect of non-uniform irrigation application on lettuce crop growth and yield.

2. MATERIALS AND METHODS

This experiment was conducted at the Department of Primary Industries and Fisheries Gatton Research Station, Queensland. The soil was a moderately self-mulching Black Vertosol. The total area planted with lettuce was 92 × 11 m. The trial area was cultivated into seven longitudinal beds, each 1.3 m wide and separated by 0.3 m furrows. A solid set irrigation system consisting of ISS Rainsprays (1.98 mm nozzles) mounted on 0.6 m risers and operating at 335-380 kPa was used to irrigate the trial. The sprinklers were arranged in a square pattern with 9 m spacings along the laterals and 11 m between laterals. Five week old Iceberg (cv. Titanic) lettuces were transplanted on the 12/4/07, with three lettuce rows on each bed and an intra-row spacing of 0.33 m.

One pre-plant (5/4/07) and ten in-crop irrigations were applied during the growing period. A total of 7.4 mm of rainfall was received from six rainfall events during the main growing period. Three measurement grids were established within the trial area: a Poor-1 grid (9 x 11 m in size; 9-18 m from the sub-main), a Control grid (36-45 m from the sub-main) and a Poor-2 grid (63-72 m from sub-main). Since water pressure in sprinkler systems has a significant role in the uniformity of water application (Hanke et al. 2004, Mateous 1998) the uniformity of sprinkler application in the Poor-1 grid was reduced after the fourth (26/4/07) in-crop irrigation by asymmetrically fitting pressure reducers (nominal pressure at sprinklers of 362, 137, 172 and 137 kPa) to the risers in each corner of the grid. The uniformity of application in the Poor-2 grid was altered by changing the sprinklers nozzles after the fifth (2/5/07) in-crop irrigation and then replacing each sprinkler head with Nelson R2000 rotators (K2 9° plate, #10 2TN nozzle) after the seventh (14/5/07) in-crop irrigation. Water application within each sprinkler grid was measured using 42 plastic catch cans arranged on a grid (1.5 × 1.56 m spacing). Irrigations were conducted late in the afternoon with catch can data collected the following morning. Irrigation performance was calculated using Christiansen's (1942) Uniformity Coefficient (CU) and Distribution Uniformity (DU) as described by Walker and Skogerboe (1987). Soilspec tensiometers were installed at 0.15 m depth next to each catch can in the Poor-1 grid and next to every second catch can in the Poor-2 and Control grids. Soil tension measurements were recorded at 9 am each day. Irrigation was applied to all grids when the average tensiometer values in the Control grid approached 25 kPa (Heisswolf et al 1997).

The lettuce canopy cover and head size of two tagged plants either side of each catch can were measured using a measuring tape after implementation of the sprinkler changes. Six lettuces were harvested for evaluation around each catch can in the Poor-1 grid and every second catch can in the Poor-2 and Control grids. Serial harvesting of the crop was conducted from the 29/5/07 to 8/6/07 using the Harvesters' Tactile Assessment of Head Maturity (Heisswolf et al. 1997) test. After harvesting, each lettuce head was individually assessed for total plant fresh weight, head fresh weight and diameter, and a range of lettuce quality characteristics.

3. RESULTS AND DISCUSSION

3.1 IRRIGATION SYSTEM PERFORMANCE

There was no significant ($P<0.05$) difference in the average depth of irrigation water applied in each grid prior to implementing the sprinkler and pressure modifications (Table 1). In general, there was also difference in the uniformity parameters for each irrigation prior to sprinkler modification. However, the Poor-1 grid did have a lower uniformity compared to the other treatments for the two irrigations (20/4/07 & 26/4/07) immediately prior to treatment implementation. Following sprinkler modification, there was no significant difference in average water applied in the Poor-2 and Control grids but the average depth applied in the Poor-1 grid was approximately 23% lower than in the other grids. As expected, the variability in the applied depths was higher in the Poor grids after sprinkler modification compared to the Control grid. The average CU of the Poor-1 grid after modification was 64.1% compared with 75.6 and 83.2% for the Poor-2 and Control grids, respectively. Similarly, the average DU decreased from 74.8% in the Control to 63.4 and 53.0% in the Poor-2 and Poor-1 grids, respectively.

3.2 SOIL MOISTURE TENSION

Soil moisture tension was generally maintained at less than 30 kPa across the majority of areas in each grid before modifying the sprinklers. However, after introducing the pressure reducers, significant differences in the soil tension were observed (Figure 1) across the Poor-1 grid in response to differences in the depth of water applied. Towards the end of the season, the low water application areas reached a maximum soil tension of 93 kPa while in the medium and high application areas the maximum value was only 55 and 22 kPa, respectively. After irrigation, soils in the high and medium water application zones within the Poor-1 grid generally re-wet to field capacity, whilst the low water application zones stayed drier. In the Control grid, soil tensions peaked at 21, 29 and 41 kPa for the high, medium and low water application areas, respectively.

Table 1 Water applied and uniformity for each irrigation event

Date of irrigation applied	Av. water applied (± std dev) (mm)			Uniformity Coefficient (%)			Distribution uniformity (%)		
	Poor-1 grid	Poor-2 grid	Control grid	Poor-1 grid	Poor-2 grid	Control grid	Poor-1 grid	Poor-2 grid	Control grid
5/4/07	20 ±5	19 ±4	19 ±4	77.7	82.2	81.6	69.6	75.9	74.7
13/4/07	31 ±7	33 ±6	29 ±5	81.5	86.2	86.1	76.6	82.0	79.8
15/4/07	25 ±4	25 ±4	23 ±4	86.1	85.8	87.4	80.8	77.6	80.8
20/4/07	17 ±6	17 ±3	16 ±5	73.5	84.4	78.2	60.5	77.3	71.3
26/4/07	19 ±6	19 ±4	17 ±3	73.1	84.9	79.2	64.6	79.2	73.6
2/5/07	16 ±6	21 ±5	21 ±4	66.5	81.7	84.1	56.0	75.8	74.1
8/5/07	16 ±7	25 ±6	22 ±5	63.4	78.8	80.9	53.1	68.6	71.0
14/5/07	17 ±7	26 ±5	22 ±3	66.6	84.1	88.9	50.1	76.1	82.9
18/5/07	8 ±3	10 ±4	10 ±3	64.6	66.9	76.0	51.6	51.2	64.9
25/5/07	14 ±5	17 ±4	17 ±3	70.3	82.0	88.9	63.1	74.0	84.7
30/5/07	7 ±4	11 ±5	11 ±3	53.4	66.0	80.4	44.3	47.1	70.9

Note: Shading indicates modified irrigation performance

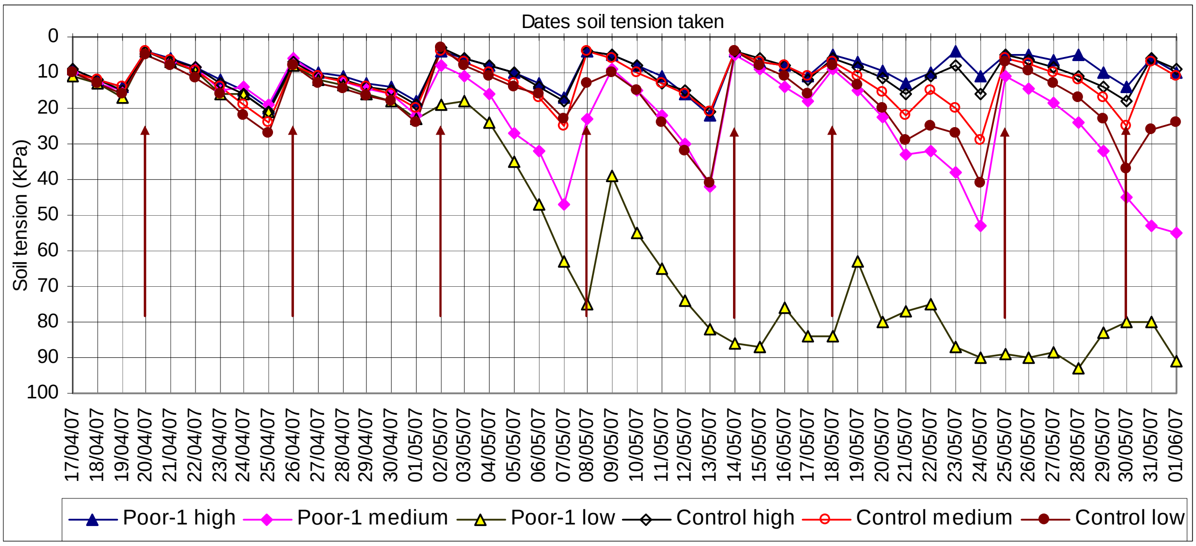

Figure 1 Representative soil tension in the low, medium and high water application areas of the Poor-1 and Control grids (arrows indicate irrigation events)

3.3 RELATIONSHIPS BETWEEN WATER APPLICATION AND LETTUCE GROWTH

After introducing the pressure reducers in the Poor-1 grid, the irrigation system generally applied more water near the sprinklers, compared to other parts of the grid (Figure 2a). This pattern was observed to be similar through the remaining irrigations. Visual inspection of the spatial patterns in lettuce canopy size, head size and the number of marketable heads suggest that there is a relationship between water application and plant response (Figures 2b-d). However, the plant canopy width data from the Poor-1 grid showed only a small non-significant trend towards smaller plants and greater variability as the season progressed (Table 2). The canopy width was also poorly correlated ($R^2 < 0.1$) with cumulative water application.

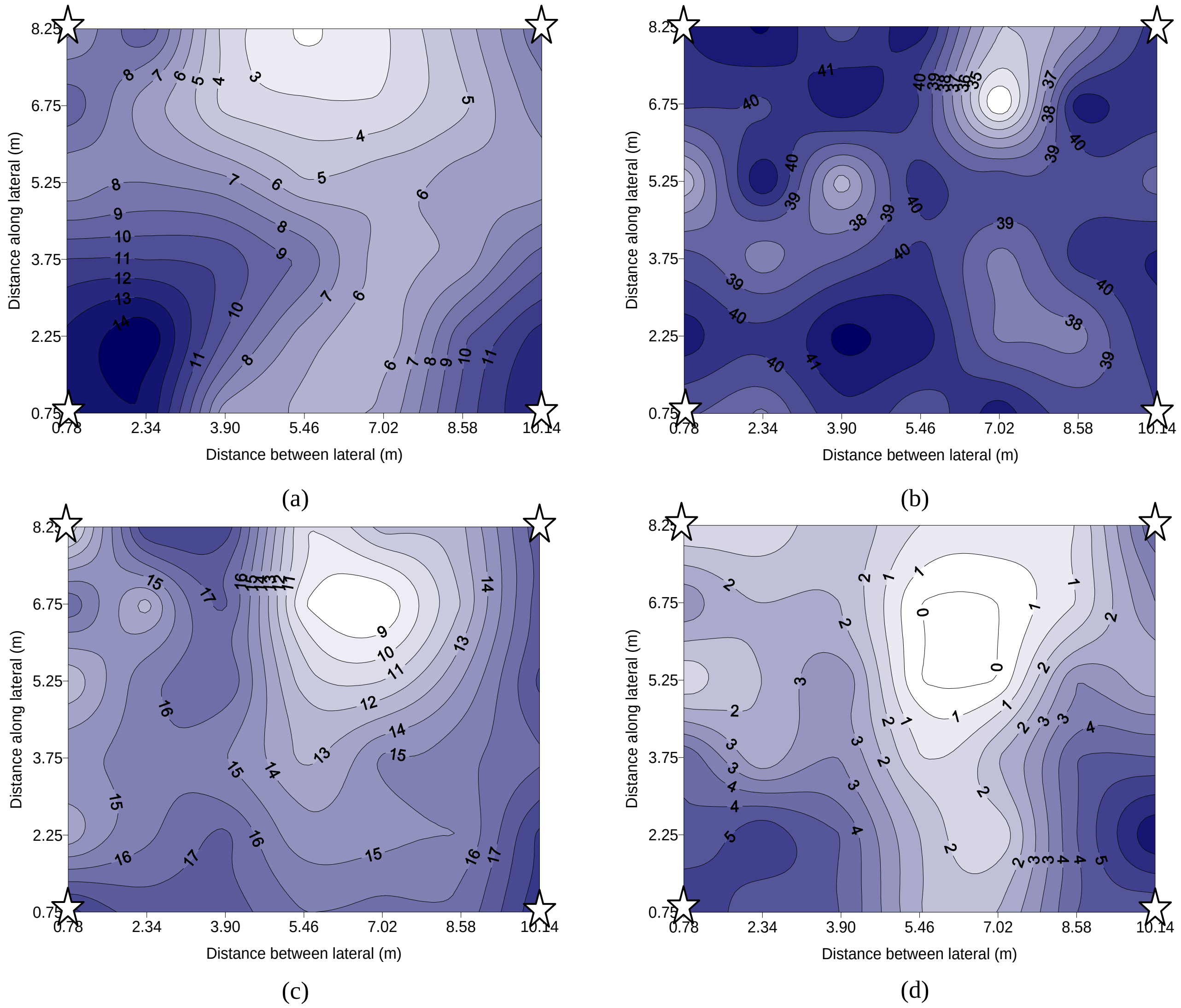

Figure 2 Poor-1 grid (a) water distribution applied on the 18/5/07 (in mm), (b) lettuce canopy size measured 24/5/07 (in cm), (c) lettuce head size measured 28/5/07 (in cm) and (d) total marketable lettuce heads (per 6 head sample)

Table 2 Effect of water application on lettuce canopy width in the Poor-1 grid

Application area	1//5/07	7/5/07	13/5/07	16/5/07	18/5/07	22/5/07	24/5/07
Low	20.7±1.3	27.8±2.3	32.0±1.0	35.8±2.0	36.7±2.7	38.0±2.6	39.0±3.6
Medium	21.6±1.1	28.4±1.1	33.0±1.5	36.9±1.8	38.9±1.5	39.3±2.0	40.6±2.3
High	21.6±2.2	28.7±1.6	33.8±1.2	36.7±2.3	37.9±1.6	40.1±2.2	40.2±1.8

Variations in water application across the Poor-1 grid were found to produce significant differences in lettuce fresh weight, head diameter and head weight at harvesting (Table 3). The average head diameter was 14% smaller and fresh weight was 18% lighter in the low water application area compared to the high water application area. These differences translated into a large reduction in the marketable heads in the low (18% marketable) and medium (24% marketable) water application areas compared to the high (73% marketable) area (Table 4; Figure 2d). Similar, but smaller, trends were found in the Poor-2 and Control grids with the low water application area in the Control grid producing 54% marketable heads compared with 87% marketable heads in the high water application area. These differences across the grids produced substantially higher total marketable heads in the Control (71%) than in the Poor-2 (58%) and Poor-1 (42%) grids (Figure 3). The number of marketable heads increased for each of the first three harvest dates but did not change substantially after the 5/6/07. There was no difference in the total marketable heads between the Poor-2 and Control grids for the first two harvest dates (29/5/07 & 1/6/07) but there were substantial differences at the third harvest date (5/6/07).

Table 3 Effect of irrigation application on harvested lettuce in the Poor-1 grid

Application area	Lettuce fresh wt. (g)	Lettuce head diameter (cm)	Lettuce head wt. (g)
Low	741 ±140	16.6 ±1.7	443 ± 96
Medium	827 ±152	16.8 ±1.8	473 ±103
High	899 ±141	19.2 ±2.1	571 ±121

Table 4 Marketable heads in the low, medium and high water application areas of each grid

Application area	Poor-1	Poor-2	Control
Low	18 %	43 %	54 %
Medium	24 %	57 %	62 %
High	73 %	82 %	87 %

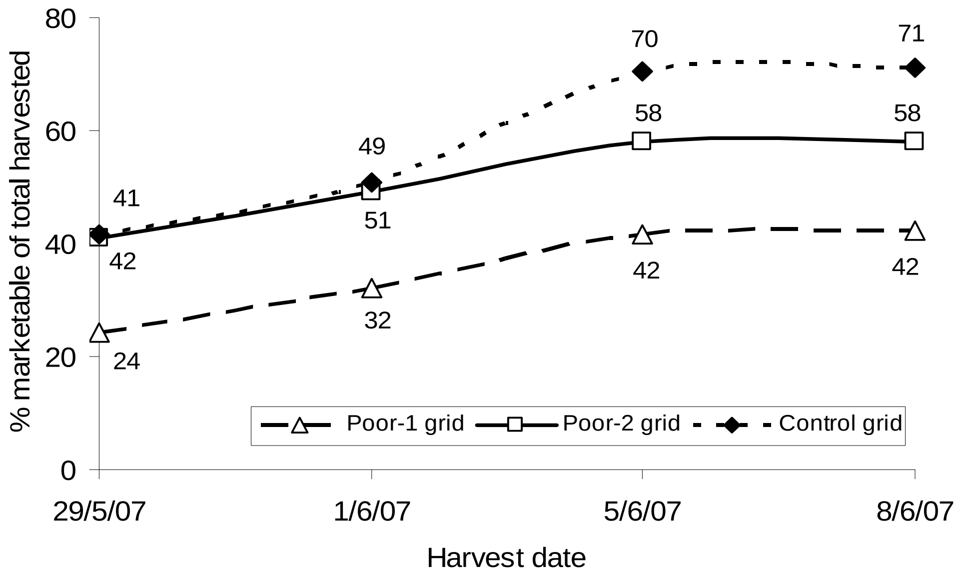

Figure 3 Effect of irrigation uniformity on cumulative marketable lettuce heads with harvest date

The catch can and marketability data was used to develop a water production function (Figure 4a) which showed there is a strong positive linear relationship between the water applied and lettuce head marketability. This confirms that increasing water application increases lettuce marketability, at least under the environmental conditions encountered and the range of water application depths applied in this trial. Only three levels of irrigation uniformity were evaluated in this study. However, the results obtained at these levels suggest that there is also a strong linear relationship between overall system uniformity and marketability.

It should be noted that there was a 30% loss in marketable yield when the application system was operating at the industry accepted benchmark level for uniformity (ie. DU ≥75%, CU ≥80%). While this may have been due to non-irrigation issues (e.g. pest or nutrition), the nature of the relationships shown in Figure 4 suggest that improving the irrigation uniformity above these levels should further increase marketability. However, local lettuce irrigators anecdotally report that they have much lower levels of non-marketability despite their application systems often having measured uniformities well below the benchmark level. This suggests that these irrigators may be compensating for low irrigation uniformity by applying higher irrigation volumes at lower application efficiencies and raises concerns over losses to deep drainage, nutrient leaching and waterlogging on high clay soils. The relative economic merits of either improving system uniformity or suffering a reduced water use efficiency due to higher application rates is the subject of on-going research but is likely to be a function of the environmental conditions (i.e. probability of in-season rainfall, sol drainage properties), crop production responses, water availability and price, as well as the cost of application system changes.

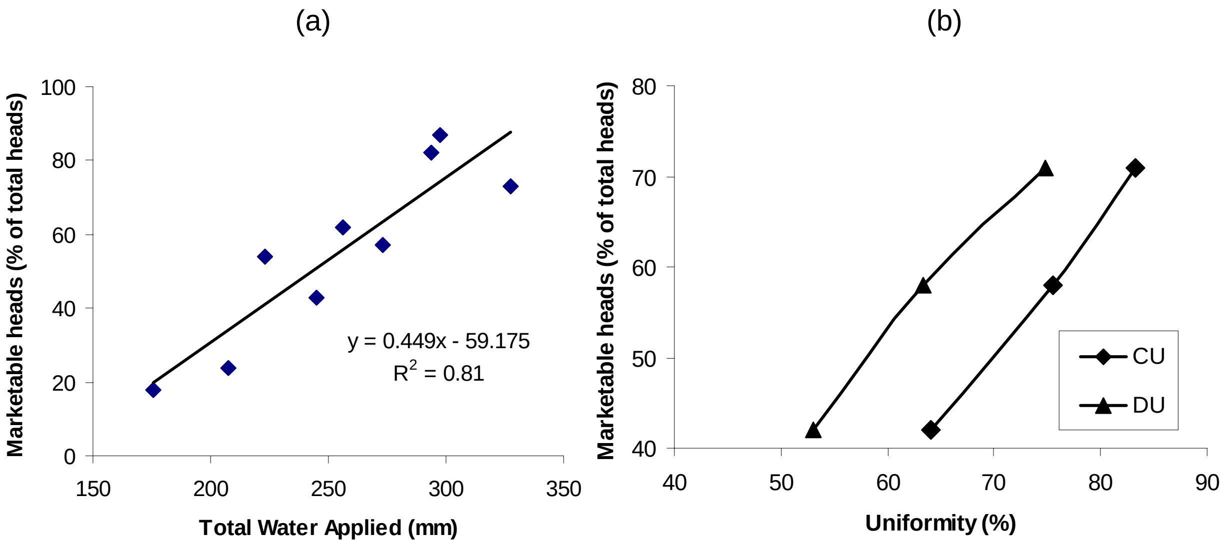

Figure 4 Effect of (a) total water applied on the marketable lettuce heads within grids and (b) irrigation uniformity on the total marketable lettuce heads in each grid

4. CONCLUSIONS

The uniformity of the irrigation application system has been shown to significantly affect the uniformity of soil moisture availability and the resultant lettuce production. While there was little impact of water application variations on the growth of the lettuce canopy, significant impacts were observed in terms of lettuce head marketability. The relationships between irrigation uniformity and lettuce marketability under the soil and rainfall conditions experienced in this trial have been demonstrated and a response function between water application and marketability developed. However, further research is required to assess the relative economic merits of either improving system uniformity or suffering a reduced water use efficiency due to higher application rates under a range of environmental conditions, crop returns and application system conversion options.

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