Alternate furrow irrigation reduces water applied without yield reduction in California processing tomatoes

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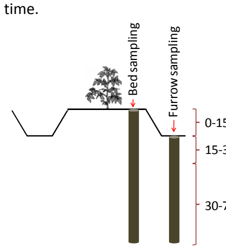
Introduction

- Alternate furrow irrigation (AFI) is based on the novel partial root drying technique for vegetables which consists of:
  - Irrigating only one side of the plant, i.e., half of the root system, at each irrigation event, while the other side receives water on the next irrigation.
  - Relying on soil moisture regulation of root to shoot signaling and control of stomatal conductance, which can reduce water transpiration.
  - Managing so that yields are not significantly affected by a reduction in stomatal conductance, which can increase water use efficiency.
- About 50% of the area planted to processing tomatoes in California is under furrow irrigation (≈115,000 ha planted to tomato annually).
- Processing tomatoes have shown a great potential to increase yields; >50% without significant changes in evapotranspiration rates (ET_c= 648 mm) since the 1970's (Hanson and May, 2006. Irrig Sci 24, 211-221).
  - Thus, alternate furrow irrigation may be suitable to processing tomatoes in California because of a suite of traits, e.g., physiological and morphological, that can favor higher productivity with less applied water.

Objectives

1. Determine the effect of alternate furrow irrigation (AFI) on plant growth, yield , agronomic water use efficiency (WUE_a; yield / applied water) and fruit quality when compared to every furrow irrigation (EFI).
2. Measure the effects of alternate furrow irrigation on leaf gas exchange parameters and how it affects intrinsic WUE (WUE_i; CO_2 assimilation/H_2O transpired, i.e., P_n/g_s) compared to every furrow irrigation.
3. Measure how soil moisture content vary depending on irrigation treatment at different depths and positions through time.

Figure 1. Representation of a planting bed and furrows. Tomato plants were planted on a single row in the middle of the bed. Soil sampling included three depths: 0-15 cm, 15-30 cm and 30-75 cm. Both sides of the bed were sampled at 35 cm from the center as well as the two adjacent furrows (76 cm from bed center).



Methodology

- A field study was conducted under controlled irrigation conditions and current management practices at the Campbell Research and Development Facility, Davis, California. Irrigation was carefully managed to not have run-off.
- Two highly-productive and widely planted processing tomato (*Solanum lycopersicum*) cultivars were used: AB2 and CXD255.
- A total of 24 plots in a randomized complete block design with a split-plot structure was established (2 irrigations x 2 cultivars x 3 reps x 2 blocks)
- Evaluations included:
  - Soil moisture sampling before planting, at mid-season, and after harvest (-6, 65 and 132 days after planting; DAP). Samples were taken from the bed and the furrow at three depths: 0-15, 15-30 and 30-75 cm (Fig. 1). Soil deep coring was done to a 3-meter depth at -5 and 137 DAP.
  - Spot measurements of furrow inflow for every furrow in all irrigations.

  - Leaf gas exchange measurements on days prior to an irrigation event using the LI-6400 (LI-COR Inc., Lincoln, NE, USA).
  - Canopy growth monitoring using an infrared digital camera (Dycam, Woodland Hills, CA).
  - $\delta^{13}C$ from shoots at harvest: dried, ground, and analyzed in the Stable Isotope Facility at UC Davis.
  - Aboveground biomass: shoots and fruits at 65 and 126 DAP.
  - Standard fruit quality parameters for the processing tomato industry: pH, soluble solids and fruit color.

Acknowledgements

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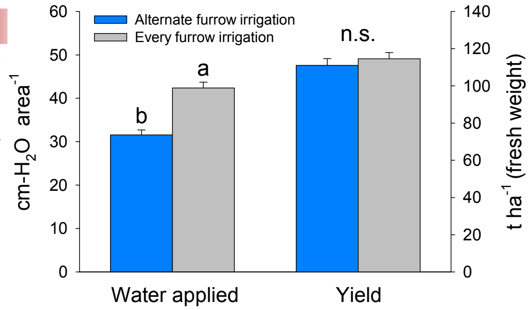

Figure 2. Comparison of alternate furrow irrigation (AFI) vs. every furrow irrigation (EFI) for total amount of applied water (left *y* axis) and total harvestable fruits (right *y* axis). Data shows mean ± standard error (n= 12). Means followed by different letters are significantly different at $p< 0.05$; n.s.= no difference.

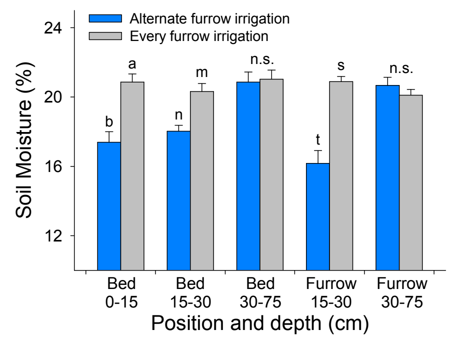

Figure 4. Soil moisture content of alternate furrow and every furrow irrigation treatments sampled at mid season (65 days after planting). Soil samples were taken from both sides of the bed and adjacent furrows at different depths (Fig. 1). Data shows mean ± standard error (n= 12). Means followed by different letters are significantly different at $p< 0.05$; n.s.= no difference.

DAP^	Measurement	Irrigation: Alternate furrow	Irrigation: Every furrow	Cultivar: AB2	Cultivar: CXD255
65	Shoot biomass ($g\ m^{-2}$)	306 ± 8	298 ± 12 n.s.	316 ± 11	307 ± 14 n.s.
65	Unripe fruit biomass ($g\ m^{-2}$)	63 ± 5	61 ± 6 n.s.	49 ± 4	75 ± 4 n.s.
69-86^^	Photosynthetic rate ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	29.8 ± 0.3	30.1 ± 0.3 n.s.	30.1 ± 0.3	29.8 ± 0.3 n.s.
69-86^^	Conductance ($mol\ H_2O\ m^{-2}\ s^{-1}$)	1.15 ± 0.03	1.20 ± 0.03 n.s.	1.25 ± 0.03	1.10 ± 0.03 n.s.
69-86^^	#WUE_i (μmol-CO_2 mol-H_2O^{-1})	26.9 ± 0.6	26.1 ± 0.6 n.s.	25.0 ± 0.6	27.9 ± 0.5 *
126	Shoot $\Delta\ ^{13}C$	20.7 ± 0.1	20.8 ± 0.1 n.s.	20.8 ± 0.0	20.7 ± 0.1 n.s.
126	Shoot biomass ($g\ m^{-2}$)	658 ± 40	709 ± 31 n.s.	655 ± 43	712 ± 26 n.s.
126	Unripe fruit biomass ($g\ m^{-2}$)	87 ± 13	112 ± 16 n.s.	64 ± 8	135 ± 13 n.s.
126	Harvestable fruit biomass ($g\ m^{-2}$)	699 ± 43	779 ± 55 n.s.	856 ± 46	622 ± 23 *
126	##WUE_a (t-yields cm-H_2O^{-1})	3.5 ± 0.1	2.7 ± 0.1 *	3.1 ± 0.1	3.1 ± 0.2 n.s.
132	Fruit pH	4.58 ± 0.02	4.59 ± 0.02 n.s.	4.53 ± 0.01	4.65 ± 0.01 ***
132	Fruit soluble solids (°Brix)	5.00 ± 0.10	5.01 ± 0.10 n.s.	5.28 ± 0.07	4.74 ± 0.06 ***
132	Fruit color (a/b)	2.19 ± 0.01	2.19 ± 0.01 n.s.	2.17 ± 0.01	2.22 ± 0.01 **

^ Days after planting; ^^ Six measurements taken from 69 DAP until 86 DAP; # Intrinsic water use efficiency; ## Agronomic water use efficiency

Table 1. Physiological and morphological parameters compared between alternate furrow and every furrow irrigation treatments, and the two processing tomato cultivars (AB2 and CXD255). Data shows mean ± standard error (n= 12). Means that are different are followed by * ($p< 0.05$), ** ($p< 0.01$), or *** ($p< 0.001$).; n.s. = no difference.

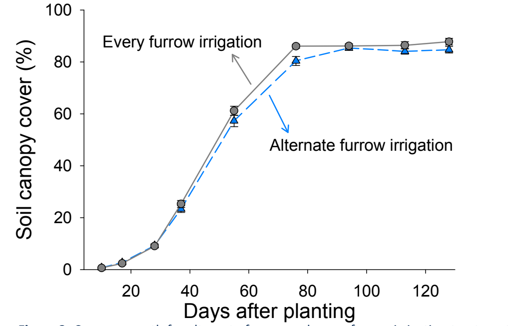

Figure 3. Canopy growth for alternate furrow and every furrow irrigation treatments from planting until harvest. Data is shown as percent of soil covered by the canopy. Data shows mean ± standard error (n= 12). No differences were found within dates.

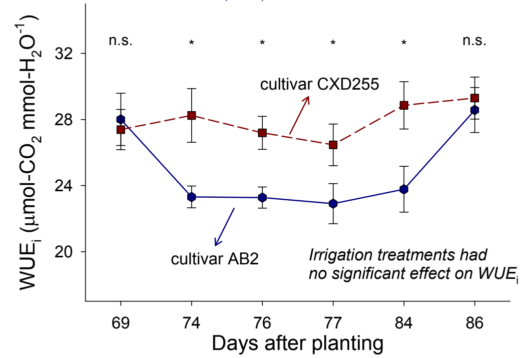

Figure 5. Intrinsic water use efficiency (WUE_i) from leaf gas exchange measurements during maximum plant growth. Shown are two tomato cultivars: AB2 and CXD255. Irrigation treatments had no effect on cultivar WUE_i. Days of irrigation between this period: 70, 78 and 87 DAP. Data shows mean ± standard error (n= 12). Mean comparisons are within each day; *= difference at $p< 0.05$; n.s.= no difference.

Results

- Alternate furrow irrigation (AFI) reduced applied water by 25% without a decrease in yields, compared to every furrow irrigation (EFI) (Fig. 2).
- Agronomic water use efficiency (WUE_a= yield/applied water) was 30% higher in alternate furrow irrigation than every furrow irrigation (Table 1).
- Tomato plants had similar canopy growth and biomass accumulation through the entire season regardless of irrigation treatment (Fig. 3 and Table 1).
  - cv. AB2 had more harvestable fruit than CXD255 by harvest (126 days after planting; DAP). Shoot, unripe fruit and total aboveground biomass were similar at both sampling times (65 and 126 DAP).
- Soil moisture content was lower with alternate furrow irrigation at mid-season (65 DAP) in the 0-15 cm and 15-30 cm depths (Fig. 4). Soil moisture to a depth of 3 meters at planting and harvest were similar (data not shown).
- The overall mean photosynthetic rate (P_n) and leaf conductance (g_s) from all measurements were not different between irrigation or cultivar treatments.
- Intrinsic WUE (WUE_i: P_n/g_s) was similar in both irrigation treatments (Table 1).
  - cv. CXD255 had higher WUE_i than cv. AB2 (Table 1 and Fig. 5).
  - Shoot ^{13}C discrimination values ($\Delta^{13}C$), an indirect indicator of WUE_i, was not fully consistent with spot-measured gas exchange data (Table 1).
- Irrigation treatments did not affect fruit quality parameters, but significant differences were found between the two cultivars (Table 1).

Conclusions

- Plant morphological and physiological responses were unaffected by the wet and dry soil moisture pattern of alternate furrow irrigation, suggesting that processing tomatoes in California are plastic enough to fulfill shifting water demands from the shoot and fruits through the growing season.
- Alternate furrow irrigation is a way to use less water without a decrease in yield or fruit quality, and without investment in technology such as drip irrigation.