Optimizing Crop Water Use Efficiency with AirJection® Irrigation

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Abstract

Evaluating the addition of ambient air via subsurface drip irrigation system, referred to as AirJection® Irrigation, has been the focus of our research over the past seven years. In the most recent phase our research we examined the potential of this system to enhance crop water use efficiency (WUE). First, we compared the "agronomic" WUE, calculated as the ratio of crop yields to water inputs, for conventionally and organically grown vegetables. Secondly, by measuring the rates of photosynthesis, transpiration, and stomatal conductance, we determined the "leaf scale" and "intrinsic" WUE. Our results to date indicate that AirJection® Irrigation had a significant ($P<0.05$) on crop WUE. In the case of the organically grown vegetables, this effect was enhanced by Nitrogen fertilization. These findings would be of benefit to vegetable growers as they continue to optimize their irrigation systems in an effort to maintain the sustainability of their farms.

Introduction

The world population is estimated to increase from 6.1 billion in 2000 to 9.1 billion by the year 2050 (UN, 2005). With this increase in population, there exists a challenge to feed the people by producing crops on relatively less arable land and limited water resources. In addition to urbanization, there is a decrease in agricultural land due to soil erosion, reduced soil fertility, and desertification of soils (Carvalho, 2006).

California is known to be one of the largest and most diverse economies in the United States. Industries such as agriculture, mineral extraction, telecommunications, and computer technology have made California a mixed economy (DWR, 2005). It is estimated that California's population may reach up to 48 million by 2030, as projected by the California Department of Finance, and by 2050, it may grow to a total of 55 million. With an increasing population, the state's demand for water, either for domestic use, or for agricultural purposes, would invariably enhance the importance of water conservation recycling strategies (DWR, 2005). The present water situation in California has to be seen as a critical need to improve the irrigation practices further but not as a limitation to farming practices.

Sub-surface Drip irrigation (SDI), has been reported to be a very effective way of applying water and nutrients to the crops (e.g. Camp et al., 2000; Ayars et al., 1999). In the San Joaquin Valley (SJV), the leading agricultural production region in California (CDFA, 2003), SDI is a major component of agricultural production systems as farmers continue to compete with municipalities and other industries for decreasing water resources. Over sixty five years ago, Durell (1941) wrote, ''a study of suitable oxygen carriers, which could be applied as fertilizer, and which would release oxygen slowly to the soil during the growing season, may be worthwhile". More recently, through work in other areas, the Mazzei® Corporation has developed high efficiency venturi injectors capable of aerating water with fine air bubbles. The combination of the venturi system with SDI has been patented as AirJection® Irrigation. Researchers in Australia have also adopted this technology and refer to it as oxygation (Bhattarai et al., 2005). The concept of modifying the root zone by injecting air into the subsurface drip irrigation system (SDI) could be an alternative for tillage operations. The hypoxic condition which might be induced due to the alternate wetting and drying using SDI can be avoided by injecting air into the irrigation water supplied through SDI (Bhattarai et al., 2004). When air alone is supplied to SDI system, it emits a vertical stream moving above the emitter outlet directly to the soil surface. As a result, the air moves away from the root zone due to chimney effect (Goorahoo et al., 2001a,b).

The major goal of our research is to evaluate the technical and economic feasibility of AirJection® Irrigation, as a best management practice for crop production. Ideally, the technology should be applied to and tested on as many crops as possible. Realistically, we plan on assessing the practice on as many vegetable and fruit crops commonly grown in the SJV. In this presentation, we review the basic concepts of AirJection® Irrigation and then describe some of the research our group has conducted to date which has focused on estimating the impact of AirJection® Irrigation on water use efficiency (WUE).

Material and Methods

Details of the design and theory of operation of the air injection system employed in the research is described above and can be found in Goorahoo et al., (2001a,b). Briefly, the injector/ drip tape assembly operates on the following principle: As water under pressure enters the injector inlet, it is constricted in the injection chamber (throat) and its velocity increases. The increase in velocity through the injection chamber can result in a decrease in pressure below the atmospheric in the chamber. This drop in pressure enables air to be drawn through the suction port and can be entrained into the water stream. As water stream moves towards the injector outlet, its velocity is reduced and the dynamic energy is reconverted into pressure energy. The aerated water from the injector is supplied to the irrigation system. The fluid mixture delivered to the root zone of the plant is best characterized as air/water slurry.

Commercial scale experiments were located in Firebaugh (tomatoes) and Mendota (cantaloupe and honeydew melons, and peppers) in the SJV, CA. Soils in this region range from sandy loams to clay loams. Crops were grown on 5 feet wide beds and an experimental plot consisted of at least 4 alternating replications of air-injected and no-air treatments (control). Each replicate was made up of seven beds to accommodate the width of the tractor-drawn trailers during harvesting. For example, the honeydew experimental plot comprised of four replicates of each treatment for a total of 56 beds (2 treatments x 4 reps per treatment x 7 beds per rep = 56 beds). The drip tape run length for the beds in the honeydew plots was 390m (1280 feet). The cantaloupe and pepper experiments were conducted on relatively larger plots than those used for the honeydews. For these crops the experimental plot consisted of 13 alternating replicates of AirJection® and control treatments for a total 182 beds with a drip tape run length of 400m (1,312 feet). The tomato experiment was a completely randomized design with four replicates of each of the aerated and water only treatments. Each replicate comprised of 12 beds which were serviced by an irrigation manifold. The drip tape run length for the tomato plot was 300m. Based on observations from our concurrent experiment in which we noticed that for air treated plants there were greater yields from the plants located at the "head" of the drip line versus the plants down at the "tail", experimental plots were blocked along the beds as Head, Middle and Tail. This was done by dividing the length of the bed into three equal sections and labelling the section closest to the irrigation manifold as the "Head" and that furthest away as the "Tail". For example in the 300m long tomato beds, the section from the inlet manifold to 100m along the direction of the water flow was designated as the "Head", the section between 100 to 200m was referred to as the "Middle" and between 200 to 300m was the "Tail" section.

One constraint of conducting the experiment on the commercial farm is that an excessive destructive plant sampling was not possible during the growing season to examine the impact of the air injection on the roots. Hence, we set up a bell pepper research plot (0.25 ac) at CIT on our campus farm, in which the destructive sampling was carried out.

In addition to the scientific studies mentioned above, we have done some observational studies on Strawberries planted in Oxnard, CA (Goorahoo et al., 2008). Air injectors were installed on drip lines serviced by one valve such that 38 beds received

AirJection® irrigation. Then six test subplots containing 40 plants from three of aerated and non aerated beds were used to collect yield data.

Both the Non-Aerated Control and AirJection® Aerated plots used the following design:

- Two lines of sub-surface drip tape (0.667 gpm / 100 ft) per row;
- 64" bed x 15" spacing x 4 rows per bed x 315' row length (25,500 plants per acre); and,
- Drip tape was operated with approximately 10 psi of inlet pressure

The AirJection® aerated test plot used the following configuration to supply the air/water mixture:

- Model A-14 Mazzei AirJection® Irrigation units
- 100% of the water for each row flows through the injector.
- The AirJection® units were operated with approximately 25 psi of inlet pressure.
- The gas to liquid ratio was approximately 11%.

All routine agronomic practices and irrigation scheduling were conducted by the growers. However, periodic growth observations, soil moisture measurements and irrigation flow meter readings were collected. In addition to the flow meters, to insure equal amounts of water were being applied to the air-treated and control plots, the irrigator regularly checked and adjusted the inlet pressure to the air injector to verify and maintain that the pressure downstream the injector was the same as that of the drip tape for the control plots.

For each of the crops in the commercial plots, the following measurements were performed:

1. Pre-Plant Soil sampling
2. Crop Growth and Irrigation Monitoring
3. Harvest and Yield Data Collection
4. Photosynthesis and transpiration
5. Plant Height and width measurements
6. Root and Shoot Post Harvest
7. Post Harvest Soil Sampling

Data collected for the various parameters were analyzed for statistical differences using the SPSS statistical package to conduct either independent-samples *t- test* or ANOVA. Yield data were to determine the agronomic WUE as a ratio of the marketable product yield to the amount of water applied.

To determine the leaf scale and intrinsic WUE, which relates the amount of photosynthesis to the transpiration rate, we used a “CIRAS-2”portable photosynthesis and soil respiration instrument. Leaf photosynthesis (Pn), transpiration (T), stomatal conductance (g_s), and soil respiration (SR) were determined for various crops. The CIRAS-2 instrument works on the principle of detecting CO_2 levels with an infrared gas analyzer (IRGA). Basically, the instrument measures the relative change in CO_2 for the volume of air in contact with the leaf or soil. Any decrease in CO_2 values is used to calculate photosynthesis rates using series of equations (PP Systems. 2002). In the case of the soil respiration, an increase in CO_2 concentration was used in the calculations. Leaf measurements for Pn, T, and g_s were taken on clear days between 0900-1200 h in order to minimize the photo-inhibition due to greater light intensity (Barth et al., 2001). 33

Results and Discussion

For melons harvested in Summer 2004, for the number of cantaloupes harvested per 20 feet section of a bed (i.e. 20' x 5' = 100 sq ft.) there was no significant difference ($t(86) = 1.164$, $p > 0.05$) with mean number of melons from the aerated and non aerated plots being 17.32 (sd=6.26) and 15.82 (sd=5.82), respectively. However, there was a statistically significant difference in the weight of the melons harvested ($t(82)=2.105$, $p<0.05$). The mean weight of AirJection® irrigated melons (m = 27.18 kg/100 sq.ft, sd= 9.54) was significantly higher than the mean weight of the melons receiving water only (m = 23.06 kg/100 sq.ft, sd= 8.38). When the cantaloupes harvested from seven of the 100sq.ft sections were categorized into grades used for packing and shipping, there was a 43% increase in the number of large melons and, a 39% increase in the weight of large melons harvested due to air injection (Tables 1 and 2). This increase in the number and weight of large air–injected melons, which are shipped in 9 per box, is important since the larger melons are the most desirable grade for the grower. While there was no significant difference in root dry weight per plant, the mean shoot dry weight of plants from the aerated treatments (m=308g, sd=179) was significantly higher ($t(28)=2.972$, $p<0.05$) than the mean shoot dry weight of plants from the non aerated plots (m=207, sd-81).

For tomatoes, our findings seem to indicate that in the case of the tomato crop, there may have been earlier fruit maturity for the air treated plants. This statement is based on the relative amounts of mature "red" and "breakers" harvested at 80 and 93 DAT (days after transplanting). Traditionally, at the commercial scale, fresh market tomatoes are harvested as mature "Green", with "reds" and "breakers" considered as either being too late for picking or marginally harvestable, respectively. These colour maturity grades are based on guidelines provided by the USDA. For the variety of tomatoes grown in 2004, the anticipated date of harvest was at 93DAT. However, at 80DAT, it was obvious that there were a number of red and breaker tomatoes on plants from both treatments. Hence a preliminary harvest was conducted in which only the red and breaker tomatoes were picked. While there was no significant difference in the number of red tomatoes at 80DAT, there was a significant difference, in both the number ($t(126)=2.492$, $p<0.05$) and weight ($t(126)=2.354$, $p<0.05$), between the breakers from ten air injected and non aerated plants. The mean number of breakers from the air injected plots comprising of 10 plants (m=24.94, sd =13.97) was significantly higher than the mean number of breakers from the control plants (m=19.50, sd=10.47). In terms of weight, the mean value of 2.54 kg (sd=1.39) for the breakers from the aerated plants was significantly higher than the mean value of 2.03 kg (sd= 1.07) for the breakers harvested from the plots receiving no aeration.

At 93 DAT, the following results were obtained from the t-test analyses of tomatoes harvested:

(i) The mean number of red tomatoes from air-injected plants (m=246,sd=38) was significantly higher (t(62)=2.939, p<0.01) than the mean number of red tomatoes from plants receiving water only (m=212, sd=53);
(ii) In the case of breakers and green tomatoes, both these categories demonstrated significant weight differences (t(62)=1,59) at the p<0.05 probability level. However, unlike the harvest at 80 DAT, at the 93 DAT harvest the mean weights of the non aerated breakers (m=13.22, sd=2.81)and greens (m=27.12 kg, sd=5.31)were significantly higher than the breakers (m=11.56, sd=2.81)and greens (m=24.34 kg, sd=5.31) from the ar injected plots.

In the 2003 experiment with peppers grown on 40acres with run of over 400m, we observed that although there was a trend of decreasing yields in terms of both numbers and weights. Generally, in moving away from the source of the air and water injection, there was still a positive effect of the air injection towards the tail end of the irrigation tape (Table 3). We are currently conducting additional research using specialized drip tape in an effort to minimize the yield variability observed along the run length of the drip tape.

For the peppers grown in the relatively smaller plots at CIT location, there has been no significant difference in the dry weights of the above ground portion of plants. However, for root dry weight, the mean weight per plant from the air injection treatment (m=11.55g, sd=1.33) was significantly higher (t930)=4.326, p<0.001) than the mean weight of the water only plants (m=8.73, sd=2.24).

The strawberry results analyzed to date indicate that there was a 18.3% increase in #1 Grade fruit in the Aerated plot vs. the Control plot. There was a 6.9% increase in #2 Grade fruit in the Aerated plot vs. the Control plot. There was a 33.7% increase in Freezer Grade fruit in the Aerated plot vs. the Control plot.

Increased yields with the similar amount of water being applied as that in non aerated crops will suggest that AirJection® Irrigation resulted in increased agronomic water use efficiency. At the leaf scale WUE for peppers, we have observed that there ia lot of variability as o whether the air injected plots show increased WUE or not with both the DAT data and the location along the drip irrigated beds (Figure 1). For example, in the case of the peppers at CIT, we observed that during the early vegetative growth stage (30 DAT) the WUE in the water only plots were 3.9 compared to 3.2 for the air inljected plants. However, by the time of fruit formation (65DAT), the air injected plots had a WUE of 3.8 versus the 3.2 value for the water only plants. At full maturity (100DAT), the air injected plants were showing a leaf scale WUE of 4.4 compared to 4.1 for the control plots. Similar analyses are currently being conducted for the other crops.

Concluding Remarks

Our recent and on-going research has shown that the incorporation of high efficiency venturi injectors in SDI systems can increase root zone aeration and add value to grower investments in SDI

From the data analyzed to date in our current research, we have observed that generally, there was a decrease in transpiration rates in the plants subjected to AirJection® Irrigation. For the majority of crops examined, the net photosynthetic rate, stomatal conductance and leaf scale water use efficiency (WUE) increased considerably with the use of AirJection® Irrigation. These findings imply that AirJection® Irrigation has great potential for optimizing water usage as farmers continue to seek out innovative practices aimed at increasing yields with relative less water being allocated to the agricultural sector.

The work conducted to date on fruits and vegetables have been aimed at evaluating AirJection® Irrigation on conventional farms. However, because the air injection system with the venturi devices uses ambient air, there exists the potential to use this system on organic farms. Hence, in summer of 2007 we began evaluating the effect of the AirJection® Irrigation on organic vegetable production at California State University-Fresno.

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Table 1: Comparison of Count for Melons per 700 sq ft- 2004

Treatment	**Large**	**Medium**	**Small**	**Total Harvestable**	**Non Harvestable**
Air	96	203	447	746	696
Water	67	180	411	658	667
*Difference	29	23	36	88	29
**% increase	43%	13%	9%	13%	4%

* Difference = Air count minus Water count

** % Increase = (Difference ÷ Water count) × 100

Table2: Comparison of Weight (kg/700 sq. ft.) for Melons-2004

Treatment	**Large**	**Medium**	**Small**	**Total Harvestable Weight**
Air	207.4	331.6	603.0	1142.0
Water	149.31	325.44	491.56	966.3
*Difference	58.05	6.13	111.49	175.66
**% increase	39%	2%	23%	18%

* Difference = Air weight minus Water weight

** % Increase = (Difference ÷ Water weight) × 100

Table 3: Summary of Pepper yield for 10 plants along the drip lines grown in 2003.

Relative distance from drip tape inlet	**No. of Peppers**	**No. of Peppers**	**Wt. of Peppers (kg)**	**Wt. of Peppers (kg)**
	Air	**Water**	**Air**	**Water**
Head (West)	100	57	13	10.72
Middle	80	84	12.26	14.03
Tail (East)	47	45	7.18	7.52
Total	**227**	**186**	**32.44**	**32.27**
***Difference**	**41**		**0.17**	
****% Difference**	**22.04%**		**0.53%**	

* Difference = Air value minus Water value

** % Increase = (Difference ÷ Water value) × 100

Figure 1:WUE along Head , Middle and Tail, in Air vs. Water Treatments at CIT Pepper Trail.