Aeration in Subsurface Drip Irrigation: Academic and Commercial Review of Eight Years of Consistent Crop Yield Increase and Water Use Efficiency

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Abstract: *Plant roots need air for optimal respiration. Without it, soil can become anaerobic, inhibiting plant growth and yield. In addition, crop yield and soil health continue to be major agricultural concerns as we continue to experience regional drought and rationed water delivery. In this presentation we review the physiology of crop production when subjected to oxygenation in large commercial row crop applications. Results from research on aeration treatments which resulted in greater Water Use Efficiency (WUE) as reported by University of Queensland, Australia and significant increase in plant's root mass (40% to 50%) at California State University, Fresno are discussed. We conclude with the findings on significant energy and input savings, from 8 years of operational data using Mazzei AirJection® Irrigation technology to improve WUE, fertilizer inputs and addition of air to the root zone on commercially grown cantaloupes, honeydews, corn, and pepper in the western San Joaquin Valley (SJV), California.*

Keywords. *AirJection® irrigation, Oxygation, Water use efficiency, Nitrogen use efficiency, Return of investment (ROI), and Energy consumption.*

Introduction

This work represents part of our ongoing efforts to evaluate the value of university research and commercial application of AirJection® irrigation for various cropping systems in western San Joaquin Valley (SJV), California.

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 has been 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).

Materials 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.

Our research plots were located in Firebaugh (tomatoes) and Mendota (cantaloupe and honeydew melons, sweet corn and peppers) in the SJV, CA. Soils in this region range from sandy loams to clay loams. Generally, 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).

Commercial scale operations included 1497 acres of cantaloupe, melons, corn, and peppers using AirJection. Over the eight year period (2005 – 2012) that equated to a total of 11,978 acres on AirJection irrigated crop production. Yield data were recorded for the various crops, and the energy consumption and return on investment (ROI) were determined using typical costs associated with that for water and power on the farm.

Preliminary Results

In previous work with growers on a commercial test plot basis, Air-jection Irrigation demonstrated bell pepper yield increases of 13 percent and 8 percent for premium and processed bell peppers, respectively. The value of the increased yield was, however, partially offset by increased energy costs. In 2000, a similar study was conducted at the Center for Irrigation Technology (CIT) at California State University (CSU) Fresno on bell peppers (Goorahoo et al. 2001). In that study an increase of 33% in bell pepper count, and a 39% increase in bell pepper weight was noted for the aerated plots versus the plots receiving only water. When the roots were examined, there was a significant difference between the root weight to total plant weight ratios for the aerated plants and the non-aerated plants. The findings from the CSU-Fresno study justified follow-up fieldwork on larger commercial plots. On average, AirJection® Irrigation has resulted in a13-18% yield increase in fresh market tomatoes, cantaloupes, honeydews, broccoli, strawberries and sweet corn (Goorahoo et al., 2008). Similar results have been obtained by a research group at Queensland University in Australia (Bhattarai, et al., 2004, 2005 & 2006). Our most recent work on organic farming systems indicated that AirJection® Irrigation also positively affected photosynthetic and soil respiration rates, stomatal conductance, leaf scale water use efficiency, plant tissue nitrate concentrations, and shoot and root biomass (Reddy, 2008). Figures 1 and 2 are provided as examples of the relative increase in weight and numbers, respectively, for melons grown with AirJection Irrigation.

At the commercial scale, over the eight year period reviewed, Cantaloupes equated to approximately 47% of the total acreage (6,480 acres) and consistently produced the best results with yields anywhere between 12%-34% above the farm average (Figure 3). In the case of sweet corn, the five year average increase was approximately 20 boxes per acre (Figure 4).

The net increase in yield using the same amount of water per acre would be an equivalent cantaloupe production to farming approximately 1000 acres less over 8 year period (Table 1). This crop yield increase would theoretically allow farmers to farm more “crop per drop of water”. While there a slight increase in the energy costs for crops grown with AirJection irrigation compared to those grown with water only (Table 2), the annual return on investment (ROI) was still greater for the air injected crops (Table 3). For example, over the 8 year period the <u>net</u> ROI for the cantaloupe crop was approximately 3.7million U.S. dollars!

Concluding Remarks

Based on the research findings to date, we believe that the use of the Air-jection® Irrigation will show a positive growth effect on other vegetables and fruits, forages, turf, tree crops and other row crops such as cotton. Besides the monetary benefits, the potential ecological benefits associated with AirJection® irrigation include improvements in nitrogen use efficiency, increased activity of soil microbes, and reduced deep drainage of irrigation water. The conservation of scarce water resources will also gain favor for sustainable irrigated agriculture. The increase in yields and potential improvement in soil quality associated with the root zone aeration implies that the adoption of Airjection injection technology could be a sound alternative for growers seeking a tool for increasing crop productivity.

Acknowledgements

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Bibliography

Bhattarai, S., J. McHugh, G. Lotz, and D. J. Midmore. 2003. Physiological responses of cotton to subsurface drip irrigation on heavy clay soil. Proc.11th Australian Agronomy Conference, 2-6 February, 2003, Geelong, Victoria, Australia: Australian Society of Agronomy. pp.1-2. htpp://www.regional.org.au/au/asa/2003/p/4/bhattarai.html.

Bhattarai, S., S. Huber, and D.J. Midmore. 2004. Aerated subsurface irrigation water gives growth and yield benefits to zucchini, vegetable soybean and cotton in heavy clay soils. Annuals of Applied Biology. 144:285-298.

Bhattarai S.P., N. Su and D. J. Midmore. 2005. Oxygation unlocks yield potentials of crops in oxygen limited soil environments. Advances in Agronomy. 88:313-337.

Goorahoo, D., D. Adhikari, F. Cassel S. and D. Zoldoske. 2008a. The impact of air injected into water delivered through subsurface drip irrigation (SDI) tape on the growth and yield of melons: Final Report. Submitted to California Agricultural Technology Institute (CATI) in February 2008 for CDFA funded project # 03-8-003.

Goorahoo, D., D. Adhikari, F. Cassel S. and D. Zoldoske. 2008b. The impact of air injected into water delivered through subsurface drip irrigation (SDI) tape on the growth and yield of tomatoes: Final Report. Submitted to California Agricultural Technology Institute (CATI) in February 2008 for ARI funded project #03-8-004.

Goorahoo D., G. Carstensen, D. F. Zoldoske, E. Norum, A. Mazzei. 2001a. Using air in subsurface drip irrigation (SDI) to increase yields in bell pepper. In Proceedings of The IrrigationAssociation Technical Conference, San Antonio, Texas, pp. 95-102.

Goorahoo D., G. Carstensen and A. Mazzei. 2001b. A Pilot Study on the Impact of Air Injected into Water Delivered through Subsurface Drip Irrigation Tape on the Growth and Yield of Bell Peppers. California Agricultural Technology Institute (CATI) Publication # 010201.

Goorahoo D., D. Adhikari, D. Zoldoske, F. Cassel S., A. Mazzei, and R. Fanucchi. 2008. Potential for AirJection® Irrigation in Strawberry Production. pp 152-155 In : Takeda, F., D.T. Handley, and E.B. Poling (ed.). Proc. 2007 N. American Strawberry Symposium. North American Strawberry Growers Association, Kemptville, ON Canada.

Figure 1: Total number of melons in “air” versus “water” plots.

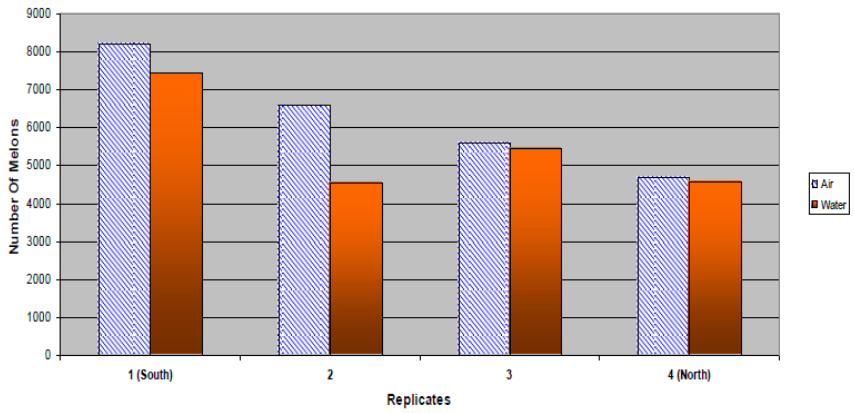

Figure 2: Total weight of melons in “air” versus “water” plots.

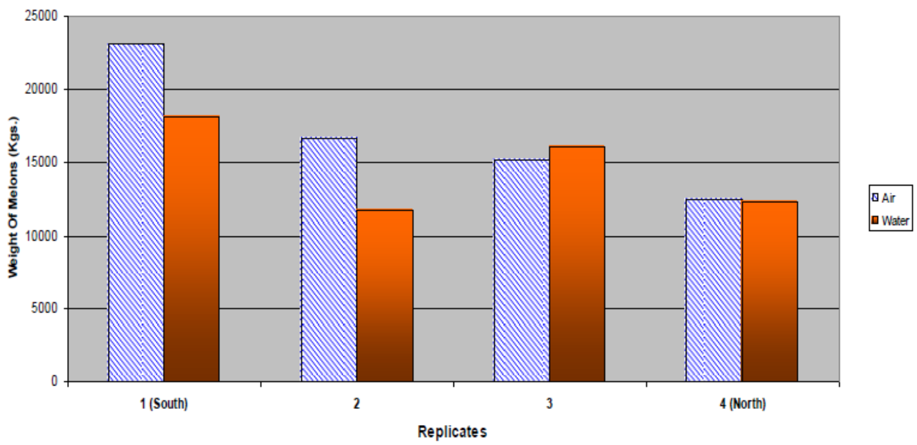

Figure 3: Average yield of melons in “air” versus “water” plots on the commercial farm.

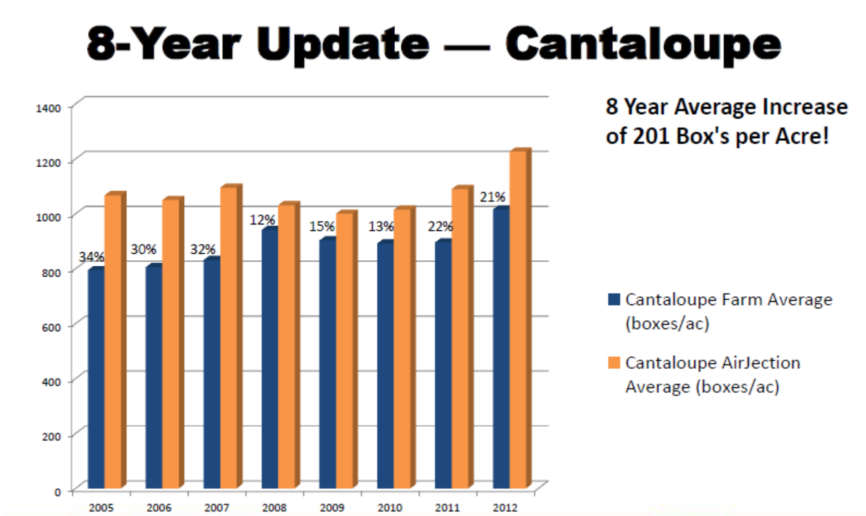

Figure 4: Average sweet corn yield in "air" versus "water" plots on the commercial farm.

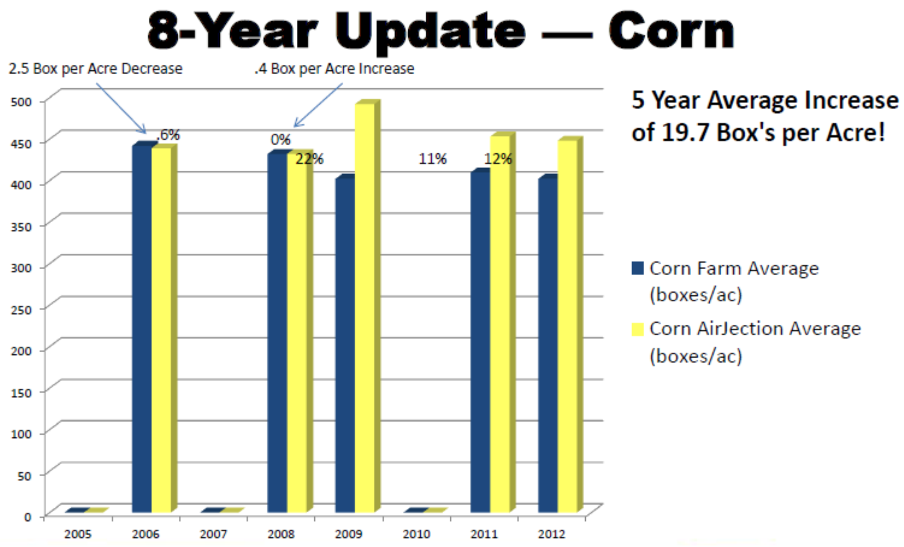

Table 1: Increases in crop production as a result of AirJection Irrigation.

Crop	Total AirJection® Acreage	Total of AirJection® Field Boxes	"Total Boxes" for equivalent AirJection® Acreage	Average per acre increase in boxes	Total Box Increase over Farm Average
Cantaloupes	6,480	6,891,383	5,590,794	201	**1,300,590**
Corn	3,416	1,513,770	1,446,499	20	**67,271**
Honeydews	1,320	2,063,656	1,855,783	134	**176,305**
Bell Peppers	460	936,365	768,581	371	**170,290**

Table 2: Summary of energy consumption for crop production on the commercial farm.

Crop	Total AirJection® Acreage	Total of AirJection® Field Boxes	AirJection Energy Cost Per Box[1]	"Total Boxes" for equivalent AirJection® Acreage	Non-AirJection equivalent energy cost per Box[1]	Average per acre increase in boxes	Total Box Increase over Farm Average
Cantaloupes	6,480	6,891,383	$0.02	5,590,794	$0.012	201	1,300,590
Bell Peppers	460	936,365	$0.010	768,581	$0.006	371	170,290

[1]Assuming 75% pump efficiency, $.11/KwH energy cost, 15 psi pressure increase for AirJection Irrigation @ same flow rate, and 2 acre-feet of water needed for 1 acre of Cantaloupes and Bell Peppers during a normal growing season. Reference www.icalcul8.com/pump_power.php

Table 3: Return of Investment for Cantaloupe grown with AirJection on the commercial farm.

AirJection® Acreage	Approximate number of AirJection® Injectors per acre	Approximate Installation Cost	Total Installation Costs of AirJection® Injectors	8 Year Weighted Installation Costs of AirJection® Injectors on Cantaloupes	Additional AirJection Energy Cost Per Box
1497	5.5	$140/acre	$209,580	$111,077	$0.0064

Total of AirJection® Field Boxes	Total Energy Cost for 6480 Acres	Average per acre increase in Cantaloupe boxes	Total Additional Box Increase over Farm Average	Conservative Net Price per Box	8-Year Return on Investment	8-Year Net Return on Investment
6,891,383	$67,327	201	1,300,590	$3.00	**$3,901,770**	**$3,723,366**