Interaction of Aqua-Phyd Treated Water and Fertilizer in Vegetable Production: Phase 1- Pot Studies with Broccoli

Final Report- Updated November 2nd 2008

Compiled by

D. Goorahoo, F. Cassel S., and D. Adhikari

Center for Irrigation Technology (CIT)
California State University-Fresno
5370 N Chestnut Avenue
Fresno. CA. 93740

Submitted to

Chuck Wagner[1] & Jerry Rai[2]
[1]Marketing and Public Relations & [2]Director of Agriculture Sales
AQUA-PHYD, Inc.
17155 Von Karman, Suite 112
Irvine, CA 92614

November 2nd 2008

Table of Contents

List of Tables & Figures

ACKNOWLEDGEMENTS

This project would not have been possible without the participation of a number of people with expertise in different disciplines. Some of these individuals are listed below. The authors recognize that the list is by no means complete and humbly apologize for the omission of any names that should have been included.

The contribution of everyone is duly acknowledged.

Center for Irrigation Technology (CIT) and Department of Plant Science project staff:

David Zoldoske, Ph.D., Director
Dave Goorahoo, Ph.D., Research Scientist
Florence Cassel S, Ph.D., Research Scientist
Diganta Adhikari, MSCS & MSIT, Research Database Analyst
Namratha Reddy, MS., Plant Science Graduate
Nancy Munday, CIT- Project Finance Manager
CIT clerical and office staff
California State University- Fresno (CSUF) Student Assistants: Geraldo Orozco, Natalio Mendez, and Javier Solis.

Interaction of Aqua-Phyd Treated Water and Fertilizer in Vegetable Production: Phase 1- Pot Studies with Broccoli

Background: Aqua-PhyD technology uses the flow of irrigation water to generate and induce Resonant Frequency Energy (RFE™) into water. This energy is highly conductive in water and soil and therefore has the potential to release soil compaction, increase hydraulic conductivity of water in soil, and increase solubility of minerals and nutrient uptake. Ultimately, crops should potentially grow better and be more productive when they are exposed to a soil environment which has been subjected to Aqua-Phyd enhanced irrigation.

To date, the majority of research on the impact of Aqua-PhyD technology on plant growth and water use efficiency has been focused on the turf grass industry. Anecdotal reports have indicated a positive impact of Aqua-PhyD irrigation on the quality and growth characteristics of the grasses, as well as the improvement in soil structure and soil hydraulic properties. Based on the encouraging results, Aqua-PhyD Inc. acknowledges the potential of adopting the Aqua-PhyD irrigation technology in agronomic crop production systems typical of the San Joaquin Valley (SJV) and other regions in California. Hence, Aqua-PhyD Inc. is currently conducting collaborative work with the Center for Irrigation Technology (CIT) at California State University- Fresno (Fresno State) to seek third party university validation for the company's technology. The planned research will comprise of initial pot studies conducted at the CIT under greenhouse conditions (Phase 1), to be followed by testing on small scale field plots at Fresno State (Phase 2) and then evaluation of the technology on large acreages typical of commercial sized operations in the San Joaquin Valley (SJV), CA.

Overall Objective of the Proposed Research with CIT: To evaluate the efficacy of the Aqua-PhyD technology in agricultural cropping systems typical of the SJV.

Specific Objectives of Phase 1: In the current research, the objective was to evaluate impact of Aqua-Phyd treated water on yield and biomass of Broccoli subjected to two irrigation rates.

This Phase 1 of the research was conducted on broccoli grown in two soil types, using pot studies, and focused on the yield and the shoot and biomass at 110 days after transplanting (DAT).

Methodology

Location: Pot studies using a Sandy Loam (SL) soil available from the Center of Irrigation (CIT) experimental plots, and a Clay (C) soil from on the Westside of the Central Valley. The study was conducted at the California State University-Fresno (Fresno State) Greenhouse facilities located opposite the CIT main office.

Crop: Broccoli (*Brassica oleracea* cv. Marathon)

Growing Season: November 2007 to February 2008.

Experimental Design: Two experiments- one with a Sandy Loam (SL) soil and one with a Clay (C) soil- comprising of two blocks were used for the randomized treatments of broccoli planted in 10- inch diameter pots. There were four treatments (T1, T2, T3 and T4) comprising of a combination of potable water (Tap) and Aqua-Phyd (APD) treated at two irrigation rates (A and B which was 80% of rate A). The initial intention was that rate A would represent 100% of the evapo-transpiration ET requirements of the crop and that rate B will represent 80% of the ET. Each treatment was replicated three times which meant that for each experiment there were 24 completely randomized pots (4 treatments x 3 replicates x 2 blocks = 24 pots). Hence there were a total of 48 pots for the two experiments.

Approximately 10.5 kg of the sandy loam and clay soils were used per pot so as to maintain the soil bulk density in each pot at 1.25 g/cm^3. Pots contained about 1" of woodchips at the bottom in order to facilitate drainage.

Treatments :

T1- APD treated water applied at rates equivalent to 100% ET.

T2- APD treated water applied at rates equivalent to 80% ET.

T3- Tap water (NON-APD treated) applied at rates equivalent to 100% ET.

T4- Tap water (NON-APD treated) applied at rates equivalent to 80% ET.

Fertilizer application: All pots were supplied with the equivalent of a total of 180lbs N per acre comprising of 6 applications of 30 lbs of N per acre as Urea Ammonium Nitrate (UAN 32) as fertigation (i.e. with the irrigation water). First application was at 19 days after planting of transplanting (DAT), and then every week up to 53 DAT (Table 1).

.

Table 1: Summary of fertilizer application dates.

No.	Application Date	DAT	UAN applied (lbs/ac)
1	01-Nov-07	0	0
2	19-Nov-07	19	30
3	26-Nov-07	26	30
4	3-Dec-07	33	30
5	10-Dec-07	40	30
6	19-Dec-07	49	30
7	23-Dec-07	53	30
Amount of fertilizer applied			**180**

Agronomic Practices: Broccoli transplants were planted on the 1st of November 2007 (DAT=0). Plants were then kept in the greenhouse under controlled environmental conditions to ensure that the plants were not subjected to any frost conditions during the growing season. Plants were irrigated at regular intervals throughout the growing season based on soil moisture monitoring data and the visual observations of plants. The amounts of water applied to pots during an irrigation event were calculated to ensure that pots labeled as treatments T2 and T4 received 20% less water than the pots labeled as T1 and T3.

Observation parameters

(1) At 110 DAT, the circumferences of broccoli florets were determined as a measure of head sizes prior to harvest.

(2) During the size measurements, the broccoli florets were also examined in an effort to determine whether or not the florets had started to bolt.

(3) All florets were then harvested and weighed to determine the average yield in kg of the six plants harvested from the two experimental blocks.

Results and Discussion

(a) Broccoli Size: The mean circumference of broccoli florets harvested at 110 DAT for plants grown in the Sandy Loam soil are presented in Table 2. Analysis of variance (ANOVA) indicated that there was no significant difference in broccoli floret sizes due to the irrigation treatments for plants grown in the Sandy loam soil (Table 3).

Table 2: Mean size of broccoli harvested at 110 DAT for Sandy Loam Experiment

Treatment Code	Description	Mean Circumference (cm)	Std. Dev. (cm)
T1	**APD water @ 100% ET**	**34.6**	**6.1**
T2	**APD water @ 80% ET**	**30.6**	**5.7**
T3	**Tap water @ 100% ET**	**33.5**	**12.4**
T4	**Tap water @ 80% ET**	**31.2**	**5.5**

Table 3: ANOVA of circumference of broccoli florets harvested at 110 DAT for Sandy Loam experiment .

Dependent Variable: Circumference in cm

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	25292.506	1	25292.506	170.371	.049
	Error	148.455	1	148.455[a]		
Treatment	Hypothesis	63.330	3	21.110	.360	.783
	Error	1114.032	19	58.633[b]		
Block	Hypothesis	148.455	1	148.455	2.532	.128
	Error	1114.032	19	58.633[b]		

The mean circumference of broccoli florets harvested at 110 DAT for plants grown in the Clay soil are presented in Table 4. Analysis of variance (ANOVA) indicated that the irrigation treatments had a significant effect ($P<0.05$) on broccoli floret size for plants grown in the clay soil (Table 5). The largest florets were observed on plants irrigated at 100% ET with APD treated water. There was no significant difference between floret sizes for plants treated with tap water and those irrigated at 80% ET with the APD treated water.

Table 4: Mean size of broccoli harvested at 110 DAT for Clay experiment

Treatment Code	Description	Mean Circumference (cm)	Std. Dev. (cm)
T1	**APD water @ 100% ET**	**29.3**	**6.4**
T2	**APD water @ 80% ET**	**22,5**	**1.6**
T3	**Tap water @ 100% ET**	**24.1**	**4.3**
T4	**Tap water @ 80% ET**	**23.6**	**2.4**

Table 5: ANOVA of circumference of broccoli florets harvested at 110 DAT for the Clay experiment .

Dependent Variable: Circumference in cm

Source		Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	14845.530	1	14845.530	564.062	.027
	Error	26.319	1	26.319[a]		
Treatment	Hypothesis	166.138	3	55.379	3.349	.041
	Error	314.182	19	16.536[b]		
Block	Hypothesis	26.319	1	26.319	1.592	.222
	Error	314.182	19	16.536[b]		

(b) Bolting Florets: The number of broccoli florets which showed signs of bolting among those harvested at 110 DAT for plants grown in the Sandy Loam and Clay soils are presented in Figures 1 and 2, respectively. Ideally, it is desirable to harvest the floret prior to this bolting stage. In retrospect, the broccoli should have been harvested between 90-100 DAT.

Figure 1: No. of "bolted" broccoli harvested at 110 DAT for Sandy Loam experiment.

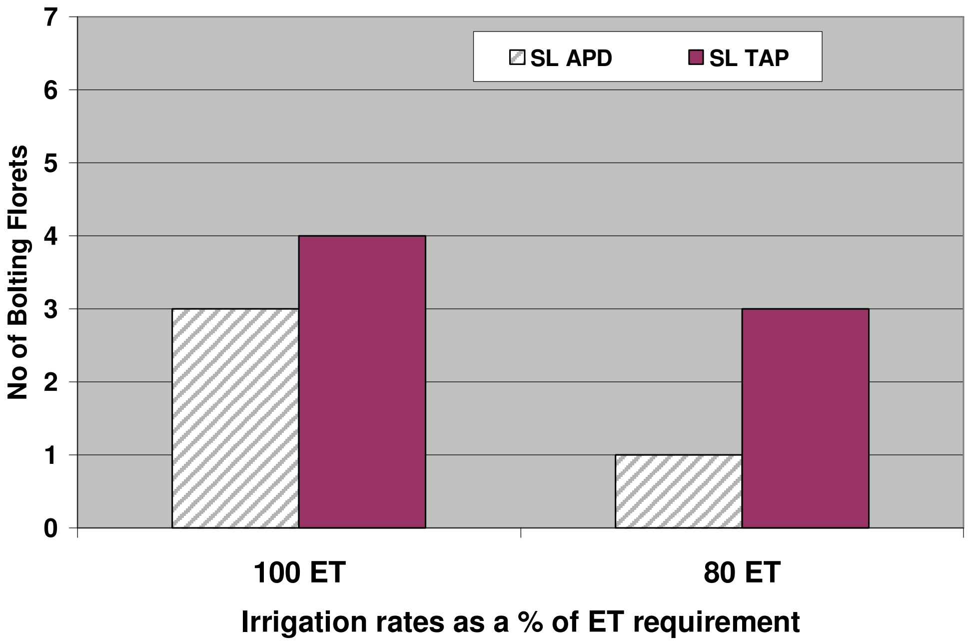
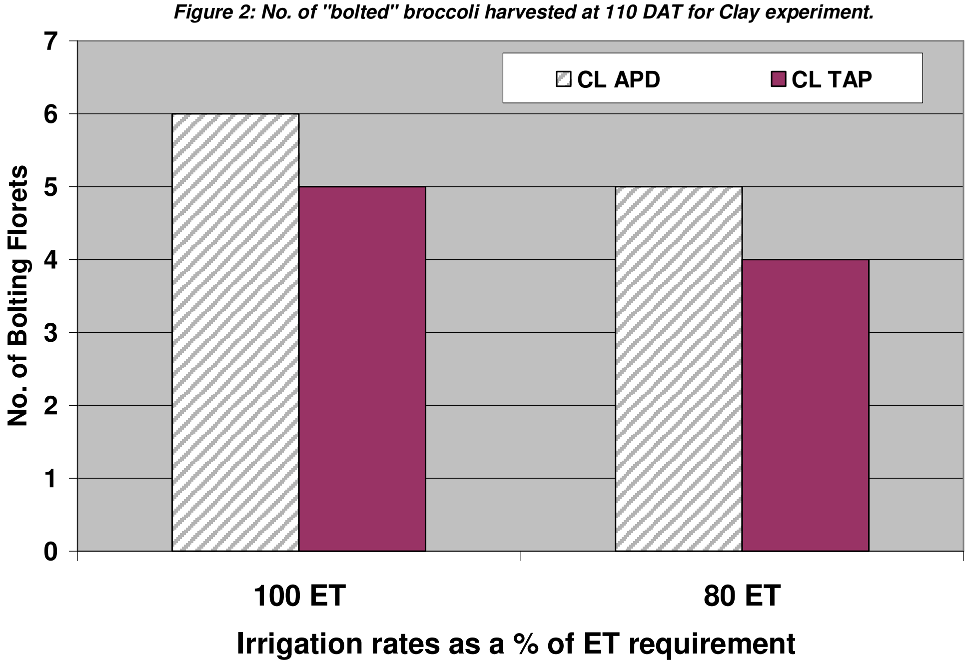


Figure 2: No. of "bolted" broccoli harvested at 110 DAT for Clay experiment.



A broccoli floret is made up of hundreds of small pin-head sized flower buds. Generally, the entire floret will grow to a certain size, then the buds will begin to swell and then each will bloom- at which stage the floret is referred to as "bolting". While there are many reasons why broccoli will begin to bolt, for plants subjected to similar environmental conditions bolting can be interpreted as an indication of relatively earlier growth maturity as the plant transitions from the vegetative to the reproductive (flowering) stage. Assuming this was the case for the plants used in the current study, it appears that the plants grown in the Sandy Loam soil and irrigated with the tap water attained greater physiological maturity than those irrigated with the APD treated water at 110 DAT (Figure 1). In the case of the plants grown in the Clay soil, the converse was true, whereby the APD treated plants seem to have attained maturity earlier than those irrigated with the Tap water (Figure 2). This finding is important since growers with salt affected clay soils, such as those in the Westside of the San Joaquin Valley (SJV), CA are continuously seeking out irrigation technologies which will improve the growth rate and thereby result in an earlier crop harvest date.

(c) Broccoli Yield: The mean weight of broccoli florets harvested at 110 DAT for plants grown in the Sandy Loam soil are presented in Table 6. Analysis of variance (ANOVA) indicated that the there were no significant differences in mean broccoli weight due to the two irrigation treatments (Table 7).

Table 6: Mean weight of broccoli harvested at 110 DAT for Sandy Loam Experiment

Treatment Code	Description	Mean weight (g)	Std. Dev. (g)
T1	**APD water @ 100% ET**	**106.5**	**19.2**
T2	**APD water @ 80% ET**	**82.8**	**21.9**
T3	**Tap water @ 100% ET**	**105.6**	**47.7**
T4	**Tap water @ 80% ET**	**84.3**	**16.6**

Table 7: ANOVA of weight of broccoli florets harvested at 110 DAT for Sandy Loam experiment .

Dependent Variable: Broccoli Weight (g)

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	215764.807	1	215764.807	161.256	.050
	Error	1338.027	1	1338.027[a]		
Treatment	Hypothesis	3046.383	3	1015.461	1.232	.326
	Error	15657.063	19	824.056[b]		
Block	Hypothesis	1338.027	1	1338.027	1.624	.218
	Error	15657.063	19	824.056[b]		

The mean weight of broccoli florets harvested at 110 DAT for plants grown in the Clay soil are presented in Table 8. Analysis of variance (ANOVA) indicated that there were no significant differences in mean broccoli weight due to the two irrigation treatments (Table 9).

Table 8: Mean weight of broccoli harvested at 110 DAT for Clay Experiment

Treatment Code	Description	Mean weight (g)	Std. Dev. (g)
T1	**APD water @ 100% ET**	**63.9**	**14.1**
T2	**APD water @ 80% ET**	**57.3**	**19.3**
T3	**Tap water @ 100% ET**	**59.7**	**16.1**
T4	**Tap water @ 80% ET**	**51.1**	**8.9**

Table 9: ANOVA of weight of broccoli florets harvested at 110 DAT for Clay experiment .

Dependent Variable: Broccoli Weight (g)

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	80724.400	1	80724.400	153.077	.051
	Error	527.344	1	527.344[a]		
Treatment	Hypothesis	515.308	3	171.769	.811	.503
	Error	4023.938	19	211.786[b]		
Block	Hypothesis	527.344	1	527.344	2.490	.131
	Error	4023.938	19	211.786[b]		

a. MS(Block) b. MS(Error)

(d) Recommendations for Future Studies

In the current study, the primary objective was to evaluate whether or not there were any significant differences in the floret yield and plant biomass for plant irrigated with APD treated and tap water. Plants were grown on two different soil types, and the data collected at 110DAT were analyzed. Future experiments should focus on the following parameters throughout the growing season in order to better ascertain the impact of the APD treated water applied at different irrigation rates.

(1) Plant heights should be measured at least three times during the growing season.
(2) Leaf samples should be collected at around the mid growth stage of the crop and analyzed for nitrate concentration.
(3) Following the harvest of the florets, the plants should be separated in the shoot and root sub portions, cleaned, dried 60-65°C for 48 h to determine the shoot and root biomass.

(4) At the beginning and end of the growing season, representative soil samples should be collected and analyzed for pH, electrical conductivity (EC), sodium adsorption ratio (SAR) and nitrate levels.

In addition to the above plant and soil factors, the researchers involved in the current study agree that based on the results observed with the clay soil and the underlying principle of Resonant Frequency Energy (RFE™) characteristic of the Aqua-PhyD technology, that future studies should be conducted:
1. Using irrigation water with relatively higher salt levels that the tap water (EC < 1dS/m) used in the current study; and,
2. Using salinity clay soils typical of the West side SJV.

Based on the findings from the current study, it is anticipated that the impact of the APD treated water will be more pronounced under the saline soil and water conditions.

Concluding Remarks:

<u>For Broccoli grown in the Sandy Loam soil:</u>

- There was no significant difference between the size broccoli florets for plants grown in the Sandy loam soil and irrigated with the APD and Tap water.
- Based on the number of plants showing bolting characteristics, it appears that the plants irrigated with the tap water attained greater physiological maturity than those irrigated with the APD treated water at 110 DAT.
- There was no significant difference between the mean weight of broccoli florets for plants grown in the Sandy loam soil and irrigated with the APD and Tap water.

<u>For Broccoli grown in the Clay soil:</u>

- The APD treated water had a significant effect on broccoli floret size.
- The largest florets (mean= 29.3cm; SD = 6.4cm) were observed on plants irrigated at 100% ET with APD treated water.
- The floret sizes for plants irrigated at 80% ET with APD treated water were similar to those irrigated at 100% ET with tap water.
- Based on the number of plants showing bolting characteristics, the APD treated plants seem to have attained maturity earlier than those irrigated with the Tap water.
- There was no significant difference between the mean weight of broccoli florets for plants grown in the Sandy loam soil and irrigated with the APD and Tap water.

This phase 1 pot study justifies the establishment of relatively larger scale experiments which should be conducted at the field scale. The primary goal of the field plots would be to determine the impact of the APD treated water on the potential for energy savings by providing a technology which optimizes water use efficiency by the plant. The finding that on the clay soil, there appeared to be earlier maturity for plant receiving the AquaPhyd (APD) treated water is a desirable feature for growers with salt affected clay soils. Also, future experiments should be conducted on relatively more degraded soils, such as the saline and sodic soils found on the Westside of the SJV, and with the APD device used to treat water with relatively greater electrical conductivity (EC) values than the tap water used in this current study.

Useful References

Hartz, T. 2000. Efficient Nitrogen Management for Cool-Season Vegetables. UC Davis, Vegetable Research and Information Center Fertility Management of Drip-Irrigated Vegetables.

Lestrange, M., K.S. Mayberry, S.T. Koike, and J. Valencia. 1996. Broccoli Production in California. Vegetable Production Series, Vegetable Research and Information Center. University of California, Division of Agriculture and Natural Resources 7211.