Arizona Department of Agriculture

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Specialty Crop Block Grant Program
Agreement No. 12-25-B-1446

2nd Annual Performance Report
December 30, 2014

Revised and Re-submitted
April 23, 2015

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Introduction

On October 1, 2012, the Arizona Department of Agriculture (ADA) entered into a cooperative agreement with the United States Department of Agriculture (USDA), Agricultural Marketing Service (AMS) in the amount of $1,265,138.45 in FY12 Specialty Crop Block Grant Program – Farm Bill funds to fund sixteen projects specifically designed to increase the consumption and enhance the competitiveness of Arizona Specialty Crops. Projects within the Arizona State Plan include two marketing projects, seven education projects and seven research projects and are one to three years in duration. The expiration of the grant period is September 29, 2015.

2013 SWAS – An Interactive Educational Experience

This project was completed on September 30, 2013

Project Summary

Over the past several years, the Southwest Ag Summit has proven to be a popular venue for the specialty crop industry. Originally conceived by a small group of local Ag industry professionals as a method of disseminating up-to-date research results, the Southwest Ag Summit delivers relevant information in a relatable manner to industry members who may not otherwise have access to it. The event provides a setting for educators, farmers, researchers, students and agriculture industry specialists to both provide and gain knowledge pertaining to new and emerging technologies. Many of the participating researchers receive Specialty Crop Block Grants themselves and use the Ag Summit forum to present their research. We all know information abounds in technical publications, in classrooms, in research labs, farm fields and government offices. Year after year, essential data and trends are highlighted at the Southwest Ag Summit in an atmosphere of learning and networking with other vegetable and melon industry personnel.

Project Approach

The Southwest Ag Summit originated as a one-day collaboration between Yuma Fresh Vegetable Association, University of Arizona and Yuma County Farm Bureau. Initially designed as an educational forum for the vegetable and melon crop industry, the Southwest Ag Summit has expanded into an annual two day event of educational programs and industry-specific speakers. Since its inception, development of the event has become more and more complex. In order to meet expanding needs, Yuma Visitors Bureau and Arizona Western College Foundation have been added to its list of partners.

In 2013, the Southwest Ag Summit changed venues for the second time in its seven year history due to the increased program size and participation by the agriculture industry. During the 2013 Southwest Ag Summit hundreds of vegetable and melon crop industry personnel attended and participated in a variety of specially-designed educational breakouts that provided timely, industry-specific information. With the event moved to Arizona Western College, attention was paid to providing a forum that allows desert southwest specialty crop personnel to better compete in an expanding global marketplace. All participants received a glut of current and important knowledge as well as written meeting materials. Everyone was encouraged to share this information with colleagues who were unable to attend the event.

Several energetic and enthusiastic members of the specialty crop industry again made up the Steering Committee to head the 2013 Southwest Ag Summit. This year's event, held March 6th and 7th, 2013, was led by Bruce Gwynn, a local chemical representative, Dr. Kurt Nolte, University of Arizona, Yuma County Cooperative Extension Service Director, and Steve Alameda, a local specialty crop grower. The Ag Summit Coordinator was tasked with organizing the sub-committees and dealing with the day-to-day details of planning the event.

Academic General Sessions and Workshops

The format of the 2013 Southwest Ag Summit was revised this year to exclude the Field Demonstrations, normally held on the morning of the first day. Instead, the morning of March 6th kicked off in Arizona Western College's College Community Center (3C Building) with a continental breakfast and welcome address and then a general session. Approximately 250 people attended the general session, entitled "*Regulatory Developments of Interest to Vegetable Growers in AZ & CA."* Several presentations were offered during the morning's general session:

- Arizona Regulatory Issues, Jack Peterson, Arizona Dept. of Agriculture
- California Regulatory Issues, Renee Pinel, Western Plant Health Association
- CCA Program & CA Nitrate Mitigation, Alan Romander, Incoming Chair CA CCA Program
- Pesticide Use in Arizona Lettuce: Understanding and Reducing Risk, Paul Jepson, Oregon State University

The Southwest Ag Summit began its second morning with a continental breakfast and keynote address by Mr. Rik Miller, President, DuPont Crop Protection. Mr. Miller delivered his presentation, "*Collaborating for a Sustainable Future*," to an audience of approximately two hundred fifty people.

Utilizing the balance of the morning and then returning again after lunch, educational workshops were held in the Ag Sciences Building at Arizona Western College. Desert Southwest growers, shippers and agriculture professionals in the vegetable and melon industry had an opportunity to attend any of nine educational workshops and listen to 37 speakers about specialty crop topics. These programs were presented by speakers from across the country, some of whom were other SCBG recipients using the setting to demonstrate and showcase their own research.

Specialty crop programs included:

- Integrated Pest Management Regulatory Update
- Fresh Produce Safety I and II
- Lettuce IPM Workshop
- Fresh Approaches to Plant Nutrition and Fertilizers
- National Ag Labor Issues
- Integrated Pest Management in Vegetables
- Alternative Crops and Management
- Ag Mechanization

An afternoon keynote event was initiated the previous year. It was such a popular portion of the Ag Summit that a speaker panel was invited to address the Southwest Ag Summit participants during lunch this year. While the Ag labor speakers originally planned were unfortunately cancelled due to crucial negotiations in Washington, D.C., Tamar Jacoby and Kristi Boswell were still able to participate in their scheduled Ag Labor and Immigration Reform panel discussion via internet. The lunch address was instead presented by Mr. Russ Jones, R.L. Jones Customs Brokers and Mr. Herb Guenther, Troubled Waters Consulting. They spoke on the subject of "Politics, Economics and Availability of Arizona's Water Resources: HB2338 and Water Augmentation Issues." This seems to still be a popular portion of the event as approximately 600 people attended the luncheon.

Southwest Ag Summit Logistics

The logistics of planning the 2013 Southwest Ag Summit in an unfamiliar venue required relentless planning alongside the Arizona Western College Events Coordinator to ensure complete coordination between the College's Conference Center and Information Technology departments. In addition, Yuma Visitors' Bureau paid added diligence to their outreach efforts in order to encourage attendance to the new location. The effective and ever-popular *Ag Summit Insider* played a leading role in their marketing campaign. The eight-page publication entitled *"Breaking News from the Southwest's Premier Ag Industry Event"* was distributed to approximately 5,000 Ag personnel in Arizona, California, Nevada and New Mexico. This year's edition – designed to entice Ag Summit attendance - provided an overview of food safety, a critical agriculture issue, Desert Southwest agriculture and local Ag education programs. Event schedules and speaker information were included as well.

Specialty Crop Block Grant Funding

With the proposal to fund the 2013 SWAS, we utilized two criteria to ensure that grant money was used solely to enhance the competitiveness of specialty crops.

First, we utilized 100% of grant funds to pay for travel and lodging costs associated with speakers who presented topics that specifically relate to the competitiveness of specialty crops. Travel and lodging costs for speakers who presented information about topics involving non specialty crop commodities were paid by other matching funds.

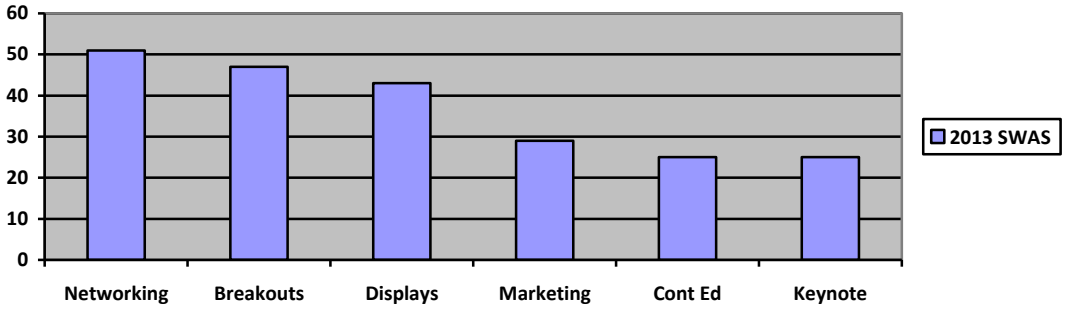
Second, we determined that grant funds should pay for 70% of costs associated with items such as meeting materials, the marketing coordinator, website upgrades, conference center rental and 30% of those items would be paid by matching funds. This 70-30% split of grant and matching funds was based on the number of participants at previous Southwest Ag Summits. When we submitted the proposal in 2012 for the 2013 SWAS, we estimated that 70% of participants' occupation would involve the melon or vegetable industry. However, according to the 2013 SWAS survey results, approximately 84% of the participants identified their occupations as involving the melon or vegetable industry. The 2013 SWAS exceeded our expectation of participation by the melon or vegetable industry by approximately 14%. In other words, at least 14% of the matching funds that paid for the 2013 SWAS also enhanced the competitiveness of specialty crops along with the 70% of the grant funds utilized for that purpose.

Goals and Outcomes Achieved

The Steering Committee originally identified three main goals they wished to target with the presentation of the 2013 Southwest Ag Summit.

1. As was our intent, several of our keynote and workshop speakers were well-known and popular industry professionals from across the country. We had originally slated Tamar Jacoby from ImmigrationWorks USA and Kristi Boswell from the American Farm Bureau Federation to lead an Ag Labor program during the Thursday lunch address. Regrettably, they were held up in Washington, D.C. with urgent Ag labor negotiations and were unable to make the trip. We were fortunate that they were still able to participate in an afternoon panel discussion via internet. In their absence, Mr. Russ Jones from R.L. Jones Customs Brokers and Mr. Herb Guenther from Troubled Waters Consulting graciously filled in and gave a presentation on HB2338 and Water Augmentation Issues, hot topics in the Southwest region Ag industry.

   The 2013 Southwest Ag Summit met its main goal of providing outstanding academic sessions as well as networking and marketing opportunities for members of the vegetable and melon industry. Survey results indicated participants' reasons for attending the 2013 Southwest Ag Summit (includes multiple overlapping answers):
   - Keynote address – 25%
   - Continuing education credits – 25%
   - Marketing opportunities – 29%
   - Booth displays – 43%
   - Academic breakout sessions – 47%
   - Networking opportunities – 51%

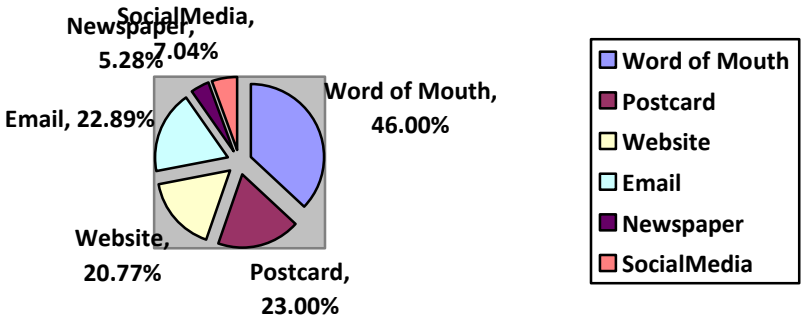


2. As the Southwest Ag Summit has grown continually since its inception, the Steering Committee is vigilant in assuring the facilities used meet the needs of the event and its participants. After the 2012 Southwest Ag Summit it was determined that the venue used for the prior two years would no longer suit the needs of the expanding event. Following a suggestion to consider Arizona Western College as the replacement venue, it was determined that their facility would fill all the needs of the growing Ag Summit and had adequate resources to staff the annual event and even to expand as the Southwest Ag Summit program continues to grow. Arizona Western College provides multiple conference rooms, exceptional in-house catering and state-of-the-art technology as well as tech personnel in place and on site. It also offers numerous classrooms that were used

as breakout rooms and land belonging to the Agriculture Department that can be used to reinstate the Field Demonstration portion of the Ag Summit if desired.

3. Yuma Visitors' Bureau has received nothing but praise for their aggressive marketing of the Southwest Ag Summit over the past few years. Beginning several months prior to the 2013 event, they notified prospective participants of the 2013 Southwest Ag Summit and its program components using a variety of media including the annual *Ag Insider* publication and periodic email blasts. Attendees were able to register for the 2013 Southwest Ag Summit using their choice of telephone, mail or via the internet, using the SWAS website. Efforts to inform vegetable and melon industry personnel about the upcoming Ag Summit netted 682 people registered to attend the Ag Summit educational programs.

Using the data from the survey it was determined that, while some methods were more effective than others, all methods used to publicize the upcoming event were useful (multiple overlapping answers).



In terms of the two measureable outcomes, the 2013 Ag Summit excelled.

1. The 2013 Southwest Ag Summit Steering strove to increase attendance by members of the vegetable and melon industry by 5% from our benchmark of 495 to our goal of 520.

   From the registration lists, the SWAS had 682 participants. Unfortunately, when participants registered, they did not always mark the box indicating whether the participant's occupation involved the melon or vegetable industry. Moreover, even though we encouraged participants to complete a survey, not every attendee completed the SWAS survey.

   One question on the survey asked:

   "2. Does your occupation involve the melon or vegetable industry?"

   a. Yes b. No

Of the 284 people who completed the survey, 236 responded "*Yes*" that their occupation involves the melon or vegetable industry, 44 responded "*No*" their occupation did not involve the melon or vegetable industry and 4 did not respond to the question. Therefore, 84.29% of respondents indicated that their occupation involves the vegetable or melon industry. Applying that percentage (84.29%) to the total number participants equates to 574.85 participants whose occupations could involve the vegetable or melon industry. Using that method of calculation, the 2013 SWAS exceeded our benchmark attendance goal by 55 participants or by about 11%.

2. We also wanted to increase the reach of the Southwest Ag Summit by encouraging participants to share information and materials with others unable to attend. The target was to increase the reach by 15% from our benchmark of 200 people to 230 people measured by a question on our survey. The question asked:

"5. How likely are you to share information you obtained from the SW Ag Summit with others? [Circle a number]"

Less Likely Very Likely

1 2 3 4 5

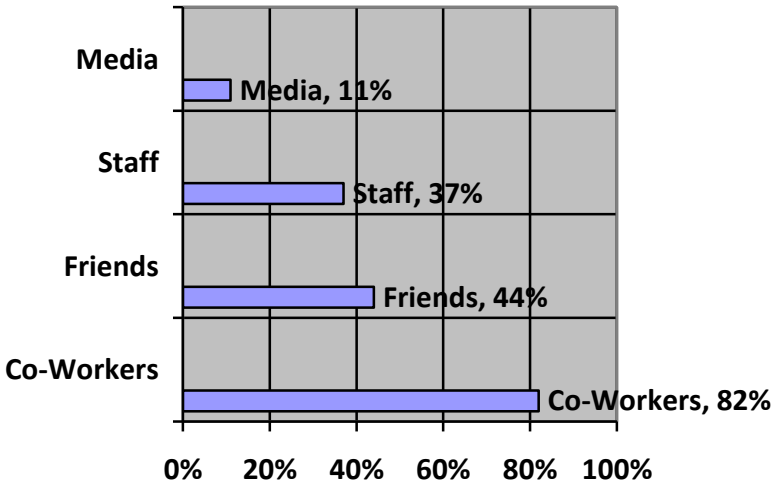
This question was answered by 235 people who identified themselves in question #2 above (Measurable Outcome #1) as having an occupation involving the melon or vegetable industry. The mean score of this group is 4.36. As a result, 235 people from the vegetable and melon industry indicated they would be "very likely" to share information from the Southwest Ag Summit with others. Again, this exceeded our goal by 5 participants or 17.5% above our benchmark.

Beneficiaries

One of our most useful tools in determining the diversity of Southwest Ag Summit participants is our annual survey. Generally distributed during the Thursday afternoon luncheon, responses to this survey give us insight into who are participants are, what drives them to attend the Ag Summit, and whether they were satisfied with the experience. A copy of the 2013 Southwest Ag Summit survey is attached, labeled **Appendix A**.

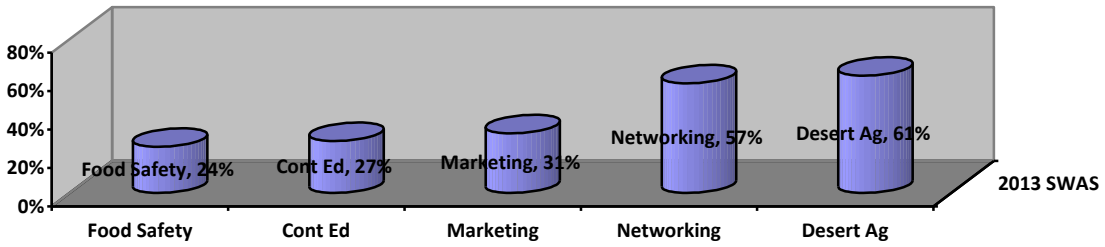
The ability to reach members of the specialty crop industry is key to increasing future participation in the Southwest Ag Summit. It is a goal of the Ag Summit Steering Committee that participants expand the reach of the event by sharing knowledge gleaned at the event with others who were unable to attend. Information obtained at the Southwest Ag Summit will be shared with (includes multiple overlapping answers):

- Coworkers – 82%
- Friends and family – 44%
- Staff – 37%
- The media – 11%



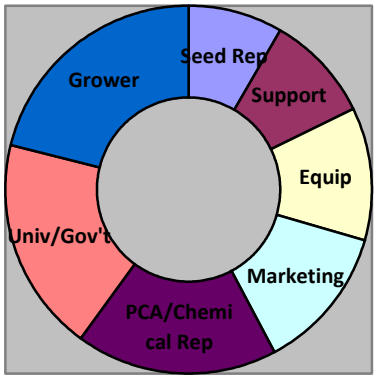
Participants used the survey to indicate that the Southwest Ag Summit affected their occupations by (multiple overlapping answers):

- Obtaining Material About Food Safety - 24%
- Gaining Continuing Education Credits - 27%
- Providing marketing opportunities - 31%
- Developing networking opportunities - 57%
- Obtaining material about desert agriculture - 61%



This year's attendance was approximately 11% higher than our target goal of 520 participants; those who completed the exit survey indicated our participants were:

- Seed related personnel – 7%
- Professional/support personnel - 8%
- Equipment dealers – 10%
- Marketing/sales representatives – 11%
- PCAs and chemical related personnel – 15%
- University/government related personnel – 15%
- Other – 16%
- Growers/Crop producers – 18%



The most recent (2007) USDA Census of Agriculture, from the National Agricultural Statistics Service exemplifies the economic impact of this project. The Census lists Yuma County as having a market value of $673,544,000 for the category of "vegetables, melons, potatoes and sweet potatoes." In addition, Yuma County ranked 3rd out of 3,079 counties in the United States for value of sales for vegetables and melons. Yuma County vegetable and melon production is not only economically significant to Arizona, but it is virtually unparalleled throughout the United States.

Lessons Learned

The size of the Community Conference Center and the variety of meeting rooms at Arizona Western College made the new venue more comfortable for all attending. Also, the move to the newer, state-of-the-art facility naturally made presentation of the educational workshops less fraught with technical complications. However, as with any event, there are lessons to be learned and carried forward to the next year. For the 2013 Southwest Ag Summit, Steering Committee members determined the following:

1. Arizona Western College was selected for the location of the 2013 Southwest Ag Summit because of the extensive resources available for our event. The seamless interdepartmental coordination helped relieve much of the burden of planning an event as complex as the Southwest Ag Summit. Due to the ease with which Arizona Western College staff and the Summit Committee were able to work together, the possibility of expansion of the Ag Summit for years to come, and the favorable feedback received from this year's participants, we would like to see the event held in this venue for years to come.
2. Yuma Visitors' Bureau maintained an increased emphasis on the use of email blasts for this year's Southwest Ag Summit due to the noticeable efficacy of them the previous year. Once again the blasts seemed to be especially efficient in drawing vegetable and melon crop personnel to register for the Ag Summit.
3. It is increasingly clear that in order to obtain the attendance of a large percentage of registrants at the Thursday morning keynote address the speaker must be someone of great importance to the Ag industry in general.

4. The use of sub-committees has been a valuable tool in effective planning of the Southwest Ag Summit. It was generally decided that Steering Committee meetings are more effective and run smoother if their attendance is held to sub-committee heads and essential personnel only.
5. Insisting on early deadlines is imperative to the timely release of marketing materials to prospective participants in the Southwest Ag Summit. The timely release of general information registration forms in printed materials, email blasts and the website is vital to increased registration for the event.
6. The use of the AWC Foundation staff and volunteers to coordinate registration lists and registrant sign-in on event day smoothed out the process considerably.
7. One of the feared drawbacks to the change of venue to Arizona Western College was its perceived distance from the city of Yuma. This turned out to be a non-factor, however, as access to the college is easy from whichever direction participants happened to be travelling. Also, there are numerous hotels within a five-mile radius.

As demonstrated, several factors were involved in deeming the 2013 Southwest Ag Summit of great value to the vegetable and melon industry personnel in attendance.

Contact Persons

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Additional Information

Each year there are innovative and exciting advancements in the vegetable and melon industry. The Southwest Ag Summit is proud to address these developments as well as any arising issues that may threaten our industry. The Steering Committee works diligently year-round to revise and update the event so it continually provides the most up-to-date research results and product information to our attendees. Due to the popularity and organized efficiency of our new location, the 2014 Southwest Ag Summit is already slated for next year with an expanded program. It is scheduled to be held February 26-27, 2014 at Arizona Western College.

Agricultural Literacy – School Garden Program

This project was completed on September 30, 2014

Project Summary

This project was a continuation of a previously funded project, SCBGP-FB10-42. It complimented the previous grant by continuing to provide additional trainings for educators

and school food service personnel as well as continuing the implementation of the AZ Department of Health Services School Garden Food Safety certification program.

The Agricultural Literacy School Garden Food Safety Program provides school district personnel and Garden Managers with research-based strategies to implement a garden food safety program as well as introduce agricultural concepts into their current curriculum. The garden food safety component is a priority since many schools are utilizing the fruits and vegetables grown in school gardens for consumption in the classroom and want to provide this produce to the school cafeteria. The program content allows Kindergarten through Twelfth grade classroom teachers to increase their knowledge about Arizona's Specialty Crop industry while meeting Arizona's College and Career Ready Academic Standards in Mathematics, Language Arts, and Science which includes nutrition. The subjects of Science, Mathematics, and Language Arts were chosen because these are the subjects currently included in Arizona's Instrument to Measure Standards test that students are required to pass.

Many schools already have gardens and other schools are implementing gardens. The University of Arizona College of Agriculture and Life Sciences Cooperative Extension has employees in several counties who are working with schools and school districts to provide the necessary knowledge to grow gardens successfully utilizing research-based information. The need to provide the information for students and teachers to use garden food safety practices is extremely important from a cafeteria Food Code perspective.

The School Garden Food Safety Program is important and timely because there is a demand by teachers to implement gardens as a vehicle to enhance lessons in their classrooms. Utilizing gardens allows the teachers to implement learning strategies that are relevant to their students but are aligned to the academic standards and enhance the curriculum the teachers are required to use. There is also an increased interest in school personnel to educate students on consumption of locally grown, healthy fruits and vegetables. Students growing their own fruits and vegetables in school gardens are more likely to want to consume the produce. This increase in awareness of what can be grown can potentially increase the consumption of Arizona grown fruits and vegetables. Implementing the garden food safety component will ensure that the harvested produce is safe for human consumption and meets the health standards for use in the school cafeteria or the classroom.

Project Approach

When the first grant was written there were no food safety guidelines for schools, and school grown produce was not allowed to be prepared or served in the school cafeteria. Upon implementation of the grant it was determined that the AZ Department of Health Services (ADHS) would need to be an important partner in the grant. The ADHS Director recognized the value of implementing a food safety approval process for schools to utilize the produce in the cafeteria. The Director approved funding for a full-time Sanitarian position within the Department. This position was filled in January 2013.

Simultaneously with the above mentioned discussions with ADHS, the PI began research on Food Safety Guidelines for school gardens. Multiple meetings were held with ADHS employees, directors of all the county health departments and pertinent health inspectors.

The guidelines went through numerous drafts between the technical expert, ADHS, AZ Department of Education (ADE), and AZ Department of Agriculture (ADA) plus national peer review. After minimal changes were made based on peer comments the guidelines are now an official publication of the University of Arizona and utilized in the School Garden Food Safety trainings.

It was originally thought that multiple trainings across the state would need to be held in the second year of this grant to train the goal of 100 teachers. This goal was exceeded in six workshops in four counties, reaching 165 attendees. The training manual, with accompanying report forms, was updated as the ADHS made changes to the certification requirements. The report forms and guidelines are available on the UA CALS CE and ADHS websites.

Monica Kilcullen Pastor, Associate Programmatic Area Agent, UA College of Agriculture and Life Sciences Cooperative Extension (UA CALS CE): Served as PI on the grant facilitating the writing, editing and publishing of the peer-reviewed School Garden Food Safety Guidelines, implementation of a listserv with approximately 800 educators receiving updated information about trainings and changes to the guidelines, coordinating the workshops and evaluations, sharing the implementation of the program at two National Meetings, plus coordinating the interactions with the partners.

Brandon Moak, Program Coordinator, Sr., UA CALS CE: Served as Program Manager to coordinate day-to-day logistical functions of the program, schedule trainings, and organizing workshop materials; as technology expert to facilitate streamlined communications with educators, develop and implement effective electronic evaluations, and coordination of training documents including presentations as well as report forms.

Kathryn Mathewson, School Garden Sanitarian, ADHS: Coordinated department input on the guidelines, developed website for educators to access department forms, trainer on the ADHS requirements for garden certification, certifies qualifying gardens, and continually updates ADHS guidelines to reflect current research.

Goals and Outcomes Achieved

Six workshops were conducted throughout Arizona, two in Tucson, one in Prescott, two in Maricopa County, and one in Yuma totaling of 165 educators and Health Department Employees. Each participant was able to receive a copy of the School Garden Food Safety guidelines; a copy of the Arizona Specialty Crop Lessons which contains 30 lessons with well-defined objectives to enhance instructional strategies and content knowledge concerning science, mathematics, writing and reading, and healthy lifestyles; and information on gardening basics for their particular climate, elevation, and soil.

Several emails were sent to participants inviting then to participate in program evaluation via an online survey. Approximately 10% chose to participate. Fourteen of the respondents are traditional K-12 teachers (meaning, they teach full-time to the same sets of students), one is a PE teacher, and one is a college instructor. A full report on the survey analysis is provided as an attachment to this report.

All training participants received a copy of the Arizona Specialty Crop Lessons. Over one-third (35.7%) of the traditional K-12 classroom teacher respondents reported utilizing these lessons, and more than half of these (60.0%) reported teaching at least three of the thirty lessons and averaged 12.2 hours of instruction on these lessons.

Students' knowledge regarding Arizona specialty crops were assessed by awareness of whether or not the foods planted in their school garden were already commercially grown in Arizona. Thirty-one and one-third percent of the surveyed respondents reported having students who are actively involved in their school garden. An average of 53.4% of these students were surprised to learn that their foods are commercially grown in Arizona.

The above mentioned students were also surveyed as to their eating habits related to the foods which they had planted. An average of 22.3 % of students reported having never eaten the foods prior to planting it, an average of 72.1% reported having tried the foods at least once since planting them, and an average of 55.2% of students reported now liking the foods since planting them.

At the end of the first year of funding, two schools had received certification through ADHS, one of which had participated in the provided trainings. Currently, there are nine certified school gardens, five of which have participated in the trainings.

Beneficiaries

The groups that benefited from the completion of the project include schools with gardens, schools that want to implement gardens, county and Arizona departments of health, county health department employees, and specialty crop growers since student awareness has been raised about the types of crops grown in Arizona. School cafeteria's also benefited because they can utilize school garden grown produce in their cafeteria once the garden is certified.

Six workshops were conducted throughout Arizona, two in Tucson (November 15 & 16, 2013), one in Prescott (2/21/14), two in Maricopa County (July 18 & August 29, 2014), and one in Yuma (September 12, 2014). Survey responses are as follow

- Conducted on-line evaluation of the trainings. Participants were free to participate in any or all of the three sections of training. All evaluation questions used a Likert scale with 1 = Strongly Disagree and 5 = Strongly Agree. Each class was evaluated separately (asking if the training objectives were met, if the activities were educational, if the training was helpful, and if the training met their expectations), each presenter was evaluated separately (rating preparedness and personableness), and the entire workshop was evaluated overall (rating the organization of the workshop, the appropriateness of the facility, and likelihood of referring others to the workshop). Below are the results of the evaluation with an indicated response rate.
- Multiple emails were sent to each of the educators who had attended the School Garden Food Safety training inviting them to participate in the above mentioned survey. Typical response rates for surveys are 10-20%, which was consistent with the response rate for the above survey (16/161 = 9.9%).

- Of the 16 respondents, 14 are traditional K-12 teachers (meaning, they teach full-time to the same sets of students), 1 is a PE teacher, and 1 is a college instructor.

Food Safety Guidelines

Training Date	Response Rate	Overall	Objectives	Activities	Helpful	Expectations	Prepared (Pastor)	Personable (Pastor)	Prepared (ADHS)	Personable (ADHS)
11/15/13	62.5%	4.20	4.40	4.20	4.30	4.15	4.45	4.40	4.40	4.45
11/16/13	75.0%	3.75	4.67	4.17	4.17	4.67	4.83	4.75	4.17	4.75
2/21/14	55.6%	3.95	4.45	4.35	4.50	4.40	4.40	4.45	4.10	4.20
7/18/14	70.6%	4.17	4.25	4.25	4.17	4.42	4.75	4.83	4.25	4.67
8/29/14	67.7%	4.43	4.67	4.57	4.71	4.67	4.86	4.81	4.62	4.81
9/12/14	63.6%	4.52	4.81	4.90	4.57	4.57	4.85	4.85	4.43	4.62
AVERAGE	**65.8%**	**4.17**	**4.54**	**4.41**	**4.40**	**4.48**	**4.69**	**4.68**	**4.33**	**4.58**

Classroom Incorporation

Training Date	Response Rate	Overall	Objectives	Activities	Helpful	Expectations	Prepared (Pastor)	Personable (Pastor)
11/15/13	62.5%	4.10	4.15	4.50	4.45	4.25	4.70	4.60
11/16/13	56.3%	4.11	4.44	4.44	4.56	4.11	4.78	4.78
2/21/14	52.8%	4.00	4.37	4.32	4.32	4.26	4.32	4.37
7/18/14	70.6%	4.42	4.50	4.67	4.67	4.58	4.75	4.83
8/29/14	67.7%	4.44	4.72	4.83	4.72	4.72	4.72	4.78
9/12/14	64.3%	4.53	4.83	4.78	4.78	4.78	4.82	4.78
AVERAGE	**62.4%**	**4.27**	**4.50**	**4.59**	**4.58**	**4.45**	**4.68**	**4.69**

Gardening 101

Training Date	Response Rate	Overall	Objectives	Activities	Helpful	Expectations	Prepared (M.G.)	Personable (M.G.)
11/15/13	–	–	–	–	–	–	–	–
11/16/13	–	–	–	–	–	–	–	–
2/21/14	52.8%	3.89	4.21	4.16	4.11	4.16	4.32	4.37
7/18/14	70.6%	4.36	4.45	4.64	4.45	4.55	4.55	5.00
8/29/14	67.7%	4.50	4.56	4.67	4.50	4.44	4.72	4.83
9/12/14	64.3%	4.33	4.56	4.47	4.61	4.44	4.61	4.78
AVERAGE	**63.8%**	**4.27**	**4.44**	**4.48**	**4.42**	**4.40**	**4.55**	**4.74**

Entire Workshop

Training Date	Response Rate	Organization	Facilities & Amenities	Referral	Apply Guidelines	Seek Certification
11/15/13	62.5%	4.40	4.40	4.10	85.0%	55.0%
11/16/13	75.0%	4.67	4.67	4.33	100.0%	33.3%
2/21/14	55.6%	4.50	4.50	4.40	80.0%	50.0%
7/18/14	70.6%	4.67	4.50	4.75	91.7%	66.7%
8/29/14	67.7%	4.81	4.86	4.67	100.0%	52.4%
9/12/14	63.6%	4.71	4.90	4.86	57.6%	39.4%
AVERAGE	**65.8%**	**4.63**	**4.64**	**4.52**	**85.7%**	**49.5%**

Lessons Learned

The most important lesson learned was the desire by schools to implement food safety practices in their school garden. Whenever a presentation, email, or phone call was conducted the overwhelming response was "thank you for taking leadership" on this implementation. It was also anticipated that multiple workshops would need to be conducted to reach the attendance goal of 200 participants in the two years of both the grants. Nine were held and there were 280 participants which was 40% higher attendance than what was anticipated.

One negative is the estimation of time to implement a new program that, by necessity, needed to have input from many stakeholders. As a university program, certain science-based guidelines needed to be included, but ADHS, which is certifying the gardens, also needed to establish protocols in which the agency was willing to take leadership and certification approval. The Guidelines underwent many drafts prior to approval by university peer review. ADHS, ADE and ADA all provided valuable input into the development of the guidelines. ADHS continued to make changes to the certification requirements over the course of this grant year which did not allow for the bulk printing of the training manuals.

An unexpected outcome of implementing this project is the acknowledgement of programs outside Arizona of the importance of the guidelines. Proposals for presenting the project were submitted for five National Conferences and all five proposals were accepted after a peer-review process. After completion of the presentation many participants indicated they intended to try implementation of the guidelines in their state.

Contact Person

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Arizona's Top 10 Specialty Crop Videos

This project was completed on September 30, 2013

Project Summary

The purpose of Arizona's Top 10 Specialty Crop Videos is to educate Arizona families about the value and importance of Arizona's top 10 specialty crops through the use of the ever-increasing popular video format and in an entertaining way that encourages Arizona families, especially children, to eat more fruits, vegetables and nuts for more nutritious diets.

Project Approach

From concept to production to final Distribution, this specialty crop grant effort took us from idea of the 10 videos for Arizona top 10 specialty crops to final distribution. In outline form, we highlight major activities.

- Sourced and selected Urban Truth & Done Well Productions, LLC (Mesa, AZ-based) as our video production entity

- Began creative development (included story line, scripts and estimated video time) & gathered content for videos including a 2-day shoot in Yuma of 7 of the 10 specialty crops: December 18th and 19th.
- We worked with 7Farmers and also consulted with them: John Boelts with Desert Premium Farms, Jonathan Dinsmore of Dinsmore Farms, Mark Freeman of Freeman Corn Patch, Green Valley Pecan, Tim Dunn of Tim Dunn Farms, GreenGate Fresh produce, Rousseau Farming Company
- December meeting of final script outlines with writing to begin on them.
- Planned next trip to capture footage of final 3 specialty crops: Cantaloupe, Watermelons and Pecan.
- Completed all Script writing for 10 videos
- Met with Production Team (Urban Truth) to review and Finalize Scripts
- Met and worked with actors to review scripts
- Captured Script scenes at 2 locations
- Scenes with family (3 kids and parents) came out spontaneously fun and humorous at times. Hoping this comes through in the video. The children appeared to have a sincere curiosity about how their food was grown. Again, we're hoping this comes through in the scenes.
- Captured final scenes related to specialty crop farming
- Captured Pecan scenes
- Captured Watermelon scenes
- Selected "music Bed" for videos
- Captured further "family" scenes of kids eating vegetables
- Video editing of scenes
- Farmers review of scenes; plus editing based on accuracy suggestions by farmers.
- Group review of scenes for assessment and accuracy (Marketing Department of Arizona Farm Bureau)
- Final Results: We now have 10 videos of the "current" top 10 specialty crops in Arizona. We are rolling them out once a month on YouTube with the first one being Broccoli: http://www.youtube.com/watch?v=qVJOzJJvoI4, RFD TV is hosting the first video on their website as promised. DVDs have been developed for Arizona Farm Bureau's 20 vegetable curriculum kits that are used in the schools in the spring, Laveen School District is already showing them in their school cafeteria (see **Appendix B**), We're uploading them on Fill Your Plate's Video section: www.fillyourplate.org, and promoting the new videos on our various social media channels.
- Survey assessment from 5th grade class (**Appendix C**)

Goals and Outcomes Achieved

Increase consumer awareness (our Arizona families) of specialty crops by distributing these 10 featured videos in the following ways (**GOAL**).

1. Increase awareness of Arizona Specialty Crops to Arizona's 6 million residents by increasing number of videos on Fill Your Plate, distributing them in educational venues like school lunchrooms, feature the new videos on our social media tools including

Facebook and Twitter and include the 10 videos in Arizona Farm Bureau's Ag in the Classroom program;

- Completed and ongoing by posting the "Veggie Man" Video on Fill Your Plate (http://fillyourplate.org/video.html),
- Laveen School District currently using them in their lunchroom
- Spring 2014 they will be distributed in our "Veggie Curriculum" kits. These kits will go statewide to a variety of our school districts.
- Currently and ongoing social media distribution including imbedding the video into our vegetable stories on our blogs.
  Example: http://info.azfb.org/blog/bid/361750/Running-the-Numbers-on-Exciting-Yuma-Arizona-Agriculture-Statistics
- Some of our partnered Agriculture groups are sharing the video with their audiences such as Yuma Fresh Vegetable Association and others. It's also permanently available on YouTube:
  http://www.youtube.com/watch?v=qVJOzJJvoI4

2. increase use of the new videos by providing the videos to RFD TV; and
   - They have featured our video up on their site (http://www.rfdtv.com/) though they've done this on a rotation.
3. share with other organizations that might wish to use them for educational teachings on nutrition.
   - Yuma Fresh Vegetable Association is one of our best examples of this.

We'll measure performance by informally surveying a selected audience segment to determine level of viewers' retention of information and understanding before and after viewing the videos (**PERFORMANCE MEASURE**), hoping for a 25% to 75% improvement rate on understanding (**TARGET**) after videos have been viewed. The same survey will be taken before and after to determine the increase in understanding (**BENCHMARK**).

Regarding performance measurement, we have so far conducted one survey with 5th graders in the Laveen School District ***(Pre and Post testing with the same quiz)*** and feel the outcomes were fairly good. (See **Appendix D** for results.) We plan to do this periodically to assess how well these videos are doing with children since they were our main target audience.

We asked the Laveen School District to use the same test for a "Pre" test (took the test prior to viewing the video) and then a "Post" test. In the attached, the left column is the "Pre Test" results. For example, in question 4 we asked "What Arizona County produces the majority of our vegetables during the winter?" The correct answer is Yuma. In the "Pretest" on the left column 13 students answered correctly. In the "post test" in the right column , 27 students got it correct, increasing student knowledge of this fact by 14 students!!

In another example, question 6 asked "What % of lettuce comes from Yuma, Arizona in the winter?" The correct answer is d. 90%. In the "pre test" only 2 students got the answer correct, but the "post test" 25 students go the answer correct.

The "pre" and "post" test shows mixed results. Three of the 6 questions show improved knowledge and understanding of specialty crop production in Arizona (Questions #4, #5 and #6). Two question results (#1, #3) appear worse. Question #2 I would classify as no real change in knowledge.

We plan to do this periodically to assess how well these videos are doing with children since they were our main target audience. The quiz, Veggie Curriculum kits and Veggie Man video will be distributed to schools in the spring of 2014.

Beneficiaries

This project will impact the State's approximately 3,000 farms involved in growing the specialty crops (**BENEFICIARIES IMPACT AND #'s**). These crops represent approximately $1 billion in farm income and are the largest crop in the State (**ECONOMIC IMPACT**). In order to continue the growth this industry has experienced in recent years, this project will develop and conduct marketing and distribution efforts to increase their market share (**HOW BENEFICIARIES WILL BE IMPACTED**).

The biggest beneficiaries are our Arizona families, but specifically students who will be viewing them in classrooms throughout Arizona this coming spring (2014). We will be testing to see what they learn too. But, for those who have currently viewed the videos, here are some following comments:

1. ***"I didn't realize how much production came out of Yuma, Arizona" Wendy Kenny***
2. ***"Veggie Man was fun and made your agriculture story fun to hear." Arizona Mom***
3. ***"Makes me want to eat more vegetables!" Jr. High Student***

We're hoping to see an ongoing benefit of these videos as we'll continue to use them will all of our outreach activities, periodically testing students that view them to see if they have a greater understanding of where their fruits and vegetables come from and the nutritional value of eating more fruits and vegetables.

Lessons Learned

The biggest lesson learned in this project is the collaborative effort in working with the farmers to complete the project. Their insights were invaluable and they even had great advice on how to improve our scripts and much more. The challenge is to try and make it entertaining enough for our key audiences. As it's rolled out into the schools this spring we'll learn more about students retention and interest in it.

The other challenge involves us not knowing how well classrooms will receive it until the spring as the schools really won't be addressing the fruits and vegetable curriculum opportunities until this spring. However, the Laveen School District is already airing them in their cafeteria to children and this is where we conducted our first pre- and post-test.

Contact Person

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Additional Information

The impact of these videos will be ongoing. As we roll these videos out to schools throughout Arizona and in other venues, we believe we'll be helping Arizonans eat more fruits and vegetables.

Continuation of GHP/GAP Certification One-on-One Assistance Program

Activities Performed

First Quarter (Oct. 2013 – Dec. 2013) Activities:

- Activities are currently being performed under SCBGP-FB11-51 until funds are depleted. It is estimated that work will begin on these project funds in July 2014.

Second Quarter (Jan. 2014 – Mar. 2014) Activities:

- Activities are currently being performed under SCBGP-FB11-51 until funds are depleted. It is estimated that work will begin on these project funds in July 2014.

Third Quarter (Apr. 2014– June 2014) Activities:

- GAP/GHP training programs
  The Food Safety Projects Coordinator (FSPC) attends GAP/GHP training programs conducted by Dr. Kurt Nolte, University of Arizona Cooperative Extension Office, Yuma, AZ, to assist and clarify the program to attendees:
  - There was one training class held this quarter in Prescott, AZ attended by 24 growers and interested parties.
- One-on-One Consultations
  - Consulted with a mushroom grower who has plans to become certified in Mushroom GAP.
  - Consulted with a grower who is growing baby greens, harvesting them and selling at farmers markets and local retail stores. The grower is developing a GHP/GAP food safety program and will be audited later this year.
- Meetings
  - Met with several growers and potential growers who are interested in becoming certified through the GHP/GAP program
  - Met with one certified grower for a refresher prior to their annual audit
  - Met with Maricopa County Environmental Services and agreed to assist their training programs in food safety.
  - Met with an Arizona State University School of Sustainability student to assist in a research paper.
- Presentations
  - Attended a presentation on aquaponics held at Arizona State University.

  - Attended and presented a food safety program to attendees of the National Farm to School conference in Austin, TX.
  - Attended and presented a food safety discussion on a panel discussion hosted by the U of A Cooperative Extension for their master Gardeners program.
- Farm to School
  - See presentations above
- Arizona Farm Bureau Blog
  - Submitted an article on Traceability
- Conference Calls
  - Attended a PACA conference call to learn about the Perishable Agricultural Commodities Act.

Fourth Quarter (July 2014 – Sept. 2014) Activities:

- GAP/GHP training programs
  The Food Safety Projects Coordinator (FSPC) attends GAP/GHP training programs conducted by Dr. Kurt Nolte, University of Arizona Cooperative Extension Office, Yuma, AZ, to assist and clarify the program to attendees:
  - There were no training classes this quarter
- One-on-One Consultations:
  - Currently assisting a Central AZ grower with GHP/GAP program development
  - Currently assisting a Northern AZ Tribe with GHP/GAP program development
- Meetings
  - Met with the Yavapai County Group GAP Project (YCGGP) steering committee in Prescott, AZ to discuss the development of a USDA Group GAP pilot project in Yavapai County.
  - Attended the Maricopa County Farm Bureau meeting
  - Met with a developer who heard of the GHP/GAP program and wanted to learn more about certification. He may develop a parcel of property into a garden/farm.
  - Met with ADA Council and reviewed a presentation prior to its delivery.
  - Attended the Arizona Environmental Health Association meeting
  - Met several times with a local developer who is beginning a program to grow fresh vegetables on a City of Phoenix vacant lot. This program is designed to encourage neighborhood participation with working in the gardens, purchasing local foods, and selling the vegetables for a profit.
  - Met with Slow Food, USA's National Director of School Gardens, and Maricopa County Cooperative Extension to discuss locally grown fresh food and school gardens
- Presentations
  - Assisted Project CENTRL with a class exercise
- Farm to School
  - Attended and participated in two farm to school meetings.
  - Attended and met Mr. Ken Concoran, USDA under Secretary of Food Safety at a local school to tour the school's garden.
- Arizona Farm Bureau Blog
  - Currently developing additional articles for the AZ FB blog

- Conference Calls
  - Participated in a conference call with AMS to discuss the YCGGP.
  - Attended a conference call with USDA's Agricultural Marketing Service (AMS) on local procurement.
  - Attended a conference call with AMS on FDA/USDA's Food Safety Modernization Act (FSMA)
  - Attended a conference call with AMS on Group GAP

Problems and Delays

First Quarter (Oct. 2013 – Dec. 2013) Activities:

- There were no problems or delays during this quarter as work was being performed under SCBGP-FB11-51.

Second Quarter (Jan. 2014– Mar. 2014) Activities:

- There were no problems or delays during this quarter as work was being performed under SCBGP-FB11-51.

Third Quarter (Apr. 2014 – June 2014) Activities:

- There was a noticeable lack of interest in holding GHP/GAP training classes this quarter. This may be due to several factors including: the advent of the FSMA may be causing growers to have a "wait and see" attitude, suspicion of USDA /state government involved in growers' affairs, cost of program audits, unwilling to maintain a food safety program with proper documentation, not required by buyers.

Fourth Quarter (July 2014 – Sept. 2014) Activities:

- There was a noticeable lack of interest in holding GHP/GAP training classes this quarter. This may be due to several factors including: the advent of the FSMA may be causing growers to have a "wait and see" attitude, suspicion of USDA /state government involved in growers' affairs, cost of program audits, unwilling to maintain a food safety program with proper documentation, not required by buyers.

Future Project Plans

- Continue 3rd quarter activities
- Will continue to assist local growers in developing their GHP/GAP Food Safety Programs

Funding Expended To Date

A total of $21,465.35 has been expended as of September 30, 2014.

Edible School Gardens

Activities Performed

First Quarter (Oct. 2013 – Dec. 2013) Activities:

- Visited three Tucson school gardens.
  - Borton Primary Magnet School
  - PPEP TEC High School
  - Hollinger School
- In April – June 2013, applications were reviewed and scored based on their project plan, garden budget, community support and commitment to fulfilling grant requirements. 50 winners were selected and confirmed with WG members their involvement and support with certain schools.

Second Quarter (Jan. 2014 – Mar. 2014) Activities:

- Worked on data integrity

Third Quarter (Apr. 2014 – June 2014) Activities:

- Worked with web team to possibly use online survey. Determining if survey should be teacher-focused (answering for students) or, provide teachers surveys that children would complete. Preparing to launch for school year (about 8/31/14).

Fourth Quarter (July 2014 – Sept. 2014) Activities

- Sent out over 2,500 hard copy surveys to schools for students and teachers to complete. From these surveys, we will be able to measure our expected outcomes.
- Added more farmer profiles to the website and added an Arizona School Garden Network area to our csgn.org website.

Problems and Delays

First Quarter (Oct. 2013 – Dec. 2013) Activities:

- Teachers and students are grateful, learning much

Second Quarter (Jan. 2014 – Mar. 2014) Activities:

- No delays

Third Quarter (Apr. 2014 – June 2014) Activities

- Website measurement continues to be a challenge because we can't discern what channel the traffic might be coming from. Would like to focus on substantiating our school garden counts and measuring the engagement and learning of the students as EMO and rethink the web EMO

Fourth Quarter (July 2014 – Sept. 2014) Activities

- No delays

Future Project Plans

First Quarter (Oct. 2013 – Dec. 2013) Activities:

- Create on-line survey with the input from various schools

Second Quarter (Jan. 2014 – Mar. 2014) Activities:

- Will launch survey when school in back in session, Aug/Sep

Third Quarter (Apr. 2014 – June 2014) Activities:

- Conduct survey
- Schedule report, summary and final report to be no later than 2/15/15

Fourth Quarter (July 2014 – Sept. 2014) Activities:

- Collect, analyze and report on survey

Funding Expended To Date

A total of $75,000.00 has been expended as of September 30, 2014.

Leafy Greens Training Resources and Outreach

Activities Performed

First Quarter (Oct. 2013 – Dec. 2013) Activities:

- The film production team has been chosen and we have had our first meeting to discuss the design and filming expectations.
- We have received commitment from Dole and Rousseau to use their fields and harvest crews for the filming. We scheduled the filming for the first week of January 2014.
- We reviewed and chose an actor to perform the food safety tasks in the field.
- The production team began developing shot sheets to organize the overall production.
- The training videos were still under development so no training classes were held, so progress on meeting our expected measurable outcomes one and two will not be seen until October 2014, upon development of the training videos. The progress on the production of the videos is listed above.

Second Quarter (Jan. 2014 – Mar. 2014) Activities:

- We have filmed at three difference locations on three separate farms.
- All seven videos have rough cut videos that were reviewed and the third video shoot was scheduled to get additional footage.
- We promoted the videos by previewing the Orientation Module at the joint board meeting of California and Arizona LGMA in January 2014 in El Centro, CA.
- The Yuma Safe Produce Council and the Southwest Ag Summit asked us to present our training program at the conference in February 2014, were we previewed the Orientation Module.
- Summited a nomination for the videos to the United Fresh Produce Association for their "Best New Food Safety Product Award".
- The training videos were still under development so no training classes were held, so progress on meeting our expected measurable outcomes one and two will not be seen until October 2014, upon development of the training videos. The progress on the production of the videos is listed above.

Third Quarter (Apr. 2014 – June 2014) Activities:

- We have scheduled review meetings and voice over recordings for next quarter.
- All packaging art design for the videos, including DVD's and USB flash drives has been completed.
- Attending the Center for Produce Safety Conference June 24-25, 2014. CPS is the national clearinghouse for Food Safety Training Programs for farmers and named as a resource in the Food Safety Modernization Act Training Guidelines.
- Attended the United Fresh Produce Conference June 10-13, 2014 with a demo product.
- Attended produce buyer meetings, which had food safety representation from McDonalds, Costco, Darden, Wegmans, Taco Bell, US Food Source, Chick-a-Filet and Jack in the Box. All participants were excited about the new product.
- We provided an insert in the United Fresh Produce Conference/ Exposition registration packet, which went to all exhibitors and participants, approximately 10,000 people.
- While we did not win the Best New Food Safety Innovation we did get nominated and delayed the demo DVD's and the United Fresh Produce Conference/ Exposition.
- The training videos were still under development so no training classes were held, so progress on meeting our expected measurable outcomes one and two will not be seen until October 2014, upon development of the training videos. The progress on the production of the videos is listed above.

Fourth Quarter (July 2014 – Sept. 2014) Activities:

- In August 2014, the Yuma Safe Produce Council held their annual Supervisor Training and asked to use the newly produced videos for this training. English and Spanish sessions were held concurrently, with a total of 143 participants trained using the resources from this project.
- On August 19, 2014 the Arizona Leafy Greens Food Safety Committee agreed that each Arizona Leafy Greens Shipper will receive two sets of the three disc DVD sets and each Arizona Leafy Greens Grower will receive one set.
- In September 2014 we began planning for the classroom training of Module Four, in which, DVD 3 will be incorporated. We scheduled a total of four English and five Spanish classroom trainings in Phoenix and Yuma. Each session is meant to train 20 participants.
- The training videos were still under development so no training classes were held, so progress on meeting our expected measurable outcomes one and two will not be seen until October 2014, upon development of the training videos. The progress on the production of the videos is listed above.

Problems and Delays

First Quarter (Oct. 2013 – Dec. 2013) Activities:

- Our plans to begin filming in October 2013 have also been delayed until January 2014 which will delay our Outreach timeline into February 2014 but we do expect to provide our first Outreach at the Southwest Ag Summit in Yuma, AZ.
- Due to production delays, the funding cycle will be delayed into the second year of the grant.

Second Quarter (Jan. 2014 – Mar. 2014) Activities:

- We have to change some of the voice over in the video to correctly depict what we have actually filmed, so we have schedule to have them redone.
- We had hoped to have a finished product to show at the Southwest Ag Summit in February 2014 but will now be presenting it at the United Fresh Produce Conference in Chicago, IL.

Third Quarter (Apr. 2014 – June 2014) Activities:

- The Spanish voice over has too many pauses and will have to be redone. The voice we used originally is not available until July 2014, so we still have to schedule to have it redone.
- Final production is pending this final voiceover work.

Fourth Quarter (July 2014 – Sept. 2014) Activities:

- While we believed that the final DVD's and packaging would be completed pending this final voiceover work we found that there was a need to develop a more comprehensive set of media files to be added to the DVD's.
- On Module Four/DVD 3, we began development of post evaluation testing to be included on the media files for DVD 3.
- During media set up on the DVD's the production company assessed the work still left to be finalized and decided that December 2014 was the target for the official release of the videos.

Future Project Plans

- We plan to incorporate the materials into classroom training session that will be held in October and November of 2014.
- We expect to finalize the product portion of this grant in December 2014, and upon finalizing we will hold a premier of the videos and supply them to the Arizona Leafy Greens Shippers and Growers.

Funding Expended To Date

A total of $125,000.00 has been expended as of September 30, 2014.

Workforce Training for Arizona's Wine Industry

Activities Performed

First Quarter (Oct. 2013 – Dec. 2013) Activities:

- Currently we are on target for the proposed time-line. During the first quarter, the project team has one time in planning for both the establishment of additional 3 acres and the Local Growers Symposium.
- Vineyard-project managers have conducted site analysis for next phase of the additional 3-acres of vineyard and are in the process of ordering the necessary supplies per year 2 budget and contracting the necessary preparation of the site. Laboratory technicians continue preparation for the next acreage and maintaining the 2 acres established through the grant.

- Postsecondary Education/Program Enrollment-Program team ran enrollment data for the Fall 2013 semester. The Benchmark was 49 students in Fall of 2011. Fall 2013 enrollments for Viticulture and Enology were 92 students. Although we did not meet our performance goal of 100 students, we did make significant progress towards the goal.
- Local Growers Symposium- Working in conjunction with the Verde Valley Wine Consortium the proposed date for the Growers symposium is scheduled for June 6th and 7th to be held at the Yavapai College Verde Campus. The next scheduled meeting is March 5th where the project coordinators and the consortium will begin creating the agenda, identify speakers and creating marketing materials.

Second Quarter (Jan. 2014 – Mar. 2014) Activities:

- Currently we are on target for the proposed time-line. During the 2nd quarter, the project team has continued to meet for the planning of additional 3 acres and the Local Growers Symposium.
- Vineyard-project managers have prepped the site for next phase of the additional 3-acres of vineyard and are in the process of ordering the necessary supplies per year 2 budget. Laboratory technicians continue to maintain established grant acreage and preparation for this year's vines.
- Local Growers Symposium- Working in conjunction with the Verde Valley Wine Consortium the date for the Growers symposium is scheduled for June 6th and 7th to be held at the Yavapai College Verde Campus. The last meeting was held on April 16th. The project coordinators and the consortium are continuing to creating the agenda, identify speakers and create marketing materials.

Third Quarter (Apr. 2014 – June 2014) Activities:

- Postsecondary Education/Program Enrollment- The Program team ran enrollment data for the Fall 2014 semester. Although the goal referred to the Fall of 2013 we wanted to continue to track progress. Fall 2014 enrollments for Viticulture and Enology were 120 as compared to 94 in 2013 showing a significant increase.

- Local Growers Symposium-on June 6th and 7th Yavapai College in conjunction with the Verde Valley Wine consortium hosted the 3rd annual grower's symposium. In attendance were over 100 participants. In addition, the college established an additional 3 acres of vineyard to be utilized for experiential learning and hands-on teaching.

Fourth Quarter (July 2014 – Sept. 2014) Activities:

- After hosting the 3rd annual grower's symposium, Yavapai College and the Verde Valley Wine Consortium held a symposium debrief. The intent of this meeting was to discuss what went well, what could have been better, and future recommendations for the symposium.

Problems and Delays

We encountered no significant problems to date.

Future Project Plans

Activities during the fourth quarter included debriefing and future planning for the continuation of the grower's symposium and continued maintenance of the vineyard. The grant team will review and assess the overall objectives, outcomes, and deliverables of the grant. The ADA is working with the subgrantee on a revised timeline to address potential unexpended funds and final report.

Funding Expended To Date

A total of $58,951.37 has been expended as of September 30, 2014.

Arizona Grown Marketing Efforts Phase 2

This project was completed on June 30, 2013

Project Summary

The AZ Grown Marketing efforts for Phase II allowed focus on a four month large media campaign effort with purchased media to educate and engage the public on why and where to buy locally grown produce and nursery plants. The digital billboards could potentially turn thousands of people who are traveling the roads into potential purchasers of AZ Grown product. The website and Facebook continue to draw in interested people who want to learn more about Arizona Grown. As an added benefit, this phase provided an elevated awareness of the AZ Grown logo in stores with supporting local purchases.

Project Approach

Paid advertising and media were geo-targeted to maximize the budget with tactics that drove traffic to the website and Facebook page. The following tactics were used:

- Digitally which has the ability to provide a high reach with a low cost per mile, (the advertising cost per thousand views), which can drive traffic to the Facebook page.
- Out of home reaching the desired target of women 25 – 54 via additional touch points within their day, focusing on reaching them during their commute, whether for business or leisure.
- Concerning Facebook, now that we have established the audience, we will be posting more reoccurring info about AZ Grown specifically; looking for the logo, benefits, etc. so the quality will continue to find its way into Facebook as well.
- Continuing on Facebook, the continued effort is to attract a local audience. We are also including some posts that also talk about how AZ Grown produce and plants make their way outside of the state as an education tool.

Goals and Outcomes Achieved

Four months of content creation for Facebook as well as ideation and calendar management (November 2012 – February 2013). The content continued to push Trivia Tuesday and other established successes of the first phase of the campaign. The content also tied into PR and advertising efforts, the AZ Grown billboards located on I-17 were particularly view worthy. Also the AZ Grown logo is appearing more frequently on store shelves. AZ Grown floor decals were developed and printed. These will be distributed to local nurseries and grocery stores as an additional means of marketing.

FACEBOOK

At the beginning of Phase 2, Facebook likes totaled 798 unique individuals. For this grant we were to track the increase from Phase 1 to Phase 2. At the end of Phase 2, AZ Grown Facebook likes totaled 1632 unique individuals accounting for a 105% increase which surpasses the targeted goal of doubling those numbers.

Specific figures for the targeted dates of the beginning date of the ad campaign, the ending date of the ad campaign and 6 months after the campaign occurred correlate with the dates of November 19, 2012, January 13, 2013 and July 13, 2013. These figures are as follows: 844, 1204 and 1634.

WEBSITE

For this grant, website visitors will be tracked and compared for years 2012 to 2013. In October of 2012, visits totaled 200 per month. This was the beginning of the advertising campaign. At the end of the campaign, for the busiest month, January, visitors totaled nearly 1,000 per month. During this grant's cycle of October 2012 through June 2013, visits totaled 3,423 and unique visitors totaled 2,988.

Listed below is a comprehensive report and narrative from R & R Partners that details the goals and accomplishments of this program thus far:

ValueClick Ad Network:

The campaign performed above average with a click thru rate (CTR) of 0.07%. This is the amount of ads that received a click to go to the website.. This is above industry standard which is .04%-.05%.
The industry standard for ad networks ranges from 0.04% to 0.05%
The leaderboard ad (728x90) performed the best with a CTR of 0.09% and the 300x350 box ad and 160x600 tower ad tying for second 715 clicks / 1,016,655 impressions.1,016,655 is the amount of times a paid ad was posted to a webpage while someone was browsing. In easier terms, the amount of times an ad "could" be seen by someone. 715 represents the .07% of people who clicked on a paid digital ad.

AZ Local Farmers Markets and sister site North Scottsdale Farmers Market:

The campaign performed extremely well on both sites with a CTR of 1.03% and 1.41&, respectively
The industry standard for direct website placements is 0.05% to 0.07%
The leaderboard ad (728x90) performed the best with a CTR of 0.09% and the 300x350 box ad and 160 x 600 tower ad tying for second.

AZ Local Farmers Markets
17 clicks / 1,651 impressions
North Scottsdale Farmers Market
13 clicks / 920 impressions

Note that Edible Phoenix, Food Connect/Phx Market and Local First AZ do not accept Google DoubleClick DART tags and therefore cannot be tracked independently.

Facebook:

The campaign performed well and produced a CTR of 0.008%. We typically see FB campaigns with CTR's between 0.005% and 0.008%

490 actions which include:
153 page likes
Photo views
Page post likes

Link clicks
Page post shares
Comments on page posts

941 clicks / 12,122,127 impressions

Digital:

- Online ads
- LocalFirstAZ.com
- 468 x 60 ad
- 30,000 impressions per month
- Monthly from Oct – Dec
- $1,000 net one-year membership cost would have already been incurred in Phase I, so no additional cost would be incurred.
- Variety of Farmers market/local food sites. Sites include:
    - AZLocalFarmersMarket.com
    - 940 x 190 ad, 150 x 150 static ad
    - Four monthly mentions across social media
    - Platforms with a link and message
    - One monthly mention in weekly email
    - $750 net per year
    - EdiblePhoenix.com
    - 160 x 600 ad
    - $275 net per month
    - FoodConnect.org/PhxMarket
    - 200 x 200 ad (in sidebar above donate button)
    - $100 net per month
    - 16,400 impressions per month
    - Monthly from November through February (2.5 months)
    - Ad network
    - Woman-focused categories
    - 300 x 250, 728 x 90, 160 600 ads
    - 1,000,000 impressions per month
    - Monthly from November through February (2.5 months)
    - $3,080 net per month
    - CPM - $3.08
    - Social Ads – Facebook
    - Phoenix metro market
    - Targeting 1,060,000 woman 18+ (this demo outperforms W 25-54)
    - 110 X 80 static ad with text
    - Estimated 9,500,000 impressions per month
    - Monthly from Oct 15th through Dec (2.5 months)
    - $1,500 net per month
    - CPM - $0.16

Out-of-Home

- Digital billboards
- Clear Channel Outdoor
- Phoenix metro area
- .08 spots rotating every .64
- 14 freeway boards across the Phoenix area
- Estimated 5,282,874 impressions per week
- Weekly from Nov 19 through Jan 13 (8 weeks)
- $24,500 net per 4 weeks
- CPM - $4.64

- Total Estimated impressions – 31,603,874

Beneficiaries

- Western Growers – a continuing tool for growers to connect with consumers.
- Arizona Nursery Association – continued appeal to budget conscious consumers who want locally grown healthy plants.
- Arizona Department of Agriculture – Keeping the Arizona Grown logo out in the public's eye brings a greater awareness of the need to purchase locally grown products.
- Consumers – Ability to purchase locally grown produce and plants.
- Although a specific number of growers who benefited from this project cannot be determined, the Arizona Nursery Association has over 60 growers in the state and the increased demand for locally grown plant material by retailers benefits all growers and retailers. Western Growers represents an estimated 120 produce growers in Arizona and again, the increase in demand for locally grown produce by consumers will benefit the retailers as well as the growers.

Lessons Learned

Continued interaction with retail nurseries, farms restaurants, Farmer's Market's, etc. to send Arizona Grown their social media relevant news to continue to keep the Facebook page and website fresh and appealing. Phase II has focused primarily on a large media campaign with purchased media to further educate and engage the public on where and why to buy locally grown produce and nursery plants. The goal of this media has been to send consumers to the newly developed AZ Grown website and Facebook page where the information to influence the decision is located. We have determined, based on the data supplied by R & R Partners, that the public relation efforts, additional social media tactics, contests and points of purchase tactics at select retailers has enhanced the goal of increasing sales of AZ Grown produce and plants.

Contact Persons

Deborah Atkinson
602-542-3579
datkinson@azda.gov

Additional Information

- www.azda.gov
- www.plant-something.org/home
- www.wga.com

Plant Something Campaign - Public Outreach II

Activities Performed

First Quarter (October 2013 – December 2013) Activities:

- Expanding state partners: Made presentations at Western Region meeting, conference call with New York, made calls to get Plant Something on national agendas.
- Marketing within AZ: worked and sponsored GoGreen conference. Distributed materials to over 500 attendees. Was the guest host for Rosie on the House local radio

show promoting planting and the website. Distributed t-shirts at our annual dinner to college students to promote planting. Filmed local TV show on Channel 3 promoting plant something. Gave a prize for a water use it wisely planting photo contest.

- Upkeep on promotion: reported to the ANA Board on progress and future projects, worked with Park & Co to make revisions to website.
- New areas: worked with Bob Lovejoy to inquire about plant something container wraps and plans are in the works for truck wrap options to act as mobile billboards for plant something.

Second Quarter (January 2014 – March 2014) Activities:

- Committee met to decide on what promotion activities they would do for spring planting for the Plant Something campaign.
- After committee meeting, placed all advertising including radio, print and digital billboards with a goal to increase sales of ornamental plants in the spring.
- Worked with agency to post Facebook postings for spring to encourage consumers to plant something.
- Ordered plant something large stakes and delivered to retail nurseries who needed them in order to promote the plant something campaign at their stores to work on brand recognition of the campaign.
- Co-Sponsored a booth and bags at the Maricopa County Home & Garden Show and the Southern Arizona Home Builder's Show to reach consumers with the Plant Something print items which encourage them to make landscape purchases.
- Attended The Next Level conference in New Orleans with over 500 national attendees to promote the Plant Something campaign to the retail nursery attendees to broaden the scope of the campaign and in-turn, increase recognition which should increase the sales of ornamental nursery crops.

Third Quarter (March 2014 – June 2014) Activities:

- Attended the Nursery and Landscape Association Executives conference in Savannah, GA to promote the Plant Something campaign to other states and their consumers to increase consumption of plants across the US.
- Gave Plant Something presentations to the ANA Board at our regular meetings and at our Long Range Planning session. This lead to the generation of new ideas to further the campaign.
- Promoted Plant Something to consumers through Arbor Day events and radio interview.
- Several telephone calls, emails, etc. with retail nurseries and other states to promote Plant Something.
- Worked with committee to place media buys and other promotional decisions.

Fourth Quarter (July 2014 – September 2014) Activities:

- Attended the national nursery meeting, Cultivate, to promote the Plant Something campaign to a national audience.
- Attended an eastern region meeting to expose 7 states to the Plant Something promotion and enlist their support.

- Gave a board report for the ANA Board about the status of the Plant Something campaign and our consumer promotional efforts.
- Continued to field calls, emails, and work with partners to promote the Plant Something message and campaign
- All Plant Something advertising and marketing is directed at consumers to educate them about the reasons to select a purchase of plants and trees as opposed to other options for home improvement. Since all advertising is directed at ornamental landscape plants, and ornamental nursery stock are specialty crops, all advertising and marketing is solely focused on these.
- All projects within the grant have worked toward the goal for which the grant was received are is two-fold: 1) make the Plant Something campaign national and 2) promote the Plant Something message to the general public in Arizona. To date 7 additional states have adopted the Plant Something campaign.

Problems and Delays
There have been no problems or delays to date.

Future Project Plans
Things are going well and we anticipate the tree videos being finished and the consumer research. Nothing will occur next quarter except working on final report.

Funding Expended To Date
A total of $73,980.67 has been expended as of September 30, 2014.

Dredging Influences on Canal Water Quality
Activities Performed
During each quarter, progress towards addressing each of the three Outcomes of the proposal will be reported.

Outcome 1. Establishing a baseline of dredging effects on irrigation water quality**,** to be realized by collecting quantitative data on the contamination of fecal indicator bacteria during and after canal maintenance over two growing seasons.

First Quarter (Oct – Dec 2013):

- During this quarter, Victoria (Tori) Obergh, a full-time graduate student, continued her work on the project, and the PIs continued to mentor her in field sampling and laboratory protocols. In addition, a University of Arizona undergraduate student, Emily Gudvangen, began to work on the project part-time (for more information, please see quarterly updates for Outcome 3). Activities also included purchasing of necessary supplies and confirmation of laboratory analyses for molecular confirmation of *Salmonella*.
- During this quarter, field sampling was performed in concurrence with canal maintenance in the Bard Irrigation District. Sampling occurred on December 1-3, 2013. This activity included the collection of an additional 49 water samples, bringing the total water samples collected to date to 353.

- Water samples were analyzed for physical parameters (temperature, turbidity, pH, conductivity) as well as select bacterial concentrations (total coliforms, *E. coli*).
- Sediment sampling continued during this quarter, with a total of 8 samples collected in December, bringing the total number of sediment samples collected to date to 24. DNA extraction has been performed on all 353 water samples and the 24 sediment samples. DNA is being stored in the laboratory at -80ºC until molecular analysis for the presence of *Salmonella*.
- Molecular *Salmonella* assays were developed and validated in the laboratory using pure culture *Salmonella* DNA.

Second Quarter (Jan – Mar 2014):

- During this quarter, Victoria (Tori) Obergh, a full-time graduate student, continued her work on the project, and the PIs continued to mentor her in developing laboratory protocols for molecular confirmation of *Salmonella*. In addition, a University of Arizona undergraduate student, Emily Gudvangen, continued her work on the project part-time.
- No field sampling occurred during this quarter. Canal maintenance is less active in Yuma and the Imperial Valley in the winter quarter, when leafy green production is in full operation. One canal maintenance event was scheduled by the irrigation district on March 6 and 7, but the graduate student's examination schedule precluded her travel to Yuma during those days. Sampling will occur during the next maintenance event, scheduled for April 22-24.
- Analysis of DNA extracted from each water sample began, with samples analyzed by PCR for the presence of *Salmonella* markers. To date, 23% of water samples (77 of 336 total) have been analyzed, and of these, 2.6% have shown the presence of *Salmonella* in the water DNA. Of these same samples, only 1.3% indicated the presence of *Salmonella* using EPA-approved cultural methods. The samples that were *Salmonella*-positive using cultural methods were *Salmonella*-negative using molecular methods, and vice-versa.

Third Quarter (Apr – Jun 2014):

- During this quarter, Victoria (Tori) Obergh, a full-time graduate student, continued her work on the project, traveling to Yuma on April 21-23 to collect samples during a routine canal maintenance event. During the April sampling event, 86 samples of canal water and 12 samples of canal sediments were collected. All water samples were assayed for pH, conductivity, and temperature in the field before transport to the lab for microbial analysis (*E. coli* and *Salmonella*).
- In the laboratory a backlog of DNA extraction and PCR analysis for *Salmonella* was reduced using the assistance of undergraduate Emily Gudavangen (April through June) and graduate student Valerisa Joe (June). DNA extraction is now completed from all 419 water samples and 26 sediment samples collected to date.
- Of 419 water samples collected to date for this project, 46 (11.0%) have shown positive results for *Salmonella* through molecular analyses by PCR. Of 36 sediment samples collected to date for this project, 10 (27.8%) have shown positive results for *Salmonella* through molecular analyses by PCR.
- Laboratory work during this quarter also included development of cultural methods for *Salmonella.* The final sampling events of this study (July and August, 2014) will include

culturing of *Salmonella* for comparison with molecular results. This information, along with cultural results from the summer of 2013, will establish the validity of molecular results for identification of viable bacteria, information that will be of interest to growers who may rely on molecular methods for testing of their product.

Fourth Quarter (Jul – Sep 2014):

- During this quarter, Victoria (Tori) Obergh, a full-time graduate student, completed the field work portion of this her project, traveling to Yuma on July 30 – August 1 and August 19 – 21 to collect samples during routine canal maintenance events. During the earlier sampling event, 58 samples of canal water and 12 samples of canal sediments were collected, while the later sampling event resulted in collection of 49 samples of canal water and 12 samples of canal sediments. All water samples were assayed for pH, conductivity, and temperature in the field before transport to the lab for microbial analysis (*E. coli* and *Salmonella*).
- In the laboratory DNA extraction was completed on all water and sediment. DNA extraction is now completed from 526 water samples and 50 sediment samples collected on this project. Molecular analysis of DNA extracted from all water and sediment samples for presence of *Salmonella* is ongoing.
- Cultural methods developed earlier in the study are being used to compare molecular (PCR) results to counts of viable *Salmonella*. Initial results show limited agreement between molecular and cultural analyses. For example, in the summers of 2013 and 2014, 34 canal water samples were *Salmonella* positive using cultural analyses but all of these samples were negative by PCR. During the same time period, 46 water samples were positive for *Salmonella* markers by PCR yet only 6 of these (13%) were also positive using cultural methods. Quantitative PCR (qPCR), a method more sensitive than PCR, is being used on all cultural-positive samples to assess if the agreement between cultural and molecular analyses can be improved. This information will establish the validity of molecular results for identification of viable bacteria, information that will be of interest to growers who may rely on molecular methods for testing of their product.

Outcome 2. Communication to growers, to be realized by developing a detailed results document that will be distributed to Food Safety Managers and Produce Quality Assurance personnel.

First Quarter (Oct – Dec 2013):

- During this reporting period, co-PI Channah Rock traveled to Yuma on December 1-3rd to assist with water sample collection. During this time she also met with the Bard Irrigation District personnel as well as Food Safety coordinators to provide them with project updates and answer and questions related to the project thus far.
- In December 2013, Graduate Student Tori Obergh was featured in an article in Arizona Water Resource, a quarterly newsletter distributed to nearly 20,000 water professionals and other subscribers throughout Arizona and beyond. The article described Tori's research project and the objectives of her work. The newsletter can be downloaded here, with the article on Page 9:

https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/AWR%20Winter%202014%2001-07-14.pdf

Second Quarter (Jan – Mar 2014):

- Graduate student Tori Obergh presented, *"Canal Maintenance Effects on Irrigation Water Quality,"* a poster of research results to date at the University of Arizona Water Resources Research Center Annual Conference (see Photo 3, below). This conference was attended by 350 water professionals from across the Southwestern U.S.

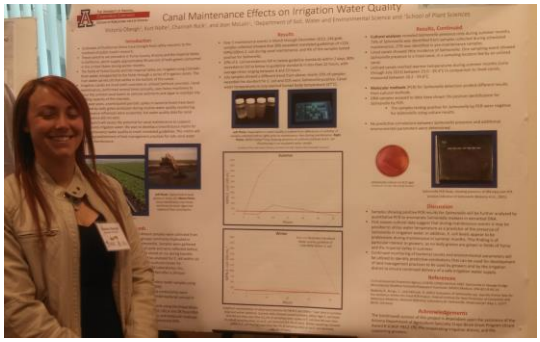

Photo 3. Graduate student Tori Obergh stands with her poster, "*Canal Maintenance Effects on Irrigation Water Quality*."

- Tori Obergh submitted an abstract to present research results at the SWESx Graduate Student Poster Exhibition, held at the University of Arizona to commemorate Earth Day.
- PI Jean McLain and Tori Obergh were scheduled to present results at a Yuma Fresh Produce Safety Meeting originally scheduled for March 12, 2014, but this meeting did not occur in March and instead was postponed to a later date.
- Co-PI Channah Rock traveled to Yuma, AZ on January 28 to meet with the irrigation district currently participating in the study. Irrigation district management provided Dr. Rock with a schedule for 2014 canal maintenance events, and in turn Dr. Rock provided an up-date on current research findings.

Third Quarter (Apr – Jun 2014):

- On Friday, April 11, graduate student Tori Obergh presented a poster, *"Canal Maintenance Effects on Irrigation Water Quality,"* showcasing the results of this work at a Student Showcase sponsored by the University of Arizona Department of Soil, Water and Environmental Science.
- On April 23-25, co-PI Dr. Channah Rock traveled to Davis, California to present research findings at the Western Irrigation Water Quality Conference. This conference was of particular interest due to the participation of the Food and Drug Administration and their draft recommendations on water quality sampling in the proposed FSMA rule. Dr. Rock shared research results and experiences working with Yuma growers and gained insight into questions that remain with respect to the FSMA recommendations.
- On June 24-26, Tori Obergh and Valerisa Joe attended the University of California Center for Produce Safety Conference held in Davis, California. This meeting, which was

attended by approximately 300 food safety professionals and researchers, provided Tori and Val with the opportunity to discuss their research results with the food safety community outside of Yuma. Please note that out-of-state travel to attend the California meeting was not charged to the SCBGP-FB12-19 grant, as this does not provide funding for travel beyond Arizona. This grant did, however, provide funding for shuttle transport to the Phoenix Airport.

Fourth Quarter (Jul – Sep 2014):

- On Thursday, August 21, project co-PI Channah Rock presented the interim results of this project at an Executive Food Safety Session hosted by the Yuma Safe Produce Council in Yuma, Arizona. In attendance at the meeting were members of the Arizona Leafy Green Marketing Agreement, as well as food safety experts who are members of the Safe Produce Council, Irrigation District Managers, University faculty, and specialists from the University of Arizona. Approximately 30 stakeholders were present at this meeting.
- Tori Obergh and Emily Gudvangen submitted an abstract to present research results at the 5th Annual University of Arizona Food Safety Consortium Meeting, to be held at the Westward Look Resort in Tucson, Arizona on October 10.
- Tori Obergh submitted an abstract to present research results at the Institute of the Environment Grad Blitz, to be held at the University of Arizona on November 13. The Blitz brings together graduate students working on environment-related research to showcase their research findings at an event attended by students, faculty, and University administrators.

Outcome 3. Development of human resources: this work will provide an opportunity for one University of Arizona graduate student for two years.
First Quarter (Oct – Dec 2013):

- Graduate Student Tori Obergh, who is pursuing a Master's Degree in the Department of Soil, Water and Environmental Science, continues to work on the project. In the fifth quarter, Tori became familiar enough with the objectives and methods used in the project that she began to work independently in the laboratory and required only minimal assistance with field sampling.
- In December 2013, University of Arizona undergraduate student Emily Gudvangen (Physiology Major) joined the project on a part time (~10 hours per week) basis. Although the addition of Emily was within the scope of the budget, an email was sent to Ashley Worthington and Lisa James to inform them of this addition on November 15, 2013. Emily will assist Tori in all laboratory analyses and will also assist with field sampling when her schedule allows.

Second Quarter (Jan – Mar 2014):

- Master's Student Tori Obergh continues to manage this project. In the sixth quarter, Tori validated the PCR assay used to identify *Salmonella* in extracted DNA and independently began testing all archived DNA samples. Tori performed an inventory of all field sampling supplies in preparation for the next canal sampling trip (April 2014). With

guidance from her advisor, Tori performed initial analyses of all data to date and designed and printed her first research poster.

- Undergraduate Emily Gudvangen continues to assist Tori in laboratory work, working 8-10 hours per week on this project. To date, Emily has been trained in gel electrophoresis of PCR product, sterile techniques used in processing microbial samples, and cleaning/sterilization of glassware.

Third Quarter (Apr – Jun 2014):

- Master's Student Tori Obergh continues to manage this project. In the seventh quarter, Tori completed the PCR testing of all archived DNA samples for the presence of *Salmonella*. With assistance from another graduate student (Valerisa Joe) who is experienced in cloning techniques and quantitative PCR, Tori developed and standardized a quantitative PCR assay used to enumerate *Salmonella* molecular markers in soil and water.
- Undergraduate Emily Gudvangen continues to assist Tori in laboratory work, working 8-10 hours per week on this project until early June, when she left for an 8-week summer course overseas. To date, Emily has been trained in gel electrophoresis of PCR product, sterile techniques used in processing microbial samples, and cleaning/sterilization of glassware.

Fourth Quarter (Jul – Sep 2014):

- Master's Student Tori Obergh continues to manage this project. In the eighth quarter, Tori standardized all methods for cultural analysis of *Salmonella*, organized and supervised all field collections, and completed laboratory molecular analyses. In addition, Tori is working with project PI to analyze all data and perform statistical calculations in preparation for the final reporting of this work.
- Also during this quarter, undergraduate Emily Gudvangen assisted Tori in laboratory and field work, working an average of 20 hours per week on this project. To date, Emily has become proficient in PCR, gel electrophoresis, DNA extraction, and cultural analysis of samples for quantification of *E. coli*, to the extent that she performs all of these without direct supervision.

Problems and Delays

First Quarter (Oct – Dec 2013):

- No problems or delays are anticipated at this time.

Second Quarter (Jan – Mar 2014):

- No problems or delays are anticipated at this time.

Third Quarter (Apr – Jun 2014):

- Not a problem or a delay, but we anticipate the likelihood of shifting some amount of the remaining salary funding to supplies, as the costs of additional supplies to complete the remainder of laboratory work may be substantial. If a need for shifting funds arises, we will notify the Arizona Department of Agriculture prior to taking any action.

Fourth Quarter (Jul – Sep 2014):

- On July 25, a critical piece of laboratory equipment, the thermocycler used to perform all PCR reactions for this study, was permanently damaged. The PIs were given written permission (by email) to utilize project funds to purchase a new thermocycler ($2,335.00), which arrived in the laboratory on August 8.
- Due to the replacement of laboratory equipment and larger number of samples collected than originally proposed, funding for the Supplies has been overspent. The PIs of this project will contact the Arizona Department of Agriculture regarding shifting of available funds from Personnel and Travel into Supplies.

Future Project Plans

Activities planned to complete this project include completion of the molecular analysis of all canal water and sediment samples, data analysis, and completion of the final report.

- Quantitative PCR to enumerate *Salmonella* will be completed on all samples that have shown positive results for *Salmonella* by PCR. These results will be compared to cultural *Salmonella* results to compare accuracy of molecular vs. cultural methods.
- Tori Obergh and Emily Gudvangen will present results of this work at events in October and November (see Outcome 2, above).
- The project team (Jean McLain, Channah Rock, Kurt Nolte, Tori Obergh) will present final results to a group of food safety and irrigation district professionals. The venue of this presentation is yet to be determined, but the monthly meeting of the Yuma Safe Produce Council in Yuma, Arizona would be an appropriate target.

Funding Expended To Date

A total of $67,478.61 has been expended as of September 30, 2014.

Efficient Sprinkler Fertigation for Vegetables

This project was completed on September 30, 2014

Project Summary

1.1 Project background and summary of results

Vegetable production in the Lower Colorado River Region (LCRR) is a multi-billion dollar business. The soils used for vegetable production range from loamy sand to silty clay with production generally skewed toward the heavier textured soils. Furrow irrigation was used as the primary irrigation method for row crops, including vegetables, in the LCRR. Recently there has been an expansion in season-long use of sprinkler systems for vegetable production, with the aim of increasing irrigation efficiency. The application of water soluble nitrogen fertilizers, such as nitrates, mixed with irrigation (fertigation) is widely practiced in the LRRC in the context of sprinkler irrigation of vegetable crops. Nitrogen fertilizer recommendations for leafy cool season vegetables range from 150 to 250 kg N/ha depending on crop, soil, and weather conditions. For leafy vegetables produced under season-long sprinkler systems 60 to 80% of the N is applied in season through the irrigation system. The sources of N fertilizer in season-long sprinkler systems are typically UAN32 and AN20.

Compared to conventional fertilizer application methods, fertigation presents a number of potential advantages. It allows a more precise matching of crop available soil nitrogen content with crop nitrogen needs (Muirhead et al., 1984, Burt et al., 1998). In addition, reduced soil compaction, crop damage, and energy and labor costs are also cited as some of the benefits of fertigation (Burt et al., 1998; Fares and Abbas, 2009).

The performance of a field-scale fertigation event can be evaluated in terms of fertigation uniformity, efficiency, and adequacy (Zerihun et al., 2003). A complete evaluation of field-scale nitrogen fertigation performance over a fertigation event, cycle, or a season requires quantification of the various nitrogen input and output fluxes and change in storage, as affected by solute transport processes as well as a host of coupled physical and biochemical mechanisms in the effective crop root depth (e.g., Burt et al., 1998). The scale of field work required as well as the equipment and data processing and analyses needs of such a study constitute a major challenge that cannot be undertaken as part of the current study. Therefore, the goal here is limited to conducting field-scale nitrogen fertigation uniformity evaluations under solid-set sprinkler systems.

In the context of solid-set sprinkler systems, the practical significance of uniformity as a performance criterion stems from the fact that high uniformity is a requirement for the attainment of adequate and efficient fertigation (Zerihun and Sanchez, 2014; Burt et al., 1998). Moreover, uniformity indices are generally considered as indirect indicators of the potential for soil water/nutrient deficit, deep percolation, nutrient leaching, and groundwater pollution from fertigation.

Considering that fertigation is a process that applies irrigation water and soluble fertilizer to croplands, it is evident that fertigation uniformity evaluation requires the use of a composite index consisting of irrigation and fertilizer application uniformity indicators. Observing that fertilizer application uniformity levels cannot be automatically deduced from irrigation uniformity, in this study irrigation and fertilizer application uniformity indices are treated as two distinct, nonetheless, related and equally important aspects of field-scale sprinkler fertigation uniformity.

Results of previous irrigation uniformity evaluations in the Yuma Valley Irrigation Districts of the LCRR (Zerihun et al., 2011; Zerihun and Sanchez, 2012) suggest that typical field-wide irrigation application uniformities in the area could be high. Average Christiansen's uniformity coefficient (UCC) and low-quarter distribution uniformity (DU_{lq}) of about 0.85 and 0.75, respectively, can be achieved, provided the systems are operated under ambient weather conditions conducive for attaining high uniformity. The results of these studies have also shown that, even when field-scale irrigation uniformities are high, significant variations in test-plot scale uniformity levels exist within a field. This highlights the significance, as related to field-scale irrigation performance, of proper setting and routine maintenance and replacement of system components or lack thereof. These results also underline the need for field-wide irrigation uniformity evaluations to be conducted based on more than one plot-scale tests, suitably distributed through the irrigated field.

Modeling studies and measured field-scale hydraulic data (Zerihun et al., 2011; Zerihun and Sanchez, 2012) show that typical sprinkler systems in the Yuma Valley Irrigation Districts are designed for high irrigation uniformity. In addition, results of the modeling studies showed that the hydraulic design of sprinkler systems in the area is robust: i.e., system hydraulics exhibit low sensitivity to appreciable changes in pipe hydraulic resistance and field slopes. The implication is that field-scale irrigation uniformity should be virtually insensitive to variations in these factors within reasonable ranges, provided the system is well maintained and operated in accordance with the operational and environmental requirements considered conducive for the attainment of high irrigation uniformity.

Considering that nitrogen fertigation is widely and routinely practiced in sold-set sprinkler systems in the Yuma Valley Irrigation Districts, the need for field studies aimed at evaluating the ranges of variations and typical averages of field-scale application uniformity of nitrogen fertilizers in the area is evident. Hence, the study reported here can be viewed as an initial step toward such a goal.

The study proposes a methodology, consisting of field and analytical procedures, for field-scale fertigation uniformity evaluation of solid set sprinkler systems. It defines fertilizer application rate as the most appropriate variable in terms of which field-scale fertilizer application uniformity can be expressed. It also presents the equations for the uniformity indices, cast in their general form, and describes their mathematical properties along with the practical fertigation management implications of those properties.

The results of a fertigation study by Zerihun and Sanchez (2014) shows the spatial variability of nitrogen application rate is a function of the interactive effects of the spatial trends in the irrigation and concentration data sets. Practically significant additional results of this study are summarized in this report. In addition, their application in the analyses of the relationships between the uniformities and the spatial variability patterns of measured irrigation depth, nitrogen concentration, and the resultant application rate data sets are highlighted.
As part of the current study, two sets of field-scale fertigation uniformity evaluations were conducted in growers' fields in the Yuma Valley Irrigation Districts. The first set of field evaluations consists of four field tests performed in different growers' fields in the winter of 2013. These uniformity evaluations took place in fields cropped with vegetables and under season-long sprinkler irrigation. Nitrogen fertilizer was applied in the form of ammonium nitrate and urea solution. A second set of field evaluations, consisting of four fertigation tests, were conducted in the winter of 2014 in a grower's field cropped with spinach. The fertilizer used in these evaluations is ammonium nitrate.

The results of these studies largely confirm the observations of past studies that typical sprinkler system configurations in the Yuma area are such that high irrigation uniformity can be achieved, provided the systems are operated under conducive ambient weather conditions. On the other hand, the computed field-wide nitrogen application rate uniformity levels for these fields are low. The field-scale average fertilizer application rate *UCC,* vary in the range 0.556 to 0.796, and DU_{lq} vary between a minimum of 0.465 and a maximum of 0.689. The overall field-scale average application rate *UCC* and DU_{lq}, calculated as the arithmetic mean of all the data sets, are 0.7 and 0.575, respectively. Computed field-wide nitrogen application rates vary between a

minimum of 0.5g/m^2 and a maximum of 2.8g/m^2, with an overall average of 1.8g/m^2. Considering an approximate required nitrogen application rate of 2.5g/m^2 per fertigation event, these application rates are considered low. However, crop available soil background nitrogen content is likely to be sufficiently high to mitigate the effects, of the apparent nitrogen deficit, on crop yield. Considering the limited scope of the study presented here, the results cannot be automatically generalized for sprinkler fertigation systems over the entire Yuma Valley Irrigation Districts. Nonetheless, the consistency of the results across different fields suggest that they may not be untypical either.

Additionally, in 2014 four test-plot scale fertigation field evaluations were performed in the Maricopa Agricultural Center of the University of Arizona. The main goal of these evaluations was to assess the effect of fertilizer application configurations (the timing and duration of fertilizer application compared to that of irrigation) on the spatial distribution of concentration. Results of the test-plot scale field evaluations show that fertigation uniformity levels for all the test-plots are high, with *UCC* and DU_{lq} values that are either sufficiently close to, or exceeding, 0.85 and 0.75, respectively. Outcomes of this study also suggest that in a sprinkler system in which the effect of solute transport processes on the spatial distribution of concentration is limited, fertilizer can be applied with high uniformity irrespective of the fertilizer application configuration, provided the solute concentration at the system inlet is kept fairly constant for the duration of fertilizer application and that the uniformity of the underlying irrigation event is high.

The study highlighted that fertilizer application rate uniformity is a function of factors and processes affecting the spatial distribution of irrigation and concentration over an irrigated field. The variables on which irrigation uniformity depends are reasonably well established and are to a significant degree controllable (e.g., Christiansen, 1942; Livingston et al., 1985; Fischer and Wallender, 1988; Keller and Bliesner, 1990; Nderitu and Hills, 1993; Martin et al., 2007; Zerihun et al, 2012). On the other hand, the same cannot be said about the variables and mechanisms affecting the field-scale spatial distribution of, sprinkler applied, nitrogen concentration. However, based on the general theory of solute transport in hydraulic networks (e.g., Tzatchkov et al., 2002; Taylor, 1954) a concise description of the factors and mechanisms affecting the uniformity of the spatial distribution of solute concentration in field-scale sprinkler systems is presented and pertinent future research need in the area is highlighted.

Overall the results of the study underline the fact that in sprinkler systems that are routinely used for fertigation purposes (such as those in the Yuma Valley Irrigation Districts of the LCRR), the design and management of the irrigation system cannot be decoupled from that of the fertilizer application subsystem. A detailed list of specific recommendations along with insights gained and lessons learned in the course of this study are outlined in sections 3.4 and 5 of the report.

The report consists of six chapters. Chapter 1 presents project summary. Chapter 2 lists the activities performed as part of the study reported here and presents a detailed description of the field uniformity evaluation methodology, uniformity equations and their properties along with field evaluation results. Chapter 3 presents goals and outcomes of the study, including specific recommendations for future studies. Chapter 4 identifies beneficiaries of the project. Chapter 5 presents a list of insights gained and lessons learned in the course of this study.

1.2 Project objectives

The specific objectives of the study reported here are: (1) To develop a field and data processing methodology for field-scale fertigation uniformity evaluations in fields under season-long (solid-set) sprinkler irrigation in the Lower Colorado River Region (LCRR), (2) To conduct limited fertigation uniformity evaluations in growers' fields in the Yuma Valley Irrigation Districts of the LCRR, and (3) To develop recommendations for further studies.

Project approach

Note: Please refer to **Appendix E** for all tables and figures referenced in this section.

This section of the report lists the activities conducted as part of the current study. The tasks accomplished include nitrogen fertigation evaluation of vegetable cropped fields under season-long sprinkler irrigation in the Yuma Valley Irrigation Districts of the LCRR; laboratory analysis of irrigation water samples to determine the concentration of applied nitrogen fertilizer; processing and analysis of field and laboratory data; and writing and submission of final report. A description of the field and laboratory methods along with the analytical tools and techniques used in the study is also provided here. The section concludes with a presentation and discussion of results obtained.

2.1 Activities

2.1.1 Field evaluations

Field-scale evaluations: Two sets of field-scale fertigation uniformity evaluations were conducted as part of the current study. During the winter season of 2013 four nitrogen fertigation field evaluations, each in a different grower's field, were conducted in the Yuma Valley Irrigation Districts. A second set, consisting of four fertigation tests, were conducted in the winter of 2014 in a grower's field, cropped with spinach and, under season-long sprinkler irrigation. Nitrogen fertilizer was applied in the form of either UAN32 or AN20 at rates typically used by growers, which range from 5 to 15 gallons of fertilizer material depending on projected nitrogen requirement of the crop.

The field-scale spatial distribution of irrigation and fertilizer application rates are functions of the interactive effects of a complex set of factors, which include: sprinkler system hydraulics, as encapsulated by sprinkler pressure heads/discharge variations, ambient weather condition (particularly wind velocity), sprinkler system operational practices (including maintenance and setting of system components), the fertilizer application configurations at the system inlet, and solute mixing due to transport processes during solute conveyance from point of injection to sprinkler nozzles.

Typically, the spatial distribution of irrigation water and fertilizer applied through fertigation exhibits significant variability over an irrigated field. Hence, a realistic characterization of field-scale fertigation uniformity requires sampling the fertigation variability at more than one point in the field. The basic field-scale sprinkler fertigation uniformity sampling unit is a test-plot. During each of the field-scale fertigation uniformity evaluations, conducted as part of the current study, three test-plots were installed over the irrigated field (section 2.4.1). The test-plots were arranged along the field diagonal from the system inlet, each representing approximately equal

fractions of the total area of the irrigated field (section 2.3). The test-plots, each measuring 9.14m×10.67m (30.0ft×35.0ft), were set in between two adjacent laterals and were subdivided into grid squares of 1.524m×1.524m (5.0ft×5.0ft). In each grid square a rain gage is installed. Irrigation precipitation depths, collected in the rain gages, were recorded immediately following a fertigation event and are used subsequently to compute test-plot scale and field-scale uniformity. Water samples were collected in appropriately labeled vials from each of the rain gages, which were then sealed and frozen within two hours following sampling, in order to preserve the integrity of sample constituents (i.e., mineral nitrogen forms) until laboratory analysis. Measured nitrogen concentration and corresponding depths will be used to determine nitrogen application uniformity.

Test-plot scale evaluations: In the winter of 2014, four test-plot scale uniformity evaluations were performed in the research farm of the Maricopa Agricultural Center (MAC) of the University of Arizona (UA). In these field evaluations, the bromide ion was applied (in the form of potassium bromide solution) in four different fertilizer application configurations (section 2.4.1). Bromide is used here as a tracer to simulate the spatial distribution of nitrate-nitrogen and the target bromide application rate was the typical nitrogen application rate in the area, $5g/m^2$. The goal of this field evaluation was to assess the effect of different bromide application configurations on the spatial distribution of bromide. The size of the test-plots used in this study vary from 9.14m×9.14m (30.0ft×30.0ft) to 9.14m×10.21m (30.0ft×33.5ft).

2.1.2. Laboratory analysis

Ammonium- and nitrate-nitrogen and bromide contents of irrigation water were determined colorimetrically using an Astoria 2 with methods specified by the manufacturer. The methods for nitrate- and ammonium-nitrogen concentration determination are based on those reported by (Mulvaey 1996). Bromide concentration as was measured based the method developed by Zitomer and Lambert (1963). Urea-nitrogen was determined with a micro-plate method as described by Greenan et al. (1995).

2.1.3. Data processing and analysis

Fertigation is a process that applies both irrigation water and soluble fertilizers to crops. During fertigation, solute concentration may vary spatially through a sprinkler hydraulic network and temporally during the course of a fertigation event. Hence, fertilizer application uniformity cannot be automatically deduced from irrigation uniformity. The implication is that fertigation uniformity is a composite parameter consisting of irrigation and fertilizer application uniformity indicators. Accordingly, throughout this manuscript irrigation and fertilizer application uniformity indices are treated as two distinct, nonetheless, related and equally important aspects of field-scale sprinkler fertigation uniformity.

Irrigation depths collected in the rain gages within a test-plot are used to compute test-plot scale average, maximum, and minimum depths along with irrigation uniformity indices. The indices used, in the current study, to evaluate test-plot scale irrigation uniformity consists of the Christiansen's uniformity coefficient and the low-quarter distribution uniformity (Keller and Bliesner, 1990; Martin et al., 2007) and are described in Section 2.3.3. Computed test-plot scale depths and uniformity indices are scaled-up to field level through averaging (Zerihun et al., 2011).

The spatial distribution uniformity of nitrogen fertilizer applied through fertigation is defined here in terms of the nitrogen application rate (section 2.3.2). However, the mass of nitrogen in the irrigation water cannot be measured directly, hence nitrogen application rate is determined here as a function of the measurable quantities of irrigation depth and concentration. The computation of nitrogen application rates and uniformity is based on total elemental nitrogen. Considering that the nitrogen fertilizers applied in these studies consist of ammonium nitrate and urea, total nitrogen is given as the sum total of nitrate-, ammonium-, and urea-nitrogen. The concentration of nitrogen in the irrigation water, collected in each of the rain gages in a test-plot, is determined through laboratory analysis of water samples (section 2.1.2). The nitrogen fertilizer application rate in a grid square is then computed as the product of the precipitation depth in the rain gage and the nitrogen concentration in the rain gage water (section 2.3.3). Grid square nitrogen fertilizer application rates are used to compute test-plot scale maximum, minimum, and average nitrogen application rates along with the uniformity indices. Test-plot scale fertilizer application rate uniformity is evaluated in terms of the Chrstiansen's uniformity coefficient and the low-quarter distribution uniformity. Following the same approach as that used to compute irrigation uniformity, test-plot scale fertilizer application rate uniformity indices are then scaled-up to field-level through averaging.

2.1.4. Report writing

The last phase of the sprinkler fertigation project presented here consists of the writing and submission of the report. A summary of the contents of this report is provided in section 1.1.

2.2 Review

2.2.1. Introduction

The application of nitrogen fertilizers through fertigation presents a number of potential advantages compared to conventional methods. Fertigation allows a more precise matching of crop available soil nitrogen content with crop nitrogen needs (Muirhead et al., 1984, Burt et al., 1998), leading to increased plant nitrogen uptake and yield. Fertigation can also minimize nitrogen loss through gaseous emissions and leaching, resulting in increased opportunity for crop nitrogen recovery and diminished adverse environmental effects (Hanson, et al., 2014). Reduced soil compaction, crop damage, and energy and labor costs are some of the additional benefits of fertigation compared to conventional methods (Burt et al., 1998; Fares and Abbas, 2009). However, in any given application the realization of these potential advantages is predicated on the assumptions that: the scheduling of nitrogen fertigation and estimation of required application rates of nitrogen fertilizer matches well with crop needs. Furthermore, irrigation needs to be efficient, uniform, and adequate and the fertilizer application configuration should favor the deposition of applied nitrogen in the region of the soil profile from which maximum nitrogen recovery by plants takes place.

2.2.2. The scheduling and estimation of required application rates of nitrogen fertilizers

In principle, the practice of fertigation involves applying seasonal nitrogen fertilizer crop consumptive use needs in smaller doses spread over multiple fertigation cycles spanning the irrigation season. Hence, accurate estimation of crop nitrogen fertilizer requirements associated

with a set number of fertigation cycles, during the growing season of a crop, and synchronizing its application schedule with the irrigation schedule is key to achieving efficient fertigation.

A description of crop nitrogen fertilizer requirement proposed by Zerihun et al. (2003) for applications in surface irrigation methods can be used for sprinkler fertigation as well. Accordingly, crop nitrogen fertilizer requirement, in the context of a fertigation event (a fertigation cycle), can be defined as the quantity of nitrogen fertilizer that needs to be stored in the effective crop rooting depth to raise the existing soil mineral nitrogen content to a level that is within an agronomic optimum. An agronomic optimum is defined here as the soil mineral nitrogen content of the effective crop root depth that is required to ensure the minimum amount of plant nitrogen uptake, associated with maximum crop yield, for the duration of a fertigation cycle.

Evidently, the description of crop nitrogen fertilizer requirement given above reflects the net effect of the interaction between plant nitrogen uptake as well as solute transport processes and a host of soil physical and biochemical processes that adds mineral nitrogen to, or removes mineral nitrogen from, the plant available soil nitrogen pool of the effective crop rooting depth. Assuming the availability water and other essential plant nutrients do not impose a limiting condition, crop nitrogen fertilizer requirement can vary as a function of optimal crop nitrogen uptake for the fertigation cycle considered, nitrogen fertilizer sources used, soil type and its organic matter content, soil mineral nitrogen content, and ambient environmental factors (soil moisture content, pH of soil solution, and temperature).

For a given crop, soil, and environmental conditions crop nitrogen fertilizer requirements can be obtained from local agronomic recommendations. From the stand point of fertigation system operation, the objective of sprinkler nitrogen fertigation is to deliver a prescribed quantity of nitrogen fertilizer (nitrogen fertilizer requirement) to a site within the soil profile where it can be used by the crop with minimum loss in the delivery process. In principle, nitrogen fertilizer losses in a sprinkler fertigation event consists of ammonia volatilization during conveyance and from droplets during their passage between the sprinkler nozzles and the irrigated field surface, if ammonia producing nitrogen fertilizer is used. Considering the significance, to ammonia volatilization, of the exposure of irrigation water to a moving air current (wind) for appreciable time (e.g., Dunmead et al., 1982), it is likely that in a field-scale sprinkler system nitrogen loss through volatilization, during conveyance, could be considered minimal. This, however, needs to be verified through future field studies. Additional pathways for nitrogen fertilizer losses are associated with spray wind drift and leaching losses, the latter mainly in the form of nitrate and to some extent urea, if applicable. Typically, sprinkler systems are operated at irrigation application rates (irrigation depth per unit time) that do not exceed the steady state soil intake rate, in which case the nitrogen fertilizer losses through surface runoff can be considered negligible.

The preceding highlights that estimation of gross nitrogen fertilizer application rate associated with a fertigation cycle should take into account both conveyance and leaching losses. Given the gross nitrogen fertilizer application rate for a fertigation cycle, the fertigation schedule needs to be synchronized with the irrigation schedule in such a way that crop water and nitrogen nutrient stress is avoided or minimized, at least during the most critical crop growth stages.

2.2.3. Effect of irrigation performance on fertigation

Irrigation performance consists of uniformity, application efficiency, and adequacy indices. The practical significance of uniformity as an irrigation performance index stems from the fact that high irrigation uniformity is a requisite condition for achieving an efficient and at the same adequate sprinkler irrigation. As would be discussed subsequently efficient and adequate irrigation has favorable influences on various soil processes related to the transport and fate of nitrogen fertilizers.

Following infiltration of irrigation applied water and nitrogen fertilizer into the soil, soil water content at the time of fertigation and subsequently (which depends on the irrigation depths) is a key factor in the solute transport as well as other soil physical and biochemical processes that affect nitrogen fertilizer availability to crops, losses in the form of gaseous emissions, and leaching below the crop root zone. Inefficient irrigations, especially those with significant deep percolation, can lead to leaching of nitrates and urea below the crop root zone. It can also create anoxic conditions, favorable for denitrification, in the soil profile. On the other hand, efficient irrigation may minimize denitrification by maintaining well aerated soil profile. In addition, when environmental factors and availability of essential plant nutrients are not limiting, adequate and efficient irrigation may lead to vigorous crop growth, optimal plant nitrogen uptake, and hence optimal yield. The preceding highlights the fact that fertilizer application uniformity, efficiency, and adequacy in a fertigation cycle or over a season is closely related to the underlying irrigation performance (irrigation uniformity, efficiency, and adequacy).

2.2.4. Effect of fertilizer application configuration

The timing and duration fertilizer application, as related to the duration of irrigation, affect the subsurface distribution of nonsorbing nitrogen species, such as nitrate and to a lesser degree urea. This in turn has a significant effect on the potential availability to crops and susceptibility to leaching below the root zone of these fertilizers. However, the goal in the current study is limited to assessing the effect of solute application configurations at the sprinkler inlet (section 2.4.1) on the spatial distribution of the bromide ion.

2.3. Development of methodology

In this section field and analytical methods are proposed for the evaluation of field-wide irrigation and fertilizer application uniformity. The field and computational procedure for test-plot scale irrigation uniformity evaluation is reasonably well developed (Keller and Bliesner, 1990; Martin et al., 2007; Zerihun et al., 2011). However, the same cannot be said about fertilizer application uniformity through sprinkler fertigation. The basic field unit for solid set sprinkler irrigation uniformity evaluation is a test-plot. Zerihun et al. (2011) proposed a procedure in which multiple test-plots suitably distributed over the irrigated field can be used to sample the effects, on irrigation uniformity, of factors related to system hydraulics as well as system component maintenance and settings. In the study reported here this approach is adopted, with appropriate modifications, for use in field-scale irrigation and fertilizer application uniformity evaluation.

2.3.1. Field evaluation of irrigation application uniformity

Factors affecting uniformity, their field-wide variability, and the need for sampling: The basic field unit for solid set sprinkler irrigation system uniformity evaluation is a test-plot. Typically, a uniformity evaluation test-plot consists of a rectangular area circumscribed by four adjacent sprinklers, with dimensions equal to the sprinkler spacing along laterals and the lateral spacing. A test-plot is further discretized into grid squares of a suitably selected dimension. During irrigation uniformity evaluation rain gages are placed at about the center of each grid square and the irrigation system is operated for a duration equal to the regular irrigation application time practiced by growers. Immediately following irrigation, the depth collected in each rain gage is recorded. Assuming depths collected in each rain gage within a test-plot represent the average precipitation rate over the corresponding grid square area, they can then be used to compute test-plot scale irrigation uniformity with a suitable set of uniformity indices (Section 2.3.3).

Test-plot scale irrigation uniformity data may not be representative of the field-scale spatial distribution of irrigation depths (e.g., Zerihun et al., 2011; Zerihun and Sanchez; 2012). Factors that affect the spatial distribution of irrigation at a field-scale include sprinkler pressure head (discharge) variation due to energy loss and field slopes as well as variation in sprinkler hydraulic characteristics due to nonuniform wear and tear and/or inadvertent mixing of different sprinklers. In addition, the proper setting and maintenance of system components or lack thereof (including vertical setting of sprinkler riser pipes, routine maintenance such as regular cleaning of sprinkler nozzles, and detection and maintenance of leakage) are important determinants of precipitation patterns about sprinklers. Although the microclimate (especially wind velocity) in close vicinity of the sprinkler field can have a significant effect on sprinkler irrigation uniformity, it can be assumed that its effect is uniform over the field.

The preceding discussion suggests that in order to take into account the effects of the factors listed above on field-scale irrigation depth and uniformity, test-plot scale evaluations may need to be conducted at more than one locations in the field. In principle the most accurate field evaluation may require conducting distribution uniformity tests over the entire irrigated field, nonetheless, such an approach is impractical if the grid squares are to be of sufficiently high spatial resolution. An approximation of the field-scale irrigation uniformity can be obtained, with reduced cost and effort, based on a small number of plot-scale evaluations distributed through the field. In which case, each of the uniformity evaluation test-plots would be used as field-wide sampling points of the spatial variability in the applied irrigation depths. The question then is how to determine the number and location of the uniformity evaluation test-plots over the irrigated field.

The relative significance of most of the factors that affect irrigation uniformity and their spatial distribution over the irrigated field is generally not predictable priori to field evaluations. On the other hand, the effect of system hydraulics on irrigation uniformity in a field-scale solid set sprinkler system is predictable, provided certain basic assumptions as regards system hydraulic, geometric, and topographic characteristics are met. This suggests that the known pattern in sprinkler pressure head (discharge) distribution, as affected by system hydraulics, can be used to advantage to develop a preliminary layout of the distribution of test-plots in the irrigated field. Although such a layout is specifically designed to capture the effects of system hydraulics on uniformity, it may also account for some of the effects of the other inherently probabilistic factors.

In the winter of 2011, a field study was conducted in a grower's farm in the Yuma Valley Irrigation Districts, with support from the Arizona Specialty Crops Council, to evaluate the practical utility of this observation in designing the layout of test-plots over an irrigated field for field-scale irrigation uniformity evaluation. A detailed discussion of the methodology and results is presented by Zerihun et al., (2011), however, subsequent section presents a concise discussion of the results.

A layout of uniformity evaluation test-plots based on consideration of system hydraulic effects: Considering a well maintained and properly set system installed on a nearly level field surface with spatially invariant laterals/mainline diameters and sprinkler characteristics (common in the Yuma Valley Irrigation Districts), the field-wide spatial distribution of sprinkler pressure head (and hence discharge) can be shown to be a decreasing nonlinear convex function of distance from the system inlet. This suggests that in order to sample the effects of sprinkler pressure head variability on field-scale irrigation uniformity effectively, the spatial distribution of the test-plots may need to be skewed towards the inlet of the sprinkler system, where much of the variability is concentrated. Accordingly, in the study referenced above, the irrigated field was subdivided into nine field blocks of varying sizes, with the smaller field blocks set close to the system inlet and the larger field blocks at the distal end of the field (Figure 1a). A uniformity evaluation test-plot is placed close to the center of each field block. The assumption here is that each field block is sufficiently small for pressure head variability to be negligible within the block, hence the associated test-plot scale uniformity can be considered representative of the field block. Test-plot scale uniformity can be quantified in terms of standard indices (section 2.3.3). The test-plot scale uniformity indices and the minimum, maximum, and average depths can then be scaled-up to field-level through averaging. During the field tests irrigation uniformity data was collected in the test-plots. In addition, hydraulic data consisting of measured pressure heads along laterals adjacent to the test-plots were obtained.

Irrigation depth data collected within the same field during three comparable irrigation events (considering hydraulic and ambient weather condition) showed significant variations in test-plot scale *UCC (*ranging between 0.77 and 0.87) and DU_{lq} (varying between 0.69 and 0.82) can exist in a well maintained and operated sprinkler system (Zerihun et al., 2011). Subsequent field uniformity evaluations conducted by the authors in the Yuma Valley Irrigation Districts, including those conducted as part of the current study, showed that even larger irrigation uniformity variations exist within a field. On the other hand, hydraulic measurements and simulation studies showed that the effect of system hydraulics on the observed variability of test-plot scale uniformity is negligible, mainly due to the relatively large pipe diameters and nearly level land slopes common in the area. Hence, some combination of such factors as variations in sprinkler characteristics due to nonuniform wear and tear, inadvertent mixing of sprinklers with different hydraulic characteristics, and issues related to routine sprinkler system component maintenance and settings could be the main contributory factors to the observed in-field variability of irrigation uniformity. Considering that the effect of wind is supposed to be uniform over an irrigated field, it cannot explain the observed variability in test-plot scale uniformities within a field.

The inferences that stem from the preceding discussion is that a realistic evaluation of field-scale sprinkler irrigation system uniformity should preferably be based on more than one test-plot scale measurements, each used as a sampling spot of the spatial variability of irrigation in the field. However, the actual number, and placement within the field, of each uniformity evaluation plot need to be left to the discretion of the irrigator conducting the evaluation. Any information on maintenance issues or the spatial distribution of sprinklers with differing hydraulic characteristics can be used to advantage in determining the placement of the test-plots in the field. Considering a scenario consisting of carefully laid out test-plots, the larger the number of the test-plots in the field, the more accurate the field-scale uniformity estimates should be. On the other hand, the time and effort needed to perform such field tests increases with the number of test-plots in a field. Hence, in subsequent field studies, conducted by the authors between 2012-2014, typically three uniformity evaluation test-plots were used in an irrigated field. The test-plots were spatially distributed along the main diagonal of the field from the system inlet and were spaced in such a way that each represents field blocks of equal size.

2.3.2 Field evaluation of fertilizer application uniformity

Irrigation uniformity evaluation test-plots can be used as the basic field (sampling) units for evaluating the spatial uniformity of any farm input applied with irrigation, including nitrogen fertilizer. Hence, in the study presented here the irrigation evaluation test-plots are treated as the basic field sampling units for the evaluation of field-scale fertigation (irrigation and fertilizer application) uniformity.

Typically, agricultural inputs for crop production, including irrigation and fertilizers, are expressed in terms of application rates: volume of water or mass of fertilizer per unit area of cropped land. Hence, sprinkler irrigation uniformity is often expressed as a function of irrigation depths, although it should not necessarily be expressed as such. Similarly nitrogen fertilizer application uniformity, with sprinklers, can be defined in terms of the spatial distribution of the fertilizer mass per unit area of field (e.g., gram per square meter). Observing that the mass of solutes in irrigation water cannot be measured directly, nitrogen application rates are computed on the basis of the measureable quantities of concentration and irrigation depth.

As pointed out in a preceding section, precipitation depths collected in the rain gages are considered as representative averages of the irrigation depths in the respective grid squares. Furthermore, the average nitrogen application rate for a grid square can be computed as a function of depth collected in the rain gage and nitrogen concentration in the rain gage water. Given the nitrogen application rates associated with each grid square in a test-plot, the spatial distribution uniformity of applied nitrogen for the test-plot can then be computed with suitable equations (section 2.3.3). Note that nitrogen concentration and application rate can conveniently expressed in terms of elemental nitrogen, especially when different sources of nitrogen are used.

Test-plot scale fertilizer application uniformity may not be representative of field-scale uniformity. The spatial distribution of nitrogen application rate is a function of factors that affect irrigation uniformity and the time and spatial evolution of fertilizer concentration through the sprinkler hydraulic network. A description of the factors that affect irrigation uniformity is presented in a preceding section. In principle, the time and spatial variation of nitrogen fertilizer concentration within a field-scale sprinkler pipe network can be a function of the fertilizer

application configuration at the system inlet, solute transport processes consisting of advection and hydrodynamic dispersion, and wind effects on dilution patterns.

The preceding highlights the need to use more than one test-plot to effectively sample the spatial variability of fertilizer application rates at a field-scale and to derive a realistic estimate of the field-scale fertigation uniformity. As would be shown subsequently (section 2.3.3), test-plot scale fertilizer application rates and corresponding uniformity indices are computed as a function of measured water depths and concentrations. Following the approach described above, the test-plot scale maximum, minimum, and average application rates and uniformity indices are then scaled up to field level through averaging.

2.3.3. Fertigation (irrigation and fertilizer application) uniformity equations and their properties

Test-plot scale uniformity

Uniformity is a measure of the variability inherent in a data set. Often variability in a data is expressed with reference to the average. In this study two standard indices that are designed to measure different aspects of data variability, with respect to the mean value, are used to quantify fertigation uniformity: Christiansen's uniformity coefficient, *UCC [-],* and the low-quarter distribution uniformity, DU_{lq} *[-]*. Although these indices are customarily used to evaluate irrigation uniformity (Martin et al., 2007; Burt et al., 1997; Keller and Bliesner, 1990), there is no limitation as regards their application to quantifying the spatial variability of any agricultural input applied with irrigation water.

For generality of notion, here a uniformity evaluation test-plot is simply considered as a well-defined area in a sprinkler irrigated field, which in turn is subdivided into smaller elemental areas of arbitrary shape and size, each of which are associated with a rain gage. Furthermore, it is assumed that the ratio of the catchment area of the rain gage to the corresponding elemental area should be sufficiently large for the measured application rate to be considered a representative average of the associated elemental area. In what follows forms of the *UCC* and DU_{lq} equations applicable to the conditions described above are presented. The equations will then be reduced to their commonly used forms.

Christiansen's uniformity coefficient

The equation for test-plot scale Christiansen's uniformity coefficient, *UCC [-]*, of a farm input applied with irrigation water can be given as:

$$UCC = 1.0 - \frac{\dfrac{\sum_{k=1}^{K} a_k \left| x_k - x_{av} \right|}{\sum_{k=1}^{K} a_k}}{x_{av}} \qquad (1)$$

where k = rain gage, K = the total number of rain gages in a test-plot, x_k = application rate of a farm input (irrigation or fertilizer) computed based on measurements in the *kth* rain gage (*[L] or*

[M/L²]), a_k = size of the *kth* elemental area in a test-plot (L^2), and x_{av} = the weighted average application rate for the test-plot (*[L] or [M/L²]*):

$$x_{av} = \frac{\sum_{k=1}^{K} a_k x_k}{\sum_{k=1}^{K} a_k} \qquad (2)$$

Note that in order to maintain consistency with the definition used for fertilizer application rate, in this paper the phrase irrigation application rate is used in reference to the volume of irrigation per unit field area (irrigation depth), instead of irrigation depth per unit time (the definition customarily used in the irrigation literature).

Low-quarter distribution uniformity

The equation for a test-plot scale low-quarter distribution uniformity, DU_{lq} *[-]*, of a farm input applied with irrigation water is given as:

$$DU_{lq} = \frac{x_{lq}}{x_{av}} \qquad (3)$$

where x_{lq} = the weighted average of the application rates in a quarter of the test-plot area with the lowest application rates (*[L] or [M/L²]*):

$$x_{lq} = \frac{\sum_{i=1}^{I} a_i x_i}{\sum_{i}^{I} a_i} \qquad (4)$$

In Eq. 4, i = index of the application rates in a quarter of the test-plot area with the lowest rates and I = a numerical value equal to the total number of measured application rates in a quarter of the test-plot area with the lowest rates.

As can be noted from Eq. 3, distribution uniformity is a measure of the significance of localized extreme negative deviations from the average application rate. Different forms of distribution uniformity (e.g., distribution uniformity based on the minimum or lower-half of the application rate data) are in common use, each assigning different levels of stringency as regards the definition of what constitutes extreme negative deviation from the average. However, the low-quarter distribution uniformity, DU_{lq}, is used here, because it has been widely applied in irrigation uniformity evaluations. The Christiansen's coefficient of uniformity, *UCC*, on the other hand, can be viewed as an index designed to measure the spatially distributed test-plot scale variability from the average.

Simplified forms of uniformity equations

Equations 1 and 3 represent more general forms of the *UCC* and DU_{lq} indices applicable to conditions in which the elemental areas constituting a test-plot can be of variable size and in principle they can also be of arbitrary shape. In practice, fertigation uniformity evaluation test-plots are rectangular and the elemental areas within the test-plots are of the same shape and dimension (typically squares because of simplicity and symmetry). In which case the equation for *UCC* reduces to the form:

$$UCC = 1.0 - \frac{\dfrac{\sum_{k=1}^{K} \left| x_k - \bar{x} \right|}{K}}{\bar{x}} \qquad (5)$$

and the equation for DU_{lq} is given as:

$$DU_{lq} = \frac{\bar{x}_{lq}}{\bar{x}} \qquad (6)$$

where $\bar{x}$ = the arithmetic average of application rates over the test-plot (*[L] or [M/L^2]*) and $\bar{x}_{lq}$ = the arithmetic mean of the lowest quarter of the application rates within the test-plot (*[L] or [M/L^2]*).

When Eqs.1 and 3 or 5 and 6 are used to quantify fertilizer application rate uniformity, the variable x_k, which represents fertilizer application rate is computed as the product of fertilizer concentration, c_k *[M/L^3]*, and irrigation depth, d_k *[L]*:

$$x_k = c_k d_k \qquad (7)$$

Properties of the fertigation uniformity equations

Equations 5 and 6 are the most commonly used forms of the uniformity indices, hence subsequent discussion will be based on these equations. The following is a list of the properties of equations 5-7 and their practical computational implications.

(1) Considering a test-plot scale irrigation depth or fertilizer application rate data, its *UCC* and DU_{lq} indices remain unaffected if each element of the data set is multiplied by a constant.
The implication is that the volume of precipitation collected in rain gages, instead of depth, can be used directly to compute irrigation uniformity. Note that this is especially convenient if rain gages graduated in volumetric units are used in fertigation uniformity evaluation. Likewise, the mass of fertilizer in the rain gages, instead of fertilizer application rates, can be used to calculate application rate uniformity, if the spatial distribution of fertilizer is expressed as such.

(2) If the fertilizer concentration over a test-plot is constant, the fertilizer application rate uniformity will be equal to irrigation uniformity. Observe that this is a corollary to the property stated above.

In such a scenario, the problem of fertigation uniformity evaluation reduces to that of irrigation uniformity evaluation. In practice this may occur in a sprinkler system in which the effect of solute transport processes on the spatial distribution of fertilizer concentration is limited and the fertilizer concentration at the system inlet is fairly constant throughout the duration of irrigation.

(3) Test-plot scale *UCC* and DU_{lq} are independent of the spatial distribution of the application rate data points within a test-plot.

This implies that two test-plots with different spatial distributions of application rate data can have the same *UCC* and DU_{lq}, provided the data sets can be shown to be equivalent after having been sorted separately in ascending/descending order. In other words, the uniformity indices associated with a given irrigation depth or fertilizer application rate data set remain unchanged under any possible spatial permutation of the data. Although the computation of irrigation uniformity or fertilizer application rate uniformity is independent of the spatial distribution of the data points, it should be noted that the computation of fertilizer application rates from depth and concentration data sets, Eq. 7, requires a proper accounting of the spatial distribution of the data points within the test-plot.

(4) Test-plot scale fertilizer application rate uniformity is an aggregate index of the interactive effects of the local spatial trends in the irrigation depth and fertilizer concentration data sets;

This property of the uniformity indices is less intuitive than those described above, but it is also key to understanding and defining the factors that affect fertilizer application uniformity. Considering that fertilizer application rate is a multiplicative function of irrigation depth and fertilizer concentration, Eq. 7, it can be reasoned that the spatial trends and scale of variability inherent in the irrigation depth data as related to those of the concentration data should be the main determinants of the uniformity of the resultant application rate data. A detailed analyses of the interactive effects, of the spatial trends in the depth and concentration data sets, on the variability (uniformity) of the resultant fertilizer application rate data was performed by Zerihun et al. (2014). The results of this study validates the preceding characterization of the application rate uniformity index. A summary of the significant results is presented in the next section.

2.3.4. The relationship between irrigation, concentration, and application rate data sets

A combination of intuitive mathematical reasoning and simplified hypothetical examples were used by Zerihun et al. (2014) to show that the spatial variability (hence uniformity) of the fertilizer application rate is a function of the interactive effects, of the local spatial trends and scale of variability, of the depth and concentration data sets. Important inferences stemming from these analyses are summarized here so that they can serve as the basis for subsequent discussion (section 2.4.4).

(1) In parts of a test-plot where the local spatial trends in the irrigation depth data have the same monotonicity as that of the concentration data, the local spatial variability of the resultant application rate data tends to be larger than the variability inherent in both the depth and concentration data sets.

(2) In any given section of a test-plot the relative contributions, of the depth and concentration data sets, to the local variability of the resultant application rate data are proportional to the scale of variability inherent in the depth and concentration data sets.

(3) In parts of a test-plot where the spatial trends in the depth and concentration data sets have opposite monotonicity, the local spatial variability of the resultant application rate data tends to be smaller than that of the depth and/or concentration data set(s).

Note that if the local spatial variability inherent in the depth and concentration data sets are of appreciably different scale, then the variability of the resultant application rate data tends to fall somewhere in between those of the depth and concentration data sets. On the other hand, the local spatial variability in the application rate data set could be less than those inherent in both the depth and concentration data sets, provided the variability in these data sets are of comparable scale.

Note that the term monotonicity is used here, in relation to the spatial trends of depth and concentration data sets, to refer to the mathematical property of the data sets as increasing or decreasing functions of distance. If, for instance, both data sets are locally increasing or locally decreasing functions of distance in some part of the test-plot, then they are described as having same monotonicity there. On the other hand, if in some part of the test-plot the depth data is a locally increasing function of distance whereas the concentration data is a decreasing function of distance or vice-versa, then the functions are considered to be of opposite monotonicity in that part of the test-plot. Note that monotonic properties of depth and concentration data sets are alternatively referred to as spatial overlap patterns between depth and concentration data. Furthermore, the term local function behavior should imply that a function exhibits a given mathematical property of interest (e.g., monotonicity) in a subset of its domain (which is the test-plot in the current application). Likewise, global function behavior implies that a property of interest spans the entire test-plot.

The results summarized above with respect to the relationships between the spatial variability of application rate, irrigation depth, and concentration data sets were obtained based on analyses of simplified hypothetical examples consisting of data sets with uniform, or locally variable yet repetitive, spatial patterns. Nonetheless, it has revealed some interesting and practically significant qualitative interrelationships between application rate uniformity and those of depth and concentration uniformity, a summary of which is presented subsequently:

(1) Irrigation or fertilizer concentration uniformity alone may not always be adequate to characterize fertilizer application rate uniformity,
(2) A combination of low irrigation and low concentration uniformity may not necessarily lead to low application rate uniformity,
(3) A combination of low irrigation uniformity and high concentration uniformity and vice-versa will likely lead to low application rate uniformity,
(4) A combination of marginally high irrigation and concentration uniformity levels, or marginally high irrigation and high concentration uniformity indices or vice-versa, may not necessarily lead to acceptably high fertilizer application rate uniformity, and

(5) The sufficiency condition for attaining acceptably high fertilizer application rate uniformity, as defined by a preset uniformity threshold, consists of a fertigation scenario with sufficiently high irrigation depth and fertilizer concentration uniformity.

A fertigation scenario meeting the sufficiency condition has significant practical advantages over any other: it ensures acceptably high irrigation and fertilizer application rate uniformity and it facilitates the attainment of efficient and adequate fertigation. The fact that a fertigation scenario meeting the sufficiency condition maximizes both irrigation and fertilizer application uniformity levels is self-evident. However, its features relating to the attainment of high efficiency and adequacy may require further discussion.

It can be readily reasoned that under a fertigation scenario with a poor fertilizer application rate uniformity, it is not feasible to attain adequate and at the same time efficient application of fertilizer. Under such a fertigation scenario one can either maximize application efficiency at the expense of adequacy (and accept some levels of apparent crop nutrient stress along with the consequent adverse effects on crop yield) or one may opt to meet crop nutrient needs fully and then accept inefficient application of fertilizer. Evidently, fertilizer application uniformity is computed based on collected depths and fertilizer concentration in rain gages (note that assuming runoff is negligible, this is considered a good approximation of conditions at the irrigated field surface). On the other hand, application efficiency takes into account irrigation water and fertilizer losses associated with conveyance and environmental effects, in addition to deep percolation losses. However, the fact that system maintenance and environmental requirements (such as wind velocity) for attaining high uniformity and application efficiency are the same, further supports the notion that high fertigation uniformity facilitates the attainment of high application efficiency. The preceding shows that, with sprinkler irrigation, high fertilizer application rate uniformity is a necessary condition for adequate and efficient field-scale application of fertilizer.

2.3.5. Sampling and laboratory analysis

In each irrigation uniformity test-plot, once irrigation depths are recorded, water samples were collected with appropriately labeled vials from each of the rain gages. One vial is needed per rain gage. In order to maintain the integrity of the chemical constituents of the sample, the vials were then immediately sealed and were frozen within 2h of sampling. Water samples were then analyzed as described in section 2.1.2.

2.4 Results and discussion

2.4.1 Introduction

Field-scale fertigation evaluations: The objective of the fertigation evaluations is to establish a baseline data on field-wide averages and ranges of variations of nitrogen application rates and uniformity indices in the Yuma Valley Irrigation Districts of the LCRR. Accordingly, two sets of field-scale fertigation evaluations were conducted in growers' fields in the winter seasons of 2013 and 2014. Four uniformity evaluations (labeled as data sets I, II, III, and IV) were conducted in different growers' fields in 2013. Four additional fertigation field tests (V, VI, VII, and VIII) were conducted in a grower's farm in 2014. For the evaluations of 2014, the field was subdivided into three sections and data sets VI and VII were collected in two different

subdivisions of the field, but data sets V and VIII were obtained from the same sections of the field.

In subsequent discussion references to nitrogen concentration and application rate should imply total elemental nitrogen concentration or application rate, instead of nitrogen fertilizer material as a whole. The type of nitrogen fertilizers used in these field evaluations are a mix of ammonium nitrate and urea solution or only ammonium nitrate solution. Hence, total nitrogen is expressed as the sum total of nitrate-, ammonium-, and urea-nitrogen where ammonium nitrate and urea were applied or it is expressed as the sum of nitrate- and ammonium-nitrogen, if only ammonium nitrate solution is used.

In order to sample field wide variability of uniformity as influenced by hydraulics and system component maintenance and settings, three test-plots were installed in each of the irrigated fields. The test-plots were arranged approximately diagonally from the system inlet and each test-plot represents nearly equal fractions of the total area of the irrigated field. A test-plot covers a rectangular area of 9.14m× 10.67m (30.0ft×35.0ft), which is discretized into 42 grid squares, measuring 1.524m×1.524m (5ft×5ft), Figure 1b. A rain gage is placed in each of the grid squares. Measured precipitation depths and concentrations were used to compute plot scale fertilizer application rate uniformity estimates. The test-plot scale fertilizer application rate uniformity estimates were then scaled-up to field level through averaging. The details of the procedure and equations used are described in section 2.3.

Test-plot scale fertigation evaluations: In the winter of 2014, four test-plot scale fertigation uniformity evaluations were conducted in the research farm of the Maricopa Agricultural Center of the University of Arizona. The test-plots used in this study vary in size from 9.14m×9.14m (30.0ft×30.0ft) to 9.14m×10.21m (30.0ft×33.5ft). In these studies the bromide ion was applied, in the form of potassium bromide solution, in four different fertilizer injection configurations. Considering a 3.0h test irrigation duration, the four different fertigation application configurations are: (1) The duration of fertilizer application lasts over the entire test irrigation event, (2) Fertilizer is applied only during the first hour of irrigation, (3) Fertilizer is applied only during the middle hour, and (4) Fertilizer is applied during the last hour of irrigation. The goal here is to assess the effect of inlet boundary condition on the spatial variability (uniformity) of fertilizer application rate.

Materials, weather data, and uniformity thresholds: The rain gages used in these field evaluations were obtained from the Irrigation Training & Research Center of the California Polytechnic State University, San Luis Obispo, CA. They have a catchment area of 104.84cm^2 and are graduated in 5.0mL increments up to 100.0mL volume. For measurements ranging between 100.0mL and 200.0mL they are graduated in 25.0mL increments. The maximum measurable depth with these rain gages is about 19.1mm with an estimated precision ranging between 0.1mm and 0.5mm (computed based on assumed volumetric reading errors ranging between ±1.0mL to ±5.0mL).

The average wind velocities for the 2013 data sets were obtained from the Yuma Valley AZMET (http://ag.arizona.edu/azmet/azdata.htm) station and hence represent average values for the area during the uniformity evaluations: i.e., they are not average wind velocities measured in the

immediate ambience of the irrigated fields. On the other hand, wind velocities for the 2014 data sets were averages computed based on measurements, during the fertigation event, with a micrometeorological station setup near the test fields or test-plots.

The uniformity of sprinkler irrigation and factors affecting it have been studied relatively more extensively (e.g., Christiansen, 1942; Fischer and Wallender, 1988; Nderitu and Hills, 1993; Zerihun et al., 2011). Hence, recommended ranges of acceptable irrigation uniformity levels for use in system design and management applications exist (e.g., Keller et al., 1980; Keller and Bliesner, 1990). However, to the best of authors' knowledge such metrics, have not yet been established, for fertilizer application rate uniformity evaluations. Based on literature data and authors' experience with field evaluation of sprinkler irrigation uniformity, tentative fertilizer application uniformity acceptability thresholds are set here. Accordingly, a fertigation event with irrigation and fertilizer application rate *UCC* and DU_{lq} equaling or exceeding 0.75 and 0.7, respectively, is considered to have an acceptably high level of fertigation uniformity. These values closely parallel the acceptability thresholds, for irrigation uniformity of field crops, suggested by Keller and Bliesner (1990). Note that the intent here is to use these uniformity thresholds only for characterizing the relative merit of computed fertigation uniformity indices in this report.

2.4.2 Field-scale uniformity evaluations

Data set I: The first fertigation evaluation was conducted on February 23, 2013 in a grower's field with an irrigated area of 192.0m×393.2m (630.0ft×1290.0ft, Table 1). Irrigation duration was 3.0h and a solution of ammonium nitrate and urea was applied throughout the test irrigation. The average wind speed in the Yuma Valley during the irrigation is about 1.2 m/s. A summary of the total nitrogen application rate over each of the test plots in the field is presented in Table 1.

Computed test-plot scale average application rates vary from 1.1g/m^2 to 1.5g/m^2. Christiansen's uniformity coefficient for the upstream, middle, and downstream test-plots are 0.755, 0.655, and 0.665, respectively. Nitrogen application rate DU_{lq} is 0.607 for the upstream end test-plot, 0.416 for the middle test-plot, and 0.459 for the downstream end test-plot. The field-scale nitrogen application rates vary in the range 0.3g/m^2 and 2.7g/m^2, with an average rate of 1.3g/m^2. The field-wide average *UCC* and DU_{lq} are 0.692 and 0.494, respectively; which suggests a poor fertilizer application rate uniformity.

A summary of the test-plot scale and field scale maximum, minimum, and average depths, nitrogen concentrations, and application rates along with related *UCC* and DU_{lq} values are summarized in Table 2. The field-wide irrigation uniformity (*UCC* of 0.864 and DU_{lq} of 0.784) is high. On the other hand, with a *UCC* of 0.726 and a DU_{lq} of 0.552, the field-scale uniformity of nitrogen concentration is low.

Data set II: The second fertigation field evaluation event was conducted on February 28 of 2013 in a section of a grower's farm measuring 128.0m (420.0ft) along the mainline and 393.2m (1290.0ft) along the laterals (Table 3). The average wind speed in the Yuma Valley area during the fertigation evaluation is 4.5m/s. The duration of irrigation was 3.0h and a solution of ammonium nitrate and urea was applied throughout the irrigation. A summary of the total nitrogen application rate over each of the test-plots in the field is presented in Table 3.

Test-plot scale average nitrogen application rates vary between 0.4g/m^2 and 0.7g/m^2. Computed *UCC* for total nitrogen fertilizer application rate in the upstream end, middle, and downstream end test-plots are 0.666, 0.607, and 0.613, respectively. Test-plot application rate DU_{lq} varies from 0.475 to 0.498. The field-scale nitrogen application rate vary between 0.1g/m^2 and 1.5g/m^2, the average application rate being 0.5g/m^2.The field-scale average nitrogen application rate *UCC* and DU_{lq} are 0.629 and 0.489, respectively, suggesting a poor uniformity.

The field-scale irrigation uniformity (*UCC* = 0.846 and DU_{lq} = 0.761) is high. The relatively high wind speed in the Yuma Valley during the irrigation evaluation suggests a more pronounced adverse effect on irrigation uniformity. However, the measured uniformity levels (Tables 3) indicate that wind speed in the immediate ambience of the irrigated field might not be as high. On the other hand, the field-scale uniformity of nitrogen concentration is low: *UCC* of 0.705 and DU_{lq} of 0.545.

Data set III: This field evaluation was performed on March 1 of 2013 in a part of a grower's field covering an area of 96.0m×374.9m (315.0ft×1230.0ft, Table 4). The duration of irrigation was 3.0h and 24min and ammonium nitrate was applied during the entire irrigation. The average wind speed in the Yuma Valley during the fertigation evaluation was about 3.3m/s. A summary of the total nitrogen application rates over each of the test-plots in the field is presented in Table 4.

Average test-plot scale nitrogen application rates vary within a narrow interval of 1.9g/m^2 to 2.2g/m^2. Total nitrogen application rate *UCC* values are 0.648, 0.614, and 0.680 for the upstream end, middle, and downstream end test-plots, respectively (Table 3). The corresponding DU_{lq} vary between 0.487 for the upstream end test-plot and 0.509 for the middle test-plot. The field-scale nitrogen application rates vary over a wide range of 0.3g/m^2 to 5.7g/m^2. The computed field-scale fertilizer application rate *UCC* of 0.647 and DU_{lq} of 0.499 fall well short of a uniformity level that can be considered satisfactory.

The field-scale nitrogen concentration *UCC* of 0.795 can be considered high, however, the corresponding DU_{lq} of 0.636 indicates significant localized negative deviations from the average (Table 2). Hence, the overall concentration uniformity can be considered low. With a *UCC* of 0.7 and a DU_{lq} of 0.571, the field-scale irrigation uniformity as well is low. Average wind speed in the Yuma Valley, during the irrigation evaluation, is appreciably higher than what is considered conducive for higher uniformities (Table 4). However, it is likely that higher wind speeds may not be the only contributing factor to the low irrigation uniformity. For instance the relatively lower irrigation *UCC* and DU_{lq} computed for the middle test-plot, compared to the rest of the test-plots in the field (Table 2), points to a localized routine maintenance issue and/or improper setting of sprinkler components as the possible causes.

Data set IV: The fourth fertigation uniformity evaluation was conducted on March 2, 2013 in a section of a grower's farm measuring 74.7m (245.0ft) along the mainline and 182.9m (600.0ft) along the laterals (Table 5). The average wind speed in the Yuma Valley area during the field evaluation was 2.2m/s. The irrigation application time was 3.0h and a solution of ammonium

nitrate and urea was applied for the entire duration of the test irrigation. A summary of the test-plot scale total nitrogen application rates is presented in Table 5.

The average test-plot scale application rate vary in the range between 2.5g/m^2 and 3.2g/m^2. Test-plot scale *UCC* values, for total nitrogen fertilizer application rate, are 0.759, 0.770, and 0.774 for the upstream end, middle, and downstream end test-plots, respectively (Table 5). Test-plot scale DU_{lq} vary in the range 0.625 to 0.666. The field-scale average application rate is 2.8g/m^2. While the computed field-scale application rate *UCC* value of 0.767 is acceptably high, the field-scale DU_{lq} value of 0.648 is considered low. Hence, the overall field-scale application rate uniformity can be described as low.

As can be noted from Table 2, the field-scale uniformity of nitrogen concentration (*UCC* of 0.881 and *DUlq* of 0.809) is high. Although the field-wide irrigation *UCC* of 0.748 can be considered marginally acceptable, the very low irrigation DU_{lq} of 0.582 implies that overall irrigation uniformity can be described as low. The average wind speed in the Yuma Valley during the irrigation evaluation (Table 5) does not suggest that the velocity of wind has appreciable adverse effect on irrigation uniformity. In addition, irrigation uniformity as measured by DU_{lq} is very low for all the test-plots, which is not the case for the corresponding *UCC* values. Hence, this points to a need for evaluating current irrigation practices as related to system component settings, routine and long term maintenance of system components, and the hydraulics of the sprinkler system in order to determine the factors contributing to the low field-scale and test-plot scale irrigation uniformities.

Data set V: This field evaluation was conducted on March 4 of 2014 in a grower's farm measuring 64.0m×365.8m (210.0ft×1200.0ft) in the Yuma Valley Irrigation Districts (Table 6). The duration of the test irrigation was 3.0h and a solution of ammonium nitrate was applied for the entire irrigation. A summary of the total nitrogen application rates for each of the test-plot in the field is presented in Table 6.

The average test-plot scale nitrogen application rate vary within a relatively narrow range of 1.3g/m^2 to 1.6g/m^2. Computed test-plot scale *UCC*, for total nitrogen application rates, are 0.768 for the downstream end test-plot, 0.717 for the middle test-plot, and 0.788 for the upstream end test-plot. Test-plot scale DU_{lq} ranges between 0.574 and 0.740. The minimum field-scale nitrogen application rate is 0.7g/m^2 and the maximum is 3.0g/m^2 and the average rate is 1.4g/m^2. Field-scale nitrogen fertilizer application rate *UCC* is 0.758 and DU_{lq} is 0.676. Although the field-wide *UCC* suggests an acceptably high application rate uniformity, the modest DU_{lq} suggests that the application rate data contains appreciable levels of localized negative deviations from the average rate. Overall, the resultant field-scale application rate uniformity can be described as low.

A summary of the test-plot scale and field scale maximum, minimum, and average depths, nitrogen concentrations, and application rates along with related *UCC* and DU_{lq} values are summarized in Table 7. The field-scale irrigation uniformity is quite high (*UCC* of 0.922 and DU_{lq} 0.889). Although the field-wide uniformity of nitrogen concentration (*UCC* of 0.754 and DU_{lq} of 0.7) is much lower than that of irrigation uniformity, it is marginally acceptable.

Data set VI: This field evaluation was conducted on February 28 of 2014 in a section of a grower's farm measuring 64.0m×420.6m (210.0ft×1380.0ft) in the Yuma Valley irrigation Districts (Table 8). The duration of the test irrigation was 3.0h and a solution of ammonium nitrate was applied during the first hour of the test irrigation. The average wind speed during the irrigation was 2.9m/s. A summary of the computed nitrogen application rate data is presented in Table 8.

Test-plot scale average nitrogen application rate vary in the range of 1.5g/m^2 and 2.0g/m^2. The test-plot *UCC* range from 0.721 to 0.808. Computed DU_{lq} is lowest, 0.611, for the downstream end test-plot and is highest, 0.675, for the middle test-plot. Field- scale nitrogen application rate vary between 0.7g/m^2 and 3.7g/m^2 and the field-wide average rate is 1.8g/m^2. Field-scale application rate *UCC* is 0.750 and DU_{lq} is 0.636, suggesting a low overall application rate uniformity.

With a field-scale *UCC* of 0.789 and DU_{lq} of 0.687 (Table 7), irrigation uniformity can be described as marginally low. During the latter part of the field evaluation wind was stronger than would be considered conducive for high irrigation uniformity. It may, therefore, have some effect on the observed level of irrigation uniformity. On the other hand, the field-scale uniformity of nitrogen concentration (*UCC* of 0.874 and DU_{lq} of 0.794) is high.

Data set VII: This field evaluation was conducted on February 27, 2014 in a section of a grower's farm measuring 64.0m (210.0ft) along the mainline and 420.6m (1380.0ft) along the laterals (Table 9). The average wind speed in the Yuma Valley area during the field evaluation was 0.6m/s. The duration of irrigation was 3.0h and a solution of ammonium nitrate was applied during the second hour of the test irrigation. Table 9 summarizes the nitrogen application rate data computed based on measured irrigation depths and concentrations.

The average test-plot scale application rate vary in the range between 2.5g/m^2 and 2.9g/m^2. Test-plot scale *UCC* values, for total nitrogen fertilizer application rate, are 0.826, 0.790, and 0.772 for the upstream end, middle, and downstream end test-plots, respectively. Test-plot scale DU_{lq} vary in the range 0.665 to 0.716. The field-scale average application rate is 2.7g/m^2. While the computed field-scale application rate *UCC* of 0.796 can be considered acceptably high, the field-scale DU_{lq} value, of 0.689 is modest. Hence, overall field-wide application rate uniformity can be described as marginally low.

The field-wide uniformity of nitrogen concentration (*UCC* of 0.833 and DU_{lq} of 0.724) and irrigation (*UCC* of 0.876 and DU_{lq} of 0.796) are both high (Table 7). Note that the low wind speed (average wind speed of 0.6m/s) during the test irrigation should be considered as a factor in the observed high irrigation uniformity.

Data set VIII: This fertigation evaluation was conducted on February 28 of 2014 in a grower's farm measuring 64.0m×365.8m (210.0ft×1200.0ft) in the Yuma Valley Irrigation Districts (Table 10). The duration of the test irrigation was 3.0h and a solution of ammonium nitrate was applied during the last hour of the test irrigation. The average wind speed during the irrigation, 6.5m/s, was significantly larger than what is considered suitable for achieving high irrigation uniformity. A summary of the computed nitrogen application rates is presented in Table 10.

The average test-plot scale nitrogen fertilizer application rate vary in the range of 1.5g/m^2 and 2.3g/m^2. The test-plot *UCC* values, for total nitrogen application rates, vary between 0.495 and 0.641. Computed DU_{lq} is lowest (0.410) for the downstream end test-plot and is highest (0.569) for the upstream end test-plot. Field-scale nitrogen application rate vary over a wide range of 0.4g/m^2 and 5.2g/m^2 with a field-wide average rate of 1.9g/m^2. Field-scale application rate *UCC* is 0.556 and DU_{lq} is 0.465, suggesting a poor field-wide nitrogen application ate uniformity.

Field-wide irrigation *UCC* of 0.660 and DU_{lq} of 0.548 suggest poor field-scale uniformity (Table 7). Considering that this evaluation was conducted on the same subdivision of the field as that of data set V and that the two evaluations were conducted only a few days apart, the sharp decrease in irrigation uniformity level during the current test compared to that of data set V is likely related to the strong wind during the current test. On the other hand, the effect of wind on the distribution uniformity of concentration (*UCC* of 0.745 and DU_{lq} of 0.617) does not appear to be as significant.

2.4.3 Field-scale uniformity evaluations, discussion

Summary: This section presents a summary of the ranges of variations and field-scale averages of the measured nitrogen application rates, along with the computed uniformity indices, of the data sets presented above. It also discusses the practical design and management implications of these results.

The field-scale minimum, maximum, and average nitrogen application rates for all the eight data sets presented above are summarized in Table 11. The measured minimum field-scale nitrogen application rates vary between 0.1g/m^2 for data set II to 1.2 g/m^2 for data sets IV and VII. The field-scale maximum application rates range between 1.5g/m^2 for data set II and 5.7 g/m^2 for data set III. The average field-wide application rates vary from 0.5g/m^2 for data set II to 2.8 g/m^2 for data set IV. The overall average field-scale application rate, computed as the arithmetic mean of all the data sets (Table 11), is 1.8g/m^2.

Considering an approximate required nitrogen application rate (per fertigation event) of about 2.5g/m^2, it then follows that the average field-scale application rates in all but two of the test fields (data sets IV and data set VII) were well below the requirement. In these fields, the difference between the required and the field-wide average nitrogen application rates vary from a minimum of 20% to a maximum of 80% of the required rate (Table 11). Appreciable under-fertilization can be noted even in those fields with an average application rate slightly greater than the requirement (Tables 5 and 9). The low application rate and the poor uniformity, particularly the very low DU_{lq}, imply severe under-fertilization in most of the test fields. While some part of this apparent deficit could possibly be explained by sampling error, it is significantly large to be entirely attributed to that. Considering the significant level of apparent fertilizer deficit, there are no indications whatsoever that crop yield was adversely affected. Perhaps the background crop available soil nitrogen content is sufficiently high to mitigate the effects of under-fertigation.

The field-scale average nitrogen application rate uniformity indices along with test-plot scale minimum and maximum values, for all the eight data sets presented above, are summarized in

Table 12. The minimum test-plot scale application rate *UCC* vary over a wide range between 0.495 (data set VIII) and 0.772 (data set VII). The maximum test-plot scale *UCC* ranges from 0.641 (data set VIII) to 0.826 (data set VII). The field-scale average *UCC* vary in the range 0.556 (data set VIII) to 0.796 (data set VII). The average field-scale *UCC* (computed as the arithmetic mean of the field-scale *UCC*'s of all the data set) is 0.7. This is significantly lower than the threshold for acceptably high *UCC* (0.75≤). As can be noted from Table 12, only four of the eight data sets (data set IV, V, VI, and VII) have field-wide *UCC* values that can be considered acceptable. Remarkably, however, three of these data sets have *UCC* values that can only be considered marginally so. On the other hand, one-half of the field data sets have *UCC* values well below the threshold, ranging between 0.556 and 0.692. Evidently, the field-wide uniformity of nitrogen application rate is typically low.

As can be noted from Table 12, the minimum test-plot scale nitrogen application rate DU_{lq} vary over a wide range, between 0.410 (data set VIII) and 0.665 (data set VII). The maximum test-plot scale DU_{lq} also spans a wide interval ranging from 0.569 (data set VIII) to 0.740 (data set V). The field-wide average DU_{lq} vary from a minimum of 0.465 (data set VIII) to 0.689 (data set VII). The average field-scale nitrogen application rate DU_{lq}, computed by taking the arithmetic mean of the DU_{lq}'s of all the data sets, is 0.575; well below the threshold for acceptably high DU_{lq} (0.7≤). It can also be noted from Table 10, that half of the data sets have very low field-scale average DU_{lq}'s (<0.5) and that none of the field-wide DU_{lq}'s exceed 0.7. The implication is that nitrogen application rates in all of the test fields show significant localized negative deviations from the field-wide averages.

Table 12 show that data sets VII and VIII have the highest and lowest field-scale application rate uniformity, respectively. These tests were conducted in two different sections of the same sprinkler system. Hence, they are of comparable hydraulic, topographic, and geometric configurations and are under the same maintenance and operational practices. However, the two fertigation evaluations were conducted under significantly different ambient wind speeds of 0.6m/s (data set VII) and 6.5m/s (data set VIII), which appears to be the main difference between these fertigation events. This, evidently, underscores the significance of the effect of wind on fertigation uniformity.

The practical significance of high fertilizer application rate uniformity stems from the fact that it is a necessary condition for adequate and efficient field-scale application of fertilizer with sprinkler irrigation. The poor field-wide fertilizer application rate uniformity of most of the data sets, presented above, therefore, suggests that with the current fertigation practices it is hardly possible to attain adequate and at the same time efficient application of nitrogen fertilizer in these farms. In other words, given the current levels of fertilizer application rate uniformity, one can either maximize application efficiency at the expense of adequacy (and accept some levels of apparent crop nutrient stress along with the consequent adverse effects on crop yield) or one may opt to meet crop nitrogen needs fully and then accept inefficient application of nitrogen fertilizer. Considering the limited scope of the study, generalization of the results to sprinkler fertigation practices over the entire Yuma Valley Irrigation Districts may not be automatic. Nonetheless, the consistency of the results across different fields suggests that they may not be untypical of fertigation practices in the area.

As summarized in Figure 2, results of a study by Zerihun and Sanchez (2014) shows that nitrogen application rate uniformity is a function of the interactive effects of the spatial trends and scale of variability inherent in the irrigation and concentration data sets. Significant outcomes of this study are summarized in section 2.3.4 and their application in analyzing the relationships between measured depth and concentration data sets and the resultant application rate data is presented in section 2.4.4. Before that, however, a concise description of the physical factors and mechanisms affecting irrigation depth and fertilizer concentration uniformity (which in turn influence application rate uniformity) is presented.

Physical factors and processes affecting fertigation uniformity: The main sources of spatial variability in sprinkler irrigation and the required design and management interventions to enhance irrigation uniformity are reasonably well established (Zerihun and Sanchez, 2012; Burt et al., 1997; Nderitu and Hills, 1993; Fischer and Wallender, 1988; Livingston et al., 1985). Figure 3 summarizes the interplay of factors considered to be the main determinants of irrigation uniformity and other performance indices in any given sprinkler irrigation event. These factors consist of system hydraulic, geometric, and topographic characteristics; maintenance and setting of system components; ambient weather conditions; and soil-crop and operational practices.

Sprinkler system hydraulic, geometric, and topographic factors are mainly set at the system design stage such that the field-scale spatial variation of sprinkler pressure head/discharge is limited to within a preset range about the design pressure head. In addition, system design should aim at ensuring that the sprinkler application rate does not exceed soil intake rate. These factors along with the state of maintenance of system components and the proper installation/setting of these components or lack thereof determine the actual field-scale spatial distribution of sprinkler pressure head/discharge (Figure 3). The field-wide spatial distribution of irrigation depths and hence uniformity follow directly from the interactive effects of the spatial distribution of sprinkler pressure heads, sprinkler design factors, and the prevailing ambient weather condition (most significantly wind velocities). Finally, the combined effect of irrigation management decisions (mainly related to the duration of irrigation), pertinent soil-crop properties, and the spatial distribution of irrigation determine the resultant irrigation application efficiency and adequacy.

It follows from the preceding discussion that a properly designed and well maintained sprinkler system can attain high application uniformity, if operated under conducive ambient weather conditions (i.e., low wind speed and cool and not so dry weather). Considering that the application rate of field sprinkler systems are generally considered steady, given a highly uniform irrigation and pertinent soil-crop parameters, the goal of attaining adequate and sufficiently efficient irrigation is reduced to the task of determining the duration of irrigation.

In sharp contrast to the more extensive studies conducted in relation to irrigation uniformity, to the best of authors' knowledge there is no published study that defines the factors and processes affecting the spatial distribution of fertilizer concentration and examine their interrelationship. However, based on the general theory of solute transport in hydraulic networks (e.g., Tzatchkov et al., 2002; Taylor, 1954) and authors' field and modeling experience with surface fertigation methods, a tentative outline of factors and mechanisms that may likely account for much of the field-scale spatial variability of sprinkler applied nitrogen concentration is proposed. These

include inlet (upstream) boundary condition, solute mixing due to the physical mechanism of advection-dispersion in the conveyance network, and ambient weather condition (Figure 4).

The inlet (upstream) boundary condition establishes the time variation of concentration at the upstream physical boundary of the sprinkler system and as such it should have a significant effect on the evolution of solute concentration with time and distance through much of the sprinkler pipe network. The solute transport mechanism of advection-dispersion acts on the incoming solute flux and modify its concentration, to a varying degree, during its passage through the conveyance network. Evaporation from droplets, modifies concentration and, is primarily a function of temperature and humidity as well as droplet size. To the extent that the effect of evaporation on concentration vary with droplet size, it is conceivable that evaporation (hence the temperature and humidity in the immediate ambience of the irrigated field) can have a subtle but likely a very limited effect on the spatial distribution of concentration. The effect of wind on concentration distribution may mainly come in the form of differential dilution and could conceivably be significant if nitrogen concentration is variable.

Evidently, the discussion in the preceding paragraphs regarding the factors and mechanisms affecting the field-scale variability of nitrogen concentration is intended here to be merely a hypothesis and as such it can only be considered as a basis for a more detailed further study.

2.4.4 Analyses of field-scale uniformity evaluation results

In this section the effects of the spatial overlap patterns and scale of variability of the measured depth and concentration data sets on the spatial variability of the resultant application rate data will be examined. The discussion will largely be based on dimensionless surfaces depicting the spatial variability of irrigation depth, nitrogen concentration, and application rates for a selected test-plot from each of the data sets. Moreover, the corresponding test-plot scale uniformity of these data sets (Tables 2 and 7) will also be used in the analyses. Here the goal is to highlight the potential sources of the observed low nitrogen application rate uniformities of the data sets presented in the preceding section.

Data set I: In order to relate the uniformity of nitrogen application rate with those of irrigation depth and nitrogen concentration, here we consider the downstream end test-plot of data set I. As can be noted from Table 2, the irrigation uniformity of the downstream end test-plot (UCC = 0.864 and DU_{lq} = 0.803) is high, but the concentration uniformity (UCC = 0.7 and DU_{lq} = 0.507) is low. The resultant application rate uniformity of (UCC = 0.665 and DU_{lq} = 0.459) is as well low. Note that a combination of high irrigation and low concentration uniformity has resulted in a low application rate uniformity, which is consistent with the inferences (pertaining to uniformity relationships) summarized in section 2.3.4.

Figures 5a-5c depict dimensionless surfaces representing the spatial variability patterns of the measured irrigation depths and nitrogen concentrations and the resultant application rates for the downstream end test-plot of data set I. The aim here is to examine the interactive effects of the spatial trends (in the irrigation and concentration data sets) on the uniformity of the resultant nitrogen application rate data. In order to remove scale effects and allow direct visual comparison between the irrigation depth, nitrogen concentration, and application rate data sets, the surfaces are expressed in dimensionless form. Each data set was normalized by dividing the

data points with the respective maximum values. With this transformation all the data sets vary in the range 0.0 to 1.0.

Figure 5a shows that the irrigation data exhibits some variability in a direction normal to the mainline at points that are close to the left-hand side lateral. On the other hand, the concentration data shows similar spatial variability attributes near the right-hand side lateral (Figure 5b). However, the dominant trend in the spatial variation of irrigation and concentration is that both data sets peak at points near the left-hand side lateral and then fall with distance in a direction parallel to the mainline, reaching their lowest points in close vicinity of the right-hand side lateral (Figures 5a and 5b). The implication is that the broader spatial trends in both data sets have the same monotonicity. As can be noted from the general inferences summarized in section 2.3.4, such an overlap pattern should result in an application rate data with a uniformity index lower than those of the depth and concentration data sets. Evidently, this explains the observation that the computed uniformity of the resultant application rate data is less than those of the depth and concentration data sets (Table 2).

Furthermore, it can be noted that the nitrogen application rate surface more closely tracks the concentration data set compared to that of the irrigation data (Figure 5a-5c). Consistent with the inferences presented in section 2.3.4, the concentration data (with a much larger variability compared to that of the irrigation data) appears to have a dominant effect on the scale and pattern of variability of the resultant application rate data set.

Although for the irrigation and concentration data sets considered here global spatial trends are clearly discernible, it should be noted that such is not often the case.
Note that for practical reasons the preceding discussion is limited to a single test-plot. Nonetheless, it highlights the practical significance of the interactive effects of the spatial trends and scale of variability, in the irrigation and concentration data sets, on the variability of the application rate data set.

Data set II: For purpose of analysis the middle test-plot of data sets II (Table 2) is considered here. The test-plot scale irrigation uniformity (*UCC* of 0.818 and DU_{lq} of 0.716) can be considered acceptably high, but the corresponding nitrogen concentration uniformity (*UCC* of 0.714 and DU_{lq} of 0.518) is low. The resultant application rate uniformity of *UCC* = 0.607 and DU_{lq} = 0.498 is as well low. Evidently, this combination concentration, irrigation, and application rate uniformity is consistent with the inferences summarized in section 2.3.4.

Dimensionless surfaces depicting the spatial variability patterns of depth, concentration, and application rate over the middle test-plot of data set II are presented in Figures 5d-5f. As can be noted from Figures 5d and 5e, both irrigation depth and nitrogen concentration surfaces peaked at the upper right hand corner of the test-plot and then exhibit a rapid decrease in the immediate vicinity of the peak, which is then followed (mostly) by a gradual decrease with distance towards the opposite edges of the test-plot. Hence, the predominant trends in both data sets have the same monotonicity. According to the inferences stated in section 2.3.4, these spatial patterns suggest that the test-plot scale application rate uniformity should be less than the uniformity of the corresponding irrigation and concentration data sets. Note that the computed test-plot scale

uniformity of the resultant application rate data set is in agreement with this observation (Table 2).

The surface for the resultant nitrogen application rate data more closely tracks the concentration distribution than the irrigation distribution (Figure 5d-5f), which is related to the much wider variability inherent in the centration data compared to that of the irrigation data.

Data set III: In order to relate test-plot scale nitrogen application rate uniformity with the corresponding irrigation and concentration uniformity, consider the middle test-plot of data set III (Table 2). The test-plot scale irrigation uniformity of UCC = 0.645 and DU_{lq} = 0.488 is low. Although the concentration UCC of 0.773 can be considered acceptably high, a DU_{lq} of 0.611 is considered low. Hence, overall the test-plot scale concentration uniformity can be described as low. The resultant application rate uniformity (UCC = 0.614 and DU_{lq} = 0.509) is as well low. As can be noted from the inferences summarized in section 2.3.4, the combination of low irrigation and concentration uniformity in itself does not necessarily imply low nitrogen application rate uniformity. However, the spatial overlap patterns and scale of variability of the irrigation depth and nitrogen concentration data sets can be examined to highlight the source of the resultant poor nitrogen application rate uniformity.

Dimensionless surfaces depicting the spatial trends in irrigation depth, concentration, and resultant application rate for the middle test-plot of data set III are presented in Figures 6a-6c. As can be noted form Figure 6a, the irrigation surface peaks at the upper right-hand corner of the test-plot and then decreases rapidly with distance toward the opposite edges of the test-plot. The depth data is dominated by a global spatial trend with much of its variability limited to the upper right hand corner to the test-plot. . On the other hand, the nitrogen concentration surface attains its peak close to the left-hand side lateral and exhibits rapid decrease to relatively lower levels near the vicinity of the peak. For the most part, however, the concentration surface is dominated by local trends and varies within a relatively narrow range, which explains the high test-plot scale UCC of *0.773*.

Some local overlap patterns, between the irrigation and concentration data sets (Figures 6a and 6b), can be discerned which may have contributed to a limited extent to the low application rate uniformity (Table 2). Nonetheless, much of the variability in the resultant fertilizer application rate data can be mainly attributed to the dominant effect of the irrigation data set, which shows a much wider range of variability compared to the nitrogen concentration data set (Figures 6a-6c).

Data set IV: For the purpose of relating nitrogen application rate uniformity to the uniformity of the corresponding irrigation and concentration data sets, here we consider the upstream end test-plot of data set IV (Table 2). The test-plot scale irrigation uniformity (UCC of 0.744 and DU_{lq} of 0.583) can be considered low. On the other hand, the corresponding concentration uniformity of UCC = 0.872 and DU_{lq} = 0.796 is high. Overall, the uniformity of the resultant application rate data set (UCC of 0.759 and DU_{lq} of 0.666) can be considered low, which is consistent with the characterization of the qualitative relationship between depth, concentration, and application rate uniformity (section 2.3.4). Dimensionless surfaces depicting the spatial distribution of depth, concentration, and application rate for the upstream end test-plot of data set IV are presented in Figures 6d-6f.

For the most part, the spatial distributions of irrigation depth and nitrogen concentration are such that areas of the test-plot with the shallowest application depths have also received some of the highest nitrogen concentration levels (Figures 6d and 6e). In addition, at points in close vicinity of the right-hand side lateral moderately high irrigation depths are overlapped with low concentrations. Overall these areas of the test-plot are characterized by overlap patterns consisting of opposite trends between the irrigation and concentration data sets. The inferences deduced in a section 2.3.4 suggest that the net effect of these overlap patterns should lead to reduced variability in the resultant application rate surface in this part of the test-plot. On the other hand, the depth and concentration overlap pattern near the upper right-hand corner of the test-plot should result in increased local variability of the resultant application rate data. However, the range of spatial variability and the test-plot scale uniformity of the resultant application rate surface fall in between those of the irrigation depth and nitrogen concentration surfaces. This suggests that spatial overlap patterns that have the effect of reducing variability in the application rate data (which covers a large fraction of the test-plot area) also have a more dominant effect on the test-plot scale uniformity compared to the overlap patterns that have the opposite effect on the application rate data.

Overall the spatial pattern and scale of variability of the nitrogen application rate data more closely track the irrigation depth data than that of the nitrogen concentration data set (Figures 6d-6f). This suggests that the much larger variability inherent in the depth data, compared to that of the concentration data set, has a dominant effect on the resultant application rate data, which is consistent with the inferences presented in section 2.3.4.

Data set V: In order to highlight the relationship between test-plot scale application rate, concentration, and irrigation uniformity, here the middle test-plot of data set V is considered (Table 7). The irrigation uniformity ($UCC = 0.897$ and $DU_{lq} = 0.855$) is quite high, but the concentration uniformity ($UCC = 0.733$ and $DU_{lq} = 0.643$) can be described as low. The fact that the resultant test-plot scale application rate uniformity ($UCC = 0.717$ and $DU_{lq} = 0.574$) is low is consistent with the broad relationship between the uniformity indices summarized in section 2.3.4.

Dimensionless surfaces depicting the spatial variations in irrigation depth, nitrogen concentration, and application rate for the middle test-plot of data set V are presented in Figures 7a-7c.

Figure 7a depicts an irrigation data with clearly discernible global spatial trend for the most part. Figure 7b, on the other hand, shows a concentration data set dominated by highly variable local spatial trends. It can be noted that the depth and concentration surfaces have same local spatial patterns (monotonicity) in a number of spots in the test-plot: upper right-hand corner, upper left-hand corner, lower left-hand corner, middle segments of the edges of the test-plot that are opposite to the upper right-hand corner. In addition, in an area of the test-plot that has received the shallowest depth, the spatial patterns of depth and concentration are the same. Evidently, these overlap patterns led to increased local variability of the resultant application rate data set compared to that of the corresponding depth and concentration data sets (Figures 7a-7c). Note that, to a significant extent, this explains the observed relatively low application rate uniformity as well (Table 7).

As can be noted from Figures 7a-7c, the scale and pattern of variability of the resultant application rate data set more closely track those of the concentration data set. Observe that this is related to the dominant effect of the concentration data set, which has a much wider range of variation compared to that of the irrigation data set.

Data set VI: For the purpose of analysis we consider here the downstream end test-plot of data set VI (Table 7). With a *UCC* of *0.783* and a DU_{lq} of *0.616,* the overall test-plot scale irrigation uniformity can be described as low. On the other hand, the uniformity of the concentration data (*UCC = 0.860* and $DU_{lq} = 0.792$) is high. The resultant test-plot scale application rate uniformity (*UCC* of 0.721 and a DU_{lq} of 0.611) is low. The combination of test-plot scale irrigation, concentration, and application rate uniformity is broadly consistent with the discussion in section 2.3.4.

Dimensionless surfaces depicting the spatial trends in depth, concentration, and application rate for the downstream end test-plot of data set VI are presented in Figures 7d-7f.

It can be noted that the irrigation data peaks at the upper right-hand corner of the test-plot and then shows a rapid decrease in close vicinity of the peak (Figure 7d). In the same area of the test-plot the concentration data set shows vary limited variability. As would be expected (section 2.3.4), the scale and pattern of variability of the resultant application rate data set in that part of the test-plot is dominated by the variability in the irrigation data set (Figure 7d). In addition, along the opposite edge of the test-plot (considering a direction parallel to the mainline), it can be noted that there is a segment of the test-plot where depth and concentration have same spatial trends and another segment where they have opposite spatial trends (Figures 7d and 7e). Note that in both these segments of the test-plot, the scale and pattern of variability of the resultant application rate surface (Figure 7f) is consistent with the inferences stated in section 2.3.4.

The significant localized variability of the application rate data, which is mainly attributable to the spatial variability in the irrigation data, is likely the main contributing factor to the observed low application rate uniformity.

Data set VII: In order to highlight the relationship between test-plot scale uniformity of application rate, depth, and concentration, we consider here the upstream end test-plot of data set VII (Table 7). The test-plot scale irrigation uniformity of *UCC = 0.870* and $DU_{lq} = 0.794$ is high. The nitrogen concentration *UCC* of 0.806 can be considered acceptably high, but the corresponding DU_{lq} of 0.69 is marginally low. Hence, overall the concentration uniformity can be described as marginally low. The resultant application rate uniformity of *UCC = 0.826* and DU_{lq} of *0.716* can be described as marginally high. Note that the computed uniformity indices for application rate, depth, and concentration data sets do not neatly fit in the relationships summarized in Section 2.3.4. However, considering that: *(i)* the uniformity relationships are qualitative, *(ii)* the nitrogen concentration uniformity is only marginally low (a percentage point below the threshold), and *(iii)* the application rate uniformity is only marginally high (a percentage point above the threshold), it can be observed that the uniformity relationships, summarized in section 2.3.4, are essentially valid here as well.

Dimensionless surfaces depicting spatial trends in irrigation depth, concentration, and application rate for the upstream end test-plot of data set VII are presented in Figures 8a-8c.

The surfaces in the middle section of the test-plot (considering the direction parallel to the laterals) are characterized by a relatively heavier irrigation and low nitrogen concentration, with discernibly opposite spatial trends (monotonicity), Figures 8a and 8b. Evidently, this combination of spatial patterns and scale of variability, between the irrigation and concentration data sets, led to a reduction in the local variability of the resultant application rate data compared to that of the concentration data set (Figure 8c). Note that this observation is consistent with pertinent inferences summarized in section 2.3.4.

Furthermore, in an area of the test-plot adjacent to the left-hand side lateral, irrigation depth tends to increase as one moves away from the lateral. Whereas concentration shows very limited localized variation within the same section of the test-plot. Note that the pattern and scale of variability in the resultant application rate data in that part of the test-plot closely tracks the irrigation data set than the more uniform nitrogen concentration data set, which is in agreement with the relevant deductions summarized in section 2.3.4.

In a part of the test-plot that is close to the lower right-hand corner, irrigation depth and concentration data sets have same spatial trends (Figures 8a and 8b), which led to a significant localized drop in the application rate surface (Figure 8c). Evidently, this is the reason for the relatively wider range of variation of the resultant application rate data set compared to that of the irrigation and concentration data sets. Interestingly the application rate DU_{lq} is slightly greater than that of the concentration data set (Table 7). The likely reason is that the very low spot in the nitrogen application rate surface is limited to a small fraction of the test-plot area (compared to that of the concentration surface), hence its effect is not sufficient to lower the test-plot scale DU_{lq} below that computed for the concentration data set.

Data set VIII: In order to relate test-plot scale application rate uniformity with the uniformity of irrigation and concentration, we consider here the upstream end test-plot of data set VIII. The test-plot scale irrigation uniformity ($UCC = 0.632$ and $DU_{lq} = 0.497$) is low. On the other hand, the nitrogen concentration uniformity of ($UCC = 0.787$ and $DU_{lq} = 0.704$) is marginally acceptable. With a $UCC = 0.641$ and $DU_{lq} = 0.569$, the resultant application rate uniformity is poor. Note that the combination of irrigation, concentration, and application rate uniformity is consistent with pertinent inferences presented in section 2.3.4.
Dimensionless surfaces of depth, concentration, and application rate for the upstream end test-plot of data set VIII are depicted in Figures 8d-8f.

The spatial variation of both the irrigation and concentration data sets are dominated by local trends. The irrigation surface peaks at the upper right-hand corner and decrease rapidly with distance toward the opposite edges of the test plot (Figure 8d). In the same part of the test–plot the nitrogen concentration surface is mainly dominated by local spatial patterns, nonetheless, its range of variability compared to the depth data is very small (Figure 8e). As would be expected, the scale and pattern of variability of the resultant application rate surface, in this part of the test-plot, is largely dominated by the variability in the irrigation data (Figures 8d-8f).

In an area of the test-plot close to the lower right-hand corner, the irrigation depth and concentration surfaces have the same spatial trends and comparable scale of variability (Figures 8d and 8e). Consistent with the inferences stated in section 2.3.4, the resultant application rate surface has the same spatial trend as the depth and concentration data sets but with a larger scale of variability (Figure 8f).

Furthermore, in the upper left-hand corner of the test-plot the irrigation and concentration surfaces have opposite monotonicity (Figures 8d and 8e). In addition, the irrigation data shows appreciably larger scale of variability compared to that of the nitrogen concentration data set. Observe that the scale of variability of the resultant application rate surface, in this part of the test-plot, falls somewhere in between the depth and concentration surfaces, but more closely approximates the irrigation surface compared to that of the concentration surface. Note that this observation regarding the scale and pattern of variability of the resultant application rate surface is consistent with relevant inferences stated in section 2.3.4.

2.4.5. Test-plot scale uniformity evaluations

In 2014, four test-plot scale field evaluations were conducted in the Maricopa Agricultural Center (MAC) of the University of Arizona. In these evaluations the bromide ion, applied in the form of potassium bromide solution, was used as a tracer to simulate the spatial distribution of a nonsorbing nitrogen fertilizer species, such as nitrate-nitrogen. The main objective is to assess the effect of inlet boundary conditions (fertilizer application configurations) on fertilizer application rate uniformity. Each fertigation test lasted for three hours and four bromide application configurations, with the same format as those described in section 2.4.1, were used in these evaluations.

Figure 9 shows the layout of the test-plots used in these field evaluations and components of the sprinkler fertigation system. Four test-plots (labeled here as test-plots I, II, III, and IV) were installed within a small field sprinkler system comprised of a main and laterals. Two of the test plots (I and II) have 42 rain gages and the other two (III and IV) have 36 rain gages. The water supply system consists of an underground farm water distribution network operating under gravity. A centrifugal pump installed at the edge of the irrigated field provides the required sprinkler system dynamic head (Figure 9). The fertilizer injection apparatus consists of a feed tank (containing a well-mixed potassium bromide solution) and a diaphragm pump. The diaphragm pump injects the potassium bromide solution at a pre-calibrated rate at the inlet of the sprinkler system.

Four fertigation evaluations were conducted, each in a different test-plot and with a different fertilizer application configuration, labeled here as data set IX, X, XI, and XII. Data set IX, X, XI, and XII were collected in test-plots I, II, III, and IV, respectively (Figure 9). Furthermore, data sets IX, X, XI, and XII were collected when the sprinkler system was operated under fertilizer application configurations 1, 2, 3, and 4, respectively (section 2.4.1). During any given field evaluation all the sprinkler riser pipes in the field, except a block of twenty (4×5) about the test-plot (rectangular area in Figure 9), are capped and sealed. The goal was to limit the number of sprinklers, operating at a time, to the bare minimum required to ensure a completely over-lapped test-plot. The resultant system can then be considered sufficiently small for the effect of solute transport processes, on concentration uniformity, to be considered negligible.

Data set IX: The first test-plot scale uniformity evaluation was conducted on March 28, 2014 in the research farm of MAC in a test-plot measuring 10.2m×9.1m (33.5ft×30.0ft). Irrigation duration was 3.0h and a solution of potassium bromide was applied throughout the test irrigation. The objective in this evaluation was to apply a constant bromide concentration throughout the test duration (fertilizer injection configuration I). However, because of fertilizer injection system malfunction bromide was not applied for approximately 30.0min right in the middle of the test irrigation (Figure 10). The bromide injection configuration can then be considered as having two consecutive finite pulses with an approximate 30min off-cycle. The overall average bromide injection rate computed based on measurements at the system inlet is 67.8mg/L. The average wind speed in the immediate ambience of the test-plot is 1.3m/s. A summary of the bromide application rates over the test-plot (Test-plot I) is shown in Table 13.

The computed test-plot scale bromide application rates vary from 0.7g/m^2 to 1.3g/m^2 and the average is 0.9g/m^2 (Table 14). The test-plot scale bromide application rate *UCC* and DU_{lq} are 0.895 and 0.853, respectively. Note that the very high test-plot scale bromide application rate uniformity is derived from an even higher irrigation uniformity (*UCC* = 0.903 and DU_{lq} = 0.867) and concentration uniformity (*UCC* = 0.954 and DU_{lq} = 0.932). This is consistent with the discussion in section 2.3.4 as regards the relationship between solute application rate uniformity, on one hand, and irrigation and concentration uniformity on the other.

The test-plot scale average concentration of 88.3mg/L, Table 14, is close to the average of the peak concentration levels of the two bromide pulses, approximately equal to 97.6mg/L and 100.9mg/L (Figure 12). Considering a condition in which all things remain unchanged, this observation suggests that if in fact bromide was applied at a fairly constant rate over the entire irrigation duration (no discontinuity), the average test-plot scale concentration would likely be appreciably closer to the average concentration at the sprinkler system inlet. The practical significance of this is that considering a fertigation event in which transport effects on concentration variation are limited, the concentration at the sprinkler nozzles (and hence the average field-scale concentration) can potentially be controlled by applying fertilizer solution at a near-constant (preset) rate throughout the irrigation duration. In which case, high fertigation uniformity can be achieved, if only the design, management, maintenance, and operational requirements for high irrigation uniformity are met.

Data set X: The second test-plot scale evaluation was conducted on March 31, 2014 at MAC in a test-plot spanning an area of 10.2m×9.1m (33.5ft×30.0ft). Irrigation duration was 3.0h and a solution of potassium bromide was applied during the first hour of the test irrigation event (Figure 10). The average wind speed in area of the test-plot is 2.9m/s. A summary of the total bromide application rates over the test-plot (Test-plot II) is shown in Table 13.

The computed bromide application rates over the test-plot vary in the range 0.7g/m^2 to 1.6g/m^2 and the average is 1.2g/m^2 (Table 14). The test-plot scale Br application rate *UCC* and DU_{lq} are 0.852 and 0.771, respectively, which suggests a very high bromide application rate uniformity. Considering the very high test-plot scale irrigation uniformity (*UCC* = 0.853 and DU_{lq} = 0.792) and concentration uniformity (*UCC* = 0.932 and DU_{lq} = 0.88), here as well the relationship

between high application rate uniformity and very high irrigation and concentration uniformity is evident.

The average bromide concentration at the sprinkler system inlet, of about 190.0mg/L (Figure 10), is significantly larger than the test-plot scale average concentration of 119.3mg/L (Table 14). The dilution of the bromide solution by the bromide free water applied during the last two hours of the fertigation may, to some extent, account for the lower concentrations in the test-plot samples.

Data set XI: The third test-plot scale uniformity evaluation was conducted on March 3, 2014 at MAC in a test-plot spanning an area of 9.1m×9.1m (30.0ft×30.0ft). Irrigation duration was 3.0h and a solution of potassium bromide was applied during the middle hour of the test irrigation (Figure 10). The average wind speed in the immediate ambience of the test-plot is 1.7m/s. A summary of the bromide application rates over the test-plot (Test-plot III) is shown in Table 13.

The computed bromide application rates over the test-plot vary in the range 0.8g/m^2 to 2.4g/m^2 and the average is 1.3g/m^2 (Table 14). The test-plot scale bromide application rate *UCC* and DU_{lq} are 0.830 and 0.771, respectively, which suggests a very high uniformity. Both the test-plot scale irrigation uniformity (*UCC* = 0.899 and DU_{lq} = 0.822) and concentration uniformity (of *UCC* = 0.885 and DU_{lq} = 0.840) are very high. Note that the high bromide application rate uniformity is a consequence of the very high irrigation and concentration uniformities.

The significant difference between the average bromide concentration at the sprinkler system inlet (of about 271.0mg/L, Figure 10) and the test-plot scale average bromide concentration of 111.6mg/L (Table 14) is, to a certain degree, related to the dilution during the remaining two-thirds of the test irrigation event.

Data set XII: The last test-plot scale uniformity evaluation was conducted on March 4, 2014 at the MAC in a test-plot spanning an area of 9.1m×9.1m (30.0ft×30.0ft). Irrigation duration was 3.0h and a solution of potassium bromide was applied during the last one-third of the irrigation application time (Figure 10). The average wind speed in the area of the test-plot is 1.2m/s. A summary of the bromide application rates over the test-plot (Test-plot IV) is shown in Table 13.

The computed bromide application rates over the test-plot vary in the range 1.2g/m^2 to 2.0g/m^2 and the average is 1.6g/m^2 (Table 14). The test-plot scale bromide application rate *UCC* and DU_{lq} are 0.890 and 0.824, respectively, suggesting a very high application rate uniformity. Comparing the application rate uniformity for data set XI with those of data sets IX and X, one may note here the favorable effect of low wind speed on application rate uniformity. Both the test-plot scale irrigation uniformity (*UCC* = 0.894 and DU_{lq} = 0.855) and concentration uniformity (of *UCC* = 0.913 and DU_{lq} = 0.861) are very high. Once again, it can be noted that the high bromide application rate uniformity is related to the very high irrigation and concentration uniformities.

To some extent as a result of dilution, here as well, the bromide concentration at the sprinkler inlet (about 348.0mg/L, Figure 10) is significantly larger than the test-plot scale average bromide concentration (145.8mg/L, Table 14).

2.4.6. Test-plot scale uniformity evaluations, a summary

A summary of some observations derived from the test-plot scale field evaluations is presented here. Note that these observations are of preliminary nature and need to be verified by more comprehensive field evaluations.

(i) In a sprinkler system in which the effects of solute transport processes on concentration variation are limited, fertilizer can be applied with high application rate uniformity irrespective of the solute application configurations at the system inlet; provided the concentration at the system inlet is kept fairly constant for the duration of fertilizer application and that the uniformity of the underlying irrigation event is high.

(ii) Considering a scenario in which fertilizer is applied in the form of a finite pulse, during a fraction of the irrigation time, to a system in which the effects of solute transport processes on concentration are limited; the resultant application rate uniformity is mainly a function of the wind velocity pattern during fertilizer application. However, concentration (as well as irrigation) uniformity would be affected by wind velocity patterns over the duration of irrigation.

(iii) In a sprinkler system in which the effects of solute transport processes on concentration variation are limited, the concentration variation at the sprinkler nozzles (and hence over the field) can potentially be controlled by applying fertilizer solution at a near-constant (preset) rate throughout the irrigation duration. In which case, high fertigation uniformity can be achieved, if only the design, management, maintenance, and operational requirements for high irrigation uniformity are met.

Goals and Outcomes Achieved

As listed in section 1.2, the specific goals of the study reported here are: (1) To develop a field and data processing methodology for field-scale fertigation uniformity evaluations in vegetable cropped fields under season-long sprinkler use in the LCRR, (2) To conduct limited fertigation uniformity evaluations in growers' fields in the Yuma Valley Irrigation Districts of the LCRR, and (3) To develop recommendations for further studies. The following is a concise description of the activities and outcomes achieved as related to each of these objectives.

3.1. Development of methodology for field-scale fertigation uniformity evaluations

A methodology for field-scale fertigation uniformity evaluation is proposed in section 2.3. In what follows a brief outline of pertinent activities is presented.

(i) Variability of field-scale irrigation and nitrogen application rates and the need for sampling: The study highlighted the fact that field-scale spatial distribution of irrigation and fertilizer application rates can be highly variable. A methodology for sampling the field-scale spatial variability of sprinkler applied irrigation depths and nitrogen application rates is proposed. Test-plots are defined here as the basic field- scale sprinkler fertigation uniformity sampling units. The number of test-plots in an evaluation field may need to be set based on considerations of cost, time, and effort needed to conduct the field evaluation, on one hand, and the required level of accuracy on the other. The spatial arrangement of the test-plots in a field can take into account the effect of factors that cause systematic variability over the field (such as system hydraulics). Other factors

whose spatial variability is less predictable and have random effects on the distribution of irrigation and fertilizer, can be used to design the spatial arrangement of the test-plots within a field only if specific data as regards their location in the field is known a priori.

Each test-plot should be placed inside a subdivision of the field within which the spatial variability of irrigation and fertilizer application rate can be considered practically negligible. In which case, the test-plot scale average irrigation depth, average nitrogen application rate, and uniformity indices can be assumed representative of the corresponding field subdivision. The area of the field subdivisions can be of the same size or can be variable. For a general application, a set of equally spaced three test-plots arranged along the field diagonal, from the system inlet, can be considered satisfactory. Note that in all of the field evaluations conducted as part of the current study this latter approach was used.

(ii) Fertigation field evaluations: Fertigation field evaluations should be conducted under suitable ambient weather conditions for a preset duration. Irrigation depths collected in the rain gages, in each of the test-plots, need to be recorded immediately following the end of a fertigation event. Subsequently, water samples are to be taken from each of the rain gages with appropriately labeled vials. The samples should then be sealed and frozen (within 2h of sampling), in order to preserve the integrity of the dissolved constituents (mineral nitrogen forms) untill laboratory analysis. The above constitute the basic data sets collected in a fertigation evaluation event. However, depending on the objective of the evaluation a more extensive set of data types (including discharge and solute concentration in the sprinkler network as well as solute concentration in the soil profile) can be measured at selected points distributed throughout the field.

(iii) Laboratory analysis of water samples: Water samples are to be analyzed in a laboratory to determine the concentration of mineral nitrogen forms (nitrate-, ammonium-, and urea-nitrogen) and bromide as described in section 2.1.2.

(iv) *Data processing*: Measured irrigation depths and nitrogen concentrations are used to compute total nitrogen application rates in each of the test-plots. Based on these data sets the test-plot scale minimum, maximum, and average irrigation depths, nitrogen concentrations, and application rates are determined. Test–plot scale uniformity indices (defined in terms of Christiansen's uniformity coefficient and low-quarter distribution uniformity) can then be calculated with appropriate equations given in section 2.3.3. The test-plot scale averages and uniformity indices can be scaled up to field level through averaging.

(v) *Analyses of fertigation uniformity equations and data sets*: As part of the methodological development fertigation uniformity equations and the relationships between pertinent data sets were analyzed: (a) important properties of the uniformity equations were identified and their practical implications discussed, (b) based on results of a study by the authors (Zerihun and Sanchez, 2014) and measured field data sets, the field-wide uniformity of nitrogen application rates was shown to be a function of the spatial trends and scale of variability inherent in the irrigation and concentration data sets, (c) based on results of the study referenced above and measured field data sets some important qualitative relationships that exist between the uniformity of irrigation, concentration, and application rate data sets have been highlighted.

3.2. Field uniformity evaluations

3.2.1 Field-scale fertigation evaluations

Field-scale fertigation uniformity evaluations were conducted in growers' fields in the Yuma Valley Irrigation Districts. The goal of the evaluations is to establish a baseline data on the ranges of variations of field-wide nitrogen application rate uniformity indices and approximate application rates. A detailed description of the measured data sets and analysis of results is presented in section 2.4.2. The following presents a concise list of activities and significant outcomes achieved.

(i) During the winter season of 2013 four nitrogen fertigation field evaluations, each in a different grower's field, were conducted in the Yuma Valley Irrigation Districts. A solution of ammonium nitrate and urea was applied in each of these field tests.

(ii) A second set of field evaluations, consisting of four fertigation tests, were conducted in the winter of 2014 in a grower's field cropped with vegetables and under season long sprinkler irrigation. The fertilizer used in these evaluations is ammonium nitrate.

(iii) Typical nitrogen application rate for the test fields is low. Six of the eight fertigation evaluation fields considered in the current study have average field-wide nitrogen application rates ranging between 0.5g/m^2 and 2.0g/m^2, which is well below the approximate required application rate of 2.5g/m^2.

(iv) Typical nitrogen application rate uniformity for the test fields is poor. Only 50% of the test fields have a marginally acceptable field-scale *UCC*, with the remaining half having only a *UCC* value well below the acceptable threshold of 0.75. Moreover, a minimum DU_{lq} of 0.465 and an overall mean DU_{lq} 0.575, suggest that severe localized under-fertilization may have occurred in many of the test fields.

(v) The measured test-plot scale nitrogen application rates and the computed uniformity indices along with their ranges of variations and field-scale averages are presented in section 2.4.2. Summaries of the significant results of the field evaluations are presented in sections 2.4.3 and 5.

3.2.2. Test-plot scale fertigation evaluations

Four test-plot scale fertigation evaluations were conducted in 2014 at the Maricopa Agricultural Center. The goal is to obtain some insight on the relationship between inlet boundary condition and the spatial distribution of nitrogen fertilizer constituents in the field.

(i) In the winter of 2014, four test-plot scale uniformity evaluations were conducted. In these evaluations the bromide ion was applied (in the form of potassium bromide solution) in four different fertilizer application configurations (section 2.4.1).

(ii) The measured test-plot scale bromide application rates, the computed uniformity indices, and their ranges of variations are presented in section 2.4.5. Summary of the results are also presented in section 5.

3.2.3

We conducted multiple demonstrations in grower fields the past two years. Growers have a better appreciation of system maintenance and operation for optimal results. We estimate we have impacted 25 producers. However, each of these producers has multiple decision makers and we estimate to date we have impacted 80% of the industry in Arizona. Outreach activities, including demonstrations will continue beyond this project and impact will increase. We

anticipate that over the next two years we will impact all producers using sprinkler fertigation systems. We have submitted a paper that is pending the peers review process. Once this is accepted we will simply a version for distribution as a fact sheet. We also hope to eventually offer our evaluation system in a mobile APP format.

3.3. Recommendations

(i) Considering the limited scope of the current study, generalization of the results to sprinkler fertigation practices over the entire Yuma Valley Irrigation Districts may not be automatic. Hence, additional field-scale fertigation uniformity evaluations may need to be conducted to better establish the range of variability as well as typical nitrogen application rate uniformity levels in the area.

(ii) An important factor that affects the uniformity of applied nitrogen is the spatial variability of nitrogen concentration. Based on the general theory of solute transport processes in hydraulic networks and authors' experience with surface fertigation systems in the Yuma Valley Irrigation Districts, a set of factors and mechanisms affecting the spatial variability of concentrations have been identified. However, thorough and comprehensive field and modeling studies may be needed in order to establish conclusively pertinent factors and mechanisms as well as their relative significance and interactions.

(iii) The practical significance of the fertigation uniformity indices stems from the fact that attaining high uniformity is a requirement for achieving an efficient and at the same time adequate fertigation. Nonetheless, high efficiency and adequacy do not automatically follow high uniformity. Hence, future studies aimed at a more comprehensive evaluation of fertigation performance (including the quantification of fertigation adequacy and efficiency) in the Yuma Valley Irrigation Districts may be needed.

(iv) Consideration of optimal application of fertilizers through fertigation needs to be an integral part of the design and management process of sprinkler systems that are routinely used for fertigation purposes.

(v) The development of a coupled field-scale sprinkler system hydraulic and solute transport model that can be used as a flexible and cost-effective tool for fertigation performance evaluation and system design and management is an important challenge.

Beneficiaries

Project beneficiaries include growers in the Lower Colorado River Region that use solid-set sprinkler systems to apply water and fertilizer to vegetable crops. We have impacted at minimum 25 producers using sprinklers. These are all large producers with multiple decision makers and we estimate we have impacted 80% of the industry. Outreach activities are on-going and we anticipate ultimately impacting all producers.

Lessons Learned

(i) Equations of irrigation uniformity indices are typically expressed as a function of irrigation depth. This study shows that the equivalent variable, to depth, in nitrogen fertigation uniformity evaluation is the nitrogen application rate.

(ii) Typical field-scale nitrogen application rates for the fields considered in this study are lower than an assumed target nitrogen application rate of $2.5 g/m^2$ per application.

(iii) Typical field-scale nitrogen application rate uniformity levels for the fields considered here can be described as low (with *UCC* and DU_{lq} values well below 0.75 and 0.7, respectively).

(iv) The low field-scale fertilizer application rate uniformities in the test fields suggest that given the current fertigation practices it may as well be hardly possible to have efficient and at the same time adequate nitrogen fertilizer application through fertigation.

(v) The standard irrigation uniformity equations are recast in a form applicable to the evaluation of fertilizer application uniformity. In addition, important properties of these equations were identified and related practical fertigation management implications are discussed.

(vi) The results of a fertigation study by the current authors (Zerihun et al., 2014) and application of those results to field measured data show that nitrogen application rate uniformity is a function of the spatial trends and scale of variability inherent in the irrigation depth and nitrogen concentration data sets.

(vii) The results of a fertigation study by the current authors (Zerihun et al., 2014) and those of the test-plot scale uniformity evaluations conducted as part of the current study show that the sufficiency condition for high nitrogen application rate uniformity consists of a fertigation scenario with very high irrigation and nitrogen concentration uniformities.

(viii) Considering a sprinkler system in which the effects of solute transport processes on concentration variation are limited, the concentration variation at the sprinkler nozzles (and hence over the field) can potentially be controlled by applying fertilizer solution at a near-constant (preset) rate throughout the irrigation duration. In which case, high fertigation uniformity can be achieved, if only the design, management, maintenance, and operational requirements for high irrigation uniformity are met.

(ix) The close interrelationship between the factors and processes affecting fertilizer application rate and irrigation uniformity underscores the fact that in sprinkler systems that are routinely used for fertigation purposes, the design and management of the irrigation system cannot be decoupled from that of the fertilizer application subsystem.

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Guidelines for Irrigation Water Sample Collection

This project was completed on September 30, 2014

Project Summary

The goals of this project were to evaluate currently used water sample collection techniques for the detection of *Escherichia coli* in canal irrigation waters used in Arizona, and to provide guidelines for a standardized protocol for sample collection of irrigation waters used for produce (leafy greens). Current recommendations for surface water sample collection proposed by the EPA (not for produce irrigation), suggest collecting a water sample at the center of flowing water at a depth of at least six inches facing up-stream of flow. Results from this study indicate that along stretches of the canal system during simulated canal contamination events of levels exceeding the LGMA guideline of 126 *E.coli* per 100 mL, that little variation was observed in the various water sampling techniques evaluated; (1) water surface and edge of canal, (2) water surface and center of canal, (3) 6 inches below surface and edge of canal, and (4) 6 inches below surface and center of canal. However, results indicate that at lower concentrations of spiked contaminants that better mimic real world conditions, the mechanism of water sample collection greatly impacted reliable assessment of water quality. In these real world contamination events, our data indicates that while each of the four techniques evaluated provided greater than 78% efficiency, the most accurate technique for the assessment of water quality was demonstrated from samples collected at a 6 inch depth at the canal center or edge. This work confirms the suggested USEPA recommendation for surface water collection and suggests that this technique is adequate and should also be used by the produce industry when evaluating irrigation canal water quality. Additionally, our work indicates that larger sample volumes of 1000mL (1L) may also provide more accurate assessment of localized water quality when compared to the recommended 100mL grab sample during real world conditions. This is critical knowledge for the food safety industry with respect to the recent proposal of the FDA Food Safety Modernization Act, which suggests water sample collection based on watershed scale assessment.

Project Approach

Currently, there is concern that the water sample collection strategy(s) may be highly variable between individual farms, growers, and food safety managers. Inconsistent sampling methodology between these groups may result in false indications of the level of risk from enteric pathogens in waters used for produce irrigation. This may lead to unnecessary costly interventions (e.g. disinfection of the water, attempts to limit wildlife access, etc.) as well as inaccurate perception of risk among consumers. For this reason it is essential to determine ways to minimize variability within water sample collection protocols and to provide a revised guideline to growers.

Sample collection protocols for the detection of *E.coli* have not been standardized for irrigation canals as they have been for surface water or drinking water. Recent research by our group and others has indicated that location of sample collection, including depth, relative location to the center of the canal, proximity of sampling to a canal curve, proximity of sampling to the agricultural field, as well as sampling frequency may result in data with deviation rates as high as 40% in Arizona and similar climates (unpublished data).

The objectives of this project were accomplished by observing water sample collection techniques of partnering organizations followed by intensive water quality monitoring and assessment. University of Arizona personnel worked with project partners and PIs to compile a database of sampling techniques currently used by growers and food safety professionals in Yuma and Maricopa, Arizona. After sample collection techniques were collated, our team evaluated the effect of these various sampling protocols on data variability and assessed various sampling strategies for the ability to detect a simulated "contamination event". The sample collection techniques evaluated included locations within the canal (center vs. edge) as well as variations in sample collection depth (surface, six inches below surface, and twelve inches below surface). Routine monitoring was completed in Yuma, AZ while "contamination events" were conducted the UA Maricopa Agricultural Center (MAC), in a section of irrigation canal that was controlled for flow-rate and duration. During these contamination events, our research team "spiked" irrigation water in this controlled canal section with a non-pathogenic strain of *E. coli* (ATCC# 25922), Rhodamine dye, Potassium Bromide, and the virus indicator Bacteriophage (MS2), each of which are commonly used as water quality tracers. Water samples were then collected at a predetermined number of locations up-stream and down-stream of the "contamination event" as well as at the identified locations and depths outlined below. Once in the laboratory, water samples were tested using the IDEXX Colilert® method for enumeration of *E.coli* according to manufacturer instructions. Rhodamine was evaluated by Fluorometer, Bacteriophage was evaluated by US EPA Method 1602, and Potassium Bromide was analyzed by ICS – 3000 Ion Chromatography.

This work builds on previous SCBG work by PIs that evaluated septic influence of irrigation canals in Yuma, by expanding our understanding of the impact of sample technique to detect contamination events such as leaching seepage. ***Ultimately this work offers recommendations towards the most reliable irrigation canal sample technique(s) to be used by the produce industry to assess irrigation water contamination.***

Significant Contributions and Roles of Project Partners:

- ***Dr. Channah Rock,*** Associate Professor and Water Quality Specialist at UA and lead PI for this project, coordinated the management of this project, including the supervision of graduate students, visiting interns and staff; organized activities and communications with project partners; convened project meetings; interacted with stakeholders to review data; supervised development of outreach and data outputs; contributed to the development of outreach materials and workshops related to the project, and has presented information about this project to irrigation districts, growers, and other local stakeholders in Arizona and California.

- ***Dr. Jean McLain***, Associate Director for the Water Resources Research Center helped to develop and refine the sampling approach used for the study and contributed to the development of outreach materials including presentation and workshop materials supplied to stakeholders.

- ***Dr. Kurt Nolte,*** Yuma County Cooperative Extension Director and Yuma Agricultural Center Director, was critical in facilitating connections of the research team to local industry members and stakeholders in order to implement the research approach. He also contributed significantly to the development of outreach events and materials supplied to stakeholders.

Goals and Outcomes Achieved

This proposal builds on our expertise in Extension as well as recent irrigation water quality research. To date, numerous studies have been conducted evaluating the impact of irrigation water as a source of enteric pathogens during crop production. In preliminary studies, we have collected data demonstrating high levels of *E. coli*, and common occurrence of the human pathogen *Salmonella* spp. in canal waters used to irrigate fresh produce. We hypothesize that sample collection technique may play a major role in the detection of contamination in canal systems by enteric bacterial pathogens. Because degraded waters in irrigation canals can serve both as a reservoir and a vehicle of produce contamination, it is imperative to identify sample collection techniques that are robust to benefit fresh produce growers.

Over the course of this project quantitative data on the spatial distribution of spiked contaminants in flowing irrigation canals were investigated. Throughout this study our team collected 407 water samples over the course of 3 replicate field experiments conducted in canal systems in Maricopa, AZ. As mentioned above, sample techniques were selected based on a survey of current practice within the produce and food safety communities and included the following; (1) SE - water surface and edge of canal, (2) SC - water surface and center of canal, (3) 6E - 6 inches below surface and edge of canal, and (4) 6C - 6 inches below surface and center of canal. It should be noted that an additional depth of 12 inches below the water surface was originally proposed as an alternative sampling technique, however, it was determined that this was too cumbersome for food safety personnel/water samplers and was removed from the final sampling regime.

The following tests were used to evaluate water quality at the various depths and locations; *E.coli* (ATCC#25922), bacteriophage MS2, Rhodamine dye, Potassium Bromide, and sample volume (100mL vs. 1L). Additional conventional water quality parameters were also collected to characterize background water quality and include conductivity, turbidity, TDS, pH, and temperature. Through the tracking and detection of this suite of parameters, our research team was able to evaluate various sampling strategies commonly used by the fresh produce industry and provide recommendations towards the most reliable technique.

Results indicate that *E.coli* was detected at all sample locations (3 locations total) and that each of the four sampling strategies was able to detect *E.coli* during contamination events under

which water quality exceeded the LGMA guideline of 126 *E.coli* per 100 mL. Our data also shows that while each of the four techniques evaluated provided greater than 78% efficiency, the most accurate technique for the assessment of irrigation water quality was demonstrated from samples collected at a 6 inch depth at the canal center or edge (6C and 6E). This data was also supported though the evaluation of bacteriophage MS2, Rhodamine, and Potassium Bromide. While sample techniques evaluated at the canal surface also provided relatively high efficiency, these sample techniques produced greater variability and were considered somewhat inconsistent throughout the experiments (see supplemental tables and figures below). It is important to note that while our research indicates that sampling at the canal center at a depth of 6 inches is preferred, in the event that this is not achievable, samples collected at the canal edge also at a depth of 6 inches did provide reliable results. It is critical however, that the sampler makes every effort to not disturb the edge of lined or unlined irrigation canal as this may negatively impact the water sample due to disturbance of sediment, canal biofilm, or other debris that may harbor pathogens.

As a result of this work, water quality information has been shared with the broader stakeholder community. It is our intention to share the final results with the Yuma Safe Produce Council at upcoming stakeholder meetings in 2014 and 2015. Stakeholder engagement of particular note is listed below:

- On September 11th, 2013 the research team and project PI led a **Food Safety Research Update** workshop at the University of Arizona, Yuma Agricultural Center. This workshop focused largely on proper water sample collection methods, the effect of canal maintenance on water quality, as well as the impact of animal intrusion in the region. There were **41** stakeholders in attendance at this outreach event.

- On November 12th, 2013 the project PI met with Rosa Brevington of the University of Arizona in Yuma to develop a **Water Sample Collection training video**. This video contains proper water sampling technique and tips for food safety managers. This video has been distributed to several members of the Yuma Safe Produce Council and their local counterparts. The training video has also been posted on the University of Arizona YouTube channel and website and can be found here in English, http://youtu.be/13UHwXyM3W0?list=UUCADb3XfQ6PdbAFdP7_3hKQ, and here in Spanish http://youtu.be/xnPJCe3dlJs?list=UUCADb3XfQ6PdbAFdP7_3hKQ. The University of Arizona will track the number of downloads and views of the training video to better understand our impact to the industry. Currently, there have been **47 views** of the English version and **192 views** of the Spanish version.
- PIs Dr. Channah Rock and Dr. Kurt Nolte traveled to Davis, CA on April 23rd -25th, 2014 to attend and present research findings at the **Western Irrigation Water Quality Conference**. This conference was of particular interest due to the participation of the FDA in regards to the recent draft recommendations towards water quality sampling in the proposed FSMA rule. Both Drs. Rock and Nolte shared research results and experiences working with local industry in Yuma on water quality sampling and gained additional insight on questions that remain with respect to the FSMA recommendations. There were approximately **100** stakeholders in attendance.

- The project PI traveled to Hartnell College (travel covered for PI by the Western Food Safety Summit) to attend and present research findings at the **Western Food Safety Summit** from May 7th to 9th, 2014. Approximately **200** stakeholders attended the Western Food Safety Summit. In this meeting there was no breakout sessions so presentations were seen/heard by all registered participants in the conference hall during that time.

- The project PI traveled to New Port Beach, CA (travel covered by the Center for Produce Safety) to attend and present research findings at the **Center for Produce Safety Annual Meeting** from June 23rd to 26th, 2014. There were approximately **300** stakeholders at the Center for Produce Safety Annual meeting. In this meeting there was no breakout sessions so presentations were seen/heard by all registered participants in the conference hall during that time.

- A project collaborator, Dr. Kelly Bright, traveled to Indianapolis, IN to present a poster based on this research at the **International Association of Food Protection** annual meeting from August 3rd through 6th.

- An **Executive Food Safety Session** hosted by the Yuma Safe Produce Council was held in Yuma, AZ with representatives from the local grower community, members of the Arizona Leafy Green Marketing Agreement, as well as food safety experts who are members of the Yuma Safe Produce Council. University Faculty and Specialists from the Universities of Arizona were also in attendance at this outreach workshop on August 21st, 2014. A total of **30** stakeholders were in attendance at this session where project PI provided a project update presentation and shared results. In this session there was no breakout sessions so presentations were seen/heard by all participants in the meeting room during that time.

As originally proposed, over the course of this project our team worked directly with the leafy greens specialty crop industry to identify a uniform water quality sampling protocol in order to minimize sample variability (**GOAL**). At the culmination of this project, the research team has directly or indirectly reached **910** stakeholders through the outreach events and online trainings mentioned above.

Because of these extensive outreach and training events, we believe that at the end of this two-year project at least **10%** or **91** of the stakeholders reached have modified their water sampling protocols using the techniques presented from this research. This has been measured by the participation in training events and follow up communications. We believe that the **GOAL** of reaching 10 growers (**TARGET**) in two years has been far exceeded.

While the team was not given the opportunity to present at the Southwest Ag Summit in 2013 as originally proposed, we were able to present at the Executive Food Safety Session hosted by the Yuma Safe Produce Council held in Yuma, AZ. During this meeting, final results were disseminated to the audience. Upon follow-up with select stakeholders (**PERFORMANCE MEASURE**) in attendance, we believe that at least **50%** or **15** stakeholders (**TARGET**) of those in attendance were planning to implement concepts learned from this research. It is our plan to

maintain communication with these stakeholder groups in order to assess additional implementation of water sampling concepts learned from this work.

Beneficiaries

This research builds on our expertise in Extension and contributes to a growing body of knowledge related to irrigation water quality. To date, numerous studies have been conducted evaluating the potential for irrigation water to act as a source of enteric pathogens during crop production. In past studies funded by ADA, we have collected data that demonstrates high levels of *E. coli*, and common occurrence of the human pathogens *Salmonella* spp., in canal waters used to irrigate fresh produce during canal maintenance events. Our additional work on failing septic systems and/or leaking sewage pipes playing a role in the contamination of canal systems by enteric bacterial pathogens has also shed light on degraded waters within irrigation canals that can in turn serve both as a reservoir and a vehicle of produce contamination. This work on FB12-20 specifically focused on how food safety professionals can assess their operation to determine if any of the above mentioned "issues" may be of concern. This work is critically important as it provides tools that stakeholders can use to best assess, and ultimately make food safety decisions, their operation.

The results of this project have been of value to stakeholders and growers, whose primary interest is the production of a high-quality, safe end product. We consider these stakeholders, mentioned above, the primary beneficiaries of this project. Several stakeholder meetings and workshops/grower interactions were held throughout the course of the study accomplishing the proposed outcome of the project to ***"offer recommendations towards the most reliable irrigation canal sample protocol(s) to be used by the produce industry to assess irrigation water contamination".*** In addition, these beneficiaries have benefitted specifically from the increased knowledge how to assess their local water quality and what confidence they have in their assessment.

Lessons Learned

A positive outcome of this, and past ADA projects, was the leveraging of our water quality expertise and knowledge in the Yuma and Maricopa regions to acquire additional funding from partners in Arizona and California. As a result of our work on this project, our team was approached to participate in broader research and Extension projects related to water quality that would directly benefit the local industry and enhance the competitiveness of the leafy green specialty crop industry. This includes support from the Center for Produce Safety, Western Growers, and additional funding from the Arizona Department of Agriculture. We are now able to say we have a "team" of Arizona researchers and Extension Specialists working together to solve problems for local industry related to food safety. The Arizona Department of Agriculture has been critical to the success of these programs.

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Additional Information

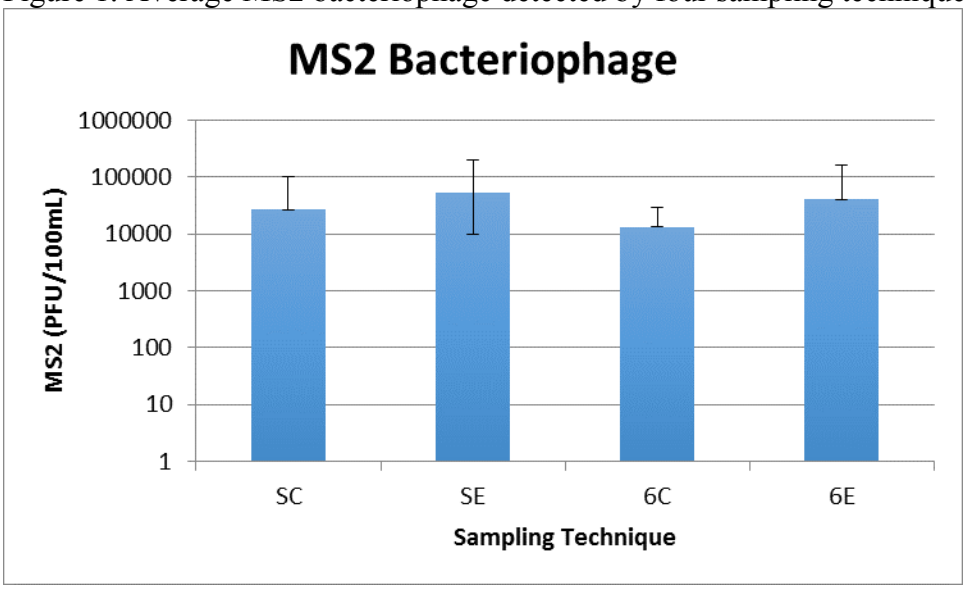
Results from this project directly enhance the competitiveness of Arizona specialty crops due to the fact that this research, and its outcomes, has showcased local stakeholders and their commitment to food safety. More importantly, this work demonstrates the active engagement between Arizona growers and the research and Extension community, working together to find tools and solutions to maintain produce safety. Our research and Extension team was fortunate to partner with stakeholders across Arizona who not only see the benefits of understanding water quality in their region but also fully comprehend the long term impact it will play on produce productivity and marketability.

Supplemental Figures and Tables

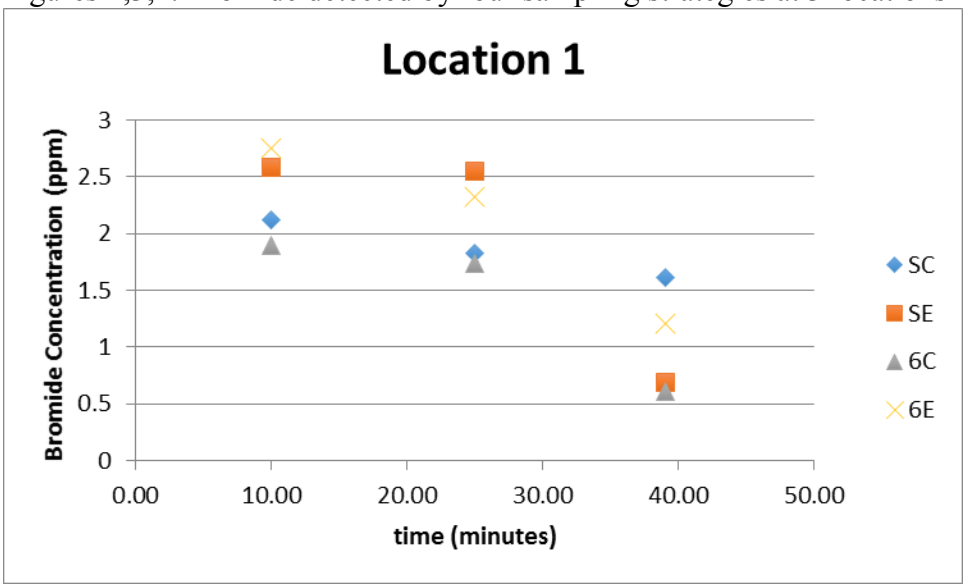
Table 1. Sampling techniques evaluated

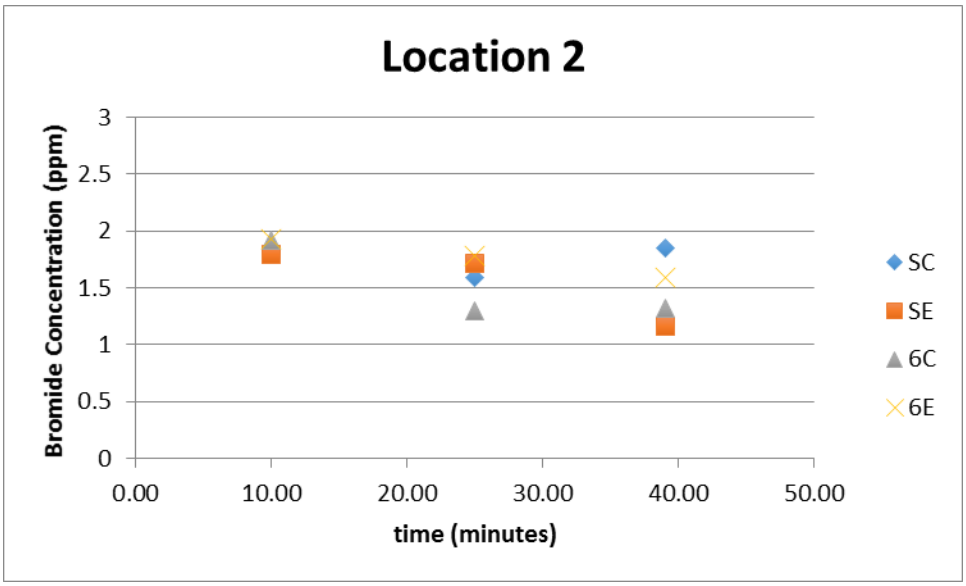
Name	Sampling Technique
SC	Surface Center
SE	Surface Edge
6C	6 inches below Center
6E	6 inches below Edge

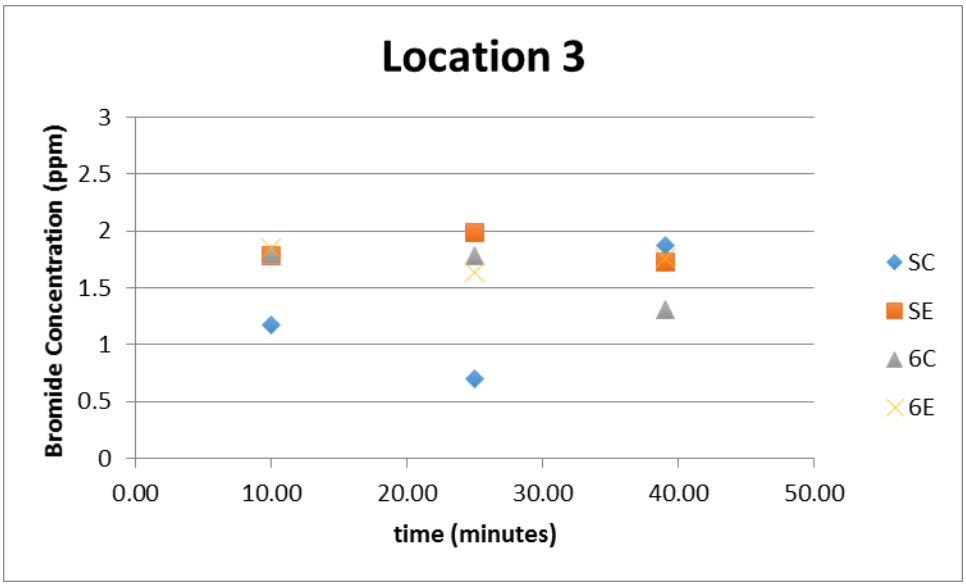
Figure 1. Average MS2 bacteriophage detected by four sampling techniques



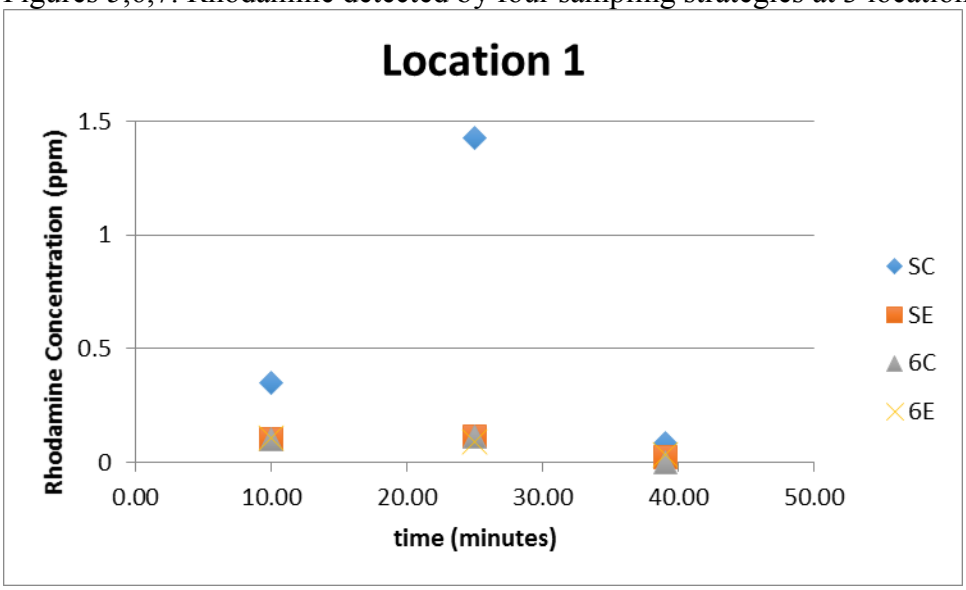
Figures 2,3,4. Bromide detected by four sampling strategies at 3 locations

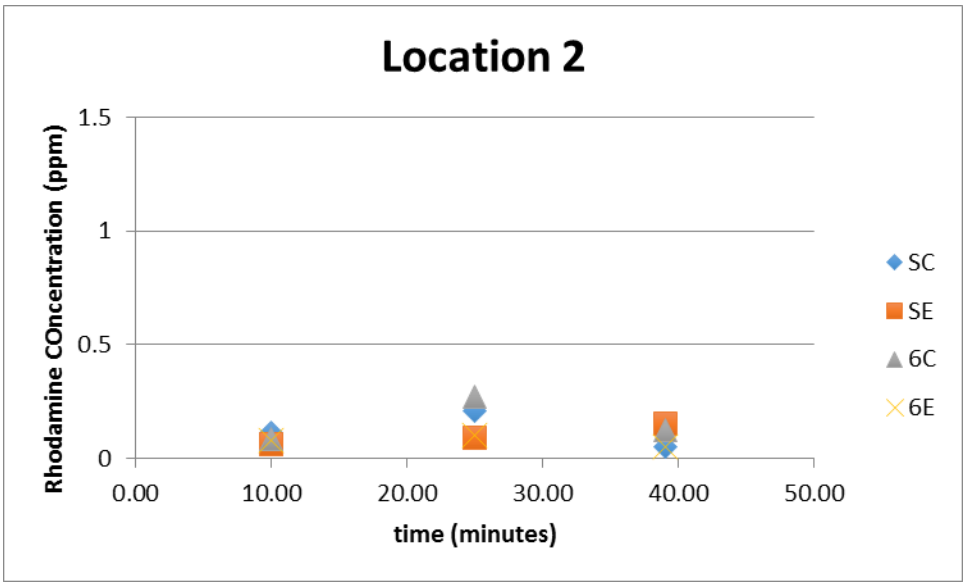


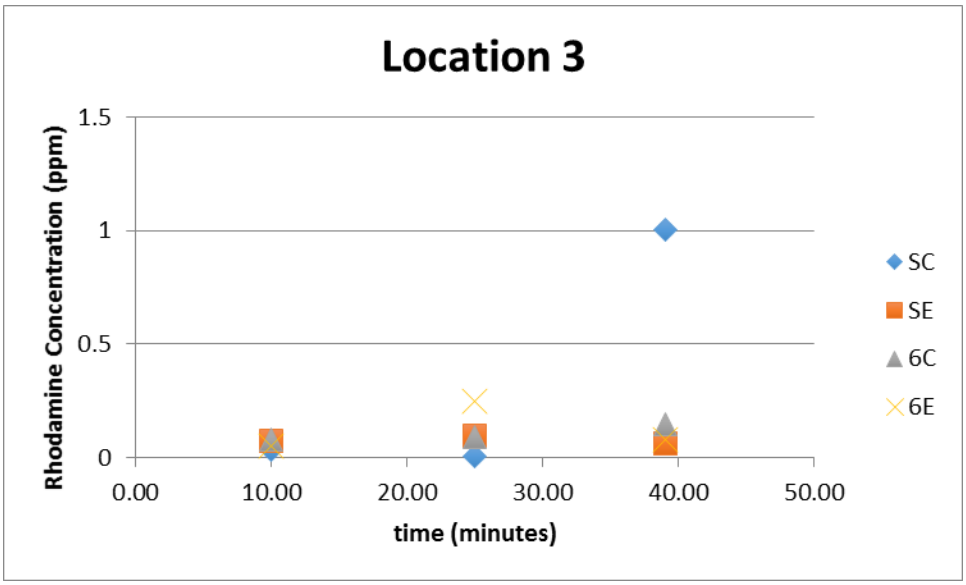




Figures 5,6,7. Rhodamine detected by four sampling strategies at 3 locations







Managing Pierce's Disease in Arizona Vineyards

Activities Performed

First Quarter (Oct 2013 – Dec. 2013) Activities:

- Sampling and collection activities at the beginning of Q5 were delayed due to the federal government shutdown. By the time that work resumed in the second half of October, many vineyards were already bare due to fall season leaf-drop. Despite the suboptimal conditions for collecting samples for the purpose of detecting and isolating the *X. fastidiosa* bacterium from leaf tissue, recovery of putative strains of *X. fastidiosa* was successful from both grapevine and non-grapevine tissues including ash and almond trees as well as wild grape, thereby providing findings to meet project targets laid out in Obj. 2. These isolates of *X. fastidiosa* have been maintained on a growth medium in Petri dish cultures and will eventually be used for DNA extraction so that DNA sequence

comparisons can be made. Comparison of *X. fastidiosa* strains recovered from Arizona vineyards and vegetation will be made against *X. fastidiosa* strains from other regions of North America using the GenBank data base. This will provide a sense of how genetically similar or different Pierce's disease in Arizona is to other regions based on DNA analyses and may provide insight into the identities of other components such as vector species and/or reservoir plant hosts involved in the epidemiology of Pierce's disease.

Grape samples collected April-July and held in the freezer for subsequent analysis of imidacloprid residues were evaluated during Q5. Imidaclodprid is a neonicotinoid insecticide that is most often applied through drip irrigation systems to the soil and then taken up by plant roots and systemically distributed throughout the plant. The effectiveness of an application is influenced by many factors including soil moisture and composition. By monitoring grapevine leaf tissue through the season, a profile of imidacloprid activity in the plant can be determined and used to evaluate the effectiveness of a treatment. Concentrations of imidacloprid measured in leaf samples were, in some cases, extremely high relative to data for grapevines that has been recorded in California vineyards. However, there was much variability among samples with both high and low concentrations recorded. In addition to the factors already cited, variability in imidacloprid concentrations can also be caused by inconsistent application procedures as well as intra-grapevine variation where differences in systemic distribution may yield both high and low concentration leaves within the same plant. During the 2013 season, imidacloprid applications were done independently by the growers while this project focused only on the monitoring of residues. For the upcoming season, a request will be made to the growers to allow access to the project team to determine if application procedures may be responsible for some of the variation. Data from 2013 has been shared with the growers to point out the level of variation that occurred and how a more uniform distribution in plant samples would equate to greater protection against vector insects that are responsible for the spread of *X. fastidiosa*.

Good progress was made on development and application of a real-time PCR test for sensitive detection of *X. fastidiosa* in grape leaves. Four sets of primer pairs were evaluated for consistency in amplifying different segments of the *X. fastidiosa* genome. Primer pair HL5 (5' – aaggcaataaagcgcacta – 3') and HL6 (5' – ggttttgctgactggcaaca – 3') performed the best and is now being used in the ongoing testing of samples collected during Q4 and Q5. An ongoing challenge has been to work out a processing system that allows simultaneous testing of samples using both ELISA and PCR techniques. The issue is that each technique requires a different buffer system during the homogenization procedure, in essence doubling the number of homogenizations. Different approaches have been tested that involve homogenizing a sample one time in a "neutral" solution that can then be divided into the respective buffer solutions for each test. Simultaneous testing will permit a robust comparison of the PCR and ELISA techniques in the context of monitoring for the incidence of Pierce's disease in Arizona.

Second Quarter (Jan. – Mar. 2014) Activities:

- Activities performed during this period included maintaining cultures of Xylella fastidiosa isolated in Q5 from grapes and natural vegetation of the Verde Valley. These cultures are maintained on a growth medium in Petri dishes and were used to inoculate greenhouse grown grapevines for the future study of X. fastidiosa transmission by insect vectors. In addition to the successful isolation of X. fastidiosa from Arizona grapevines, further testing was conducted of plant samples collected in Q5 for simultaneous analysis of X. fastidiosa by PCR and ELISA. As expected, greater sensitivity was observed with the PCR test, but sensitivity diminished if sample homogenization was performed in water rather than in lysis buffer as called for in the PCR protocol. The rationale for trying water as an alternative to lysis buffer is that a single homogenization could be used downstream in both ELISA and PCR protocols, saving time and labor costs. But with the goal of maximizing detection sensitivity of X. fastidiosa, a conclusion was reached that sample homogenization will have to be performed separately for PCR and ELISA procedures.

  The warm winter of 2014 resulted in vineyards breaking dormancy three weeks earlier than normal according to one vineyard manager in the Verde Valley. This means that sampling in vineyards has already begun in Q6 with early efforts focused on evaluating residual levels of imidacloprid in grapevines treated the previous year. Some concern has been expressed that long-term persistence of imidacloprid applied to the soil could affect the taste quality of wine if high enough concentrations persist and are detectable in grapes. Results thus far suggest that only minor levels are carried forward to the next season and that growers should not be concerned about accumulation over time that might affect wine quality.

  Preparation for the 2014 field season was also carried out during Q6. Arrangements have been made with cooperating vineyards to monitor incidence of Pierce's disease and vector activity within vineyards. Metal frames for holding yellow sticky cards on trellises have been fabricated for positioning within vineyards. These will facilitate quick collection and changing of yellow cards and enable more intensive monitoring of vector activity within vineyards in 2014.

Third Quarter (Apr. – June 2014) Activities:

- Field activities commenced in early April with sampling of four vineyards in the Yavapai Co. wine region of Verde Valley and the Cochise Co. region of Willcox to evaluate carryover concentrations of the systemic insecticide imidacloprid applied the previous year. Some concern had been expressed by vineyard managers over the remote possibility that concentrations of imidacloprid in grapevines that reached too high of a level during the season could potentially affect wine quality. Therefore, it was important to establish what concentrations of imidacloprid from previous season applications of imidacloprid occurred in grapevine tissues prior to a fresh application in the new season. Laboratory analysis of grapevine tissue indicated relatively low concentrations of imidacloprid, mostly <20 parts per billion (ppb). These levels were considered low enough to warrant new-season applications of imidacloprid that were applied during April and May. Monitoring of imidacloprid concentrations have continued to the present on a biweekly

schedule that together with the 2013 data of the same type will provide a robust profile of imidacloprid concentrations in grapevines.

Early season evidence of Pierce's disease in Verde Valley and Willcox area grapevines was tested by collecting hundreds of leaf tissue samples and performing analysis using ELISA and PCR protocols. Although potential early season symptoms of Pierce's disease including delayed shoot growth and necrotic shoot tissue were observed in many of the samples, relatively few positives were observed in either the ELISA or PCR results. It is unclear at this time whether low detection of Xylella fastidiosa in grapevine tissue was due to the earliness of the season where detectable titers of X. fastidiosa had not yet developed in early season leaf tissue, yet had affected shoot development, or whether some other disease or low water issue(s) were involved in the delayed development. Repeated testing of the same early season, delayed-growth grapevines is continuing through the 2014 season to determine whether mid- to late-season expression of Pierce's disease occurs and tests positive in the laboratory by ELISA and PCR tests. Three different primer sets are being used for real-time PCR analysis to improve chances of detecting X. fastidiosa if present in a sample. Sequencing of DNA from recovered X. fastidiosa isolates has not yet been conducted, and thus the use of multiple primer sets enables a greater diversity of X. fastidiosa strains to be detected from grapevine and other wild plant tissues.

An improved method of yellow sticky-card sampling was developed during Q7 that allows more efficient changing of yellow cards and greater throughput in monitoring vector activity in vineyards. Wire frames that suspend from vineyard trellises were developed to hold a single yellow sticky-card each. The frames are easily removed from the trellis and replaced with another frame already loaded with a new yellow card. A minimum of 12 frames per vineyard have been selectively placed around the periphery of four vineyards in the Verde Valley and three vineyards in the Willcox region, with the largest vineyard (80 acres) being monitored by 24 yellow-card frames. In addition to the construction of the wire frames, slotted wooden boxes that hold 24 yellow cards each were constructed to hold yellow cards as they are removed from the suspended wire frames. The yellow cards are then transported back to the laboratory and inspected under a microscope to identify and count the number of xylophagous sharpshooters on each card. The highest vector activity observed thus far has been in the Verde Valley, especially in one vineyard that is in the riparian zone created by Oak Creek. Numerous blue-green sharpshooters (Hordnia atropunctata), well known for vectoring X. fastidiosa, were trapped on yellow sticky-cards during May and June. Additional species of xylem-feeding sharpshooters have also been trapped in other vineyards and are presently being investigated by taxonomic experts for species identification. Identifying vector species and quantifying their relative abundance in Arizona vineyards remains a critical element of this project. Experience from the current season (Q7) suggests that yellow sticky-card trapping will need to begin earlier in 2015 in order to catch the beginning of vector activity in vineyards from the time of bud-break onward.

Sampling of grapevines and other vegetation in the vicinity of vineyards continues to be performed in the interest of isolating and culturing different specimens of X. fastidiosa.

No isolations were made from grapevine tissue in Q7, but one from a hackberry tree (Celtis occidentalis) was made from a tree located near the campus of Yavapai Community College in Cottonwood. This particular tree was the sole surviving member of a small group of ornamental hackberry trees, but itself appeared to be in a dying state. Sequencing of DNA from this and other isolates of X. fastidiosa will be performed for phylogenetic comparison to strains outside of Arizona.

Fourth Quarter (July – Sept 2014) Activities:

- Monitoring vector activity with yellow-sticky traps in Verde Valley and Willcox area vineyards continued through most of July, but trap catches dropped off considerably compared to the previous quarter. The covering of vineyard rows with bird netting began the last week of July as grape clusters began maturing and increasing in palatability as sugar levels rose. Access to the vineyards was greatly diminished that, combined with already low trap catches, cemented the decision to terminate vector monitoring for the season. The importance of vector monitoring diminishes in the late season based on indications from research conducted in California that inoculations of Xylella fastidiosa to extended grapevine branches will not be retained beyond the current season due to pruning of the inoculated branches. One potentially important vector species, the Arizona spittlebug (Clastoptera arizonana), began appearing in vineyards in early September and continued to increase through the end of the month. Visual evidence of spittlebug activity in vineyards comes from the white frothy spittle mass that accumulates as immature spittlebugs develop on grapevine branch terminals. Because of the late season nature of these infestations and that feeding occurs principally at branch terminals, there was only mild concern that possible inoculations of X. fastidiosa would lead to permanent infections in the targeted grapevines. However, feeding intensity in one vineyard in the Verde Valley was sufficiently high to trigger a decision by the vineyard manager to apply an insecticide treatment. A spittlebug colony was established in the greenhouse from branch samples collected from three different vineyards in the Verde Valley. These insects will be used experimentally to evaluate their susceptibility to imidacloprid and other soil-applied insecticides in greenhouse conducted insecticide bioassays.

  Multiple vineyard sites continued to be monitored for X. fastidiosa by collecting leaf samples and conducting ELISA and PCR analytical tests in the laboratory. The relatively low incidence of grapevines positive for X. fastidiosa observed in the previous quarter continued to be observed with samples collected during the present quarter. Visible symptoms of Pierce's disease in these vineyards were also quite rare, suggesting that although the disease is present, impact on vineyards being monitored is relatively limited. Variability in how susceptible different grape varieties are to Pierce's disease may account for some of the apparently low impact on vineyard productivity. Most of the vineyards under monitoring are less than 10 years old which may also be a contributing factor to the low incidence of disease. However, Pierce's disease is a progressive disease of grapevines that continues to develop and worsen with time. Monitoring for disease incidence over successive years will provide the required continuity to evaluate the longer term impact of Pierce's disease on Arizona vineyards. The components for disease occurrence and spread are definitely present in the vicinity of the vineyards, especially those located in the Verde Valley. In addition to the higher trap catches of xylophagous

sharpshooters that are known vectors of X. fastidiosa, surrounding native and ornamental plants have been detected as infected hosts of X. fastidiosa. Numerous Petri dish cultures of X. fastidiosa have been established from riparian vegetation sampled in the Oak Creek canyon area of the Verde Valley, including from ash, sycamore, hackberry, and cottonwood trees. This range of vegetation is not a surprise as X. fastidiosa is known to infect hundreds of plant species that vary from herbaceous plants to perennial shrubs and trees.

Evaluation of native vegetation as potential reservoir plant hosts of X. fastidiosa addresses an important aspect of the epidemiology of Pierce's disease in Arizona vineyards.

Results of field samples collected from various vineyards in the three wine-production regions of Arizona are reported back to vineyard growers and managers to keep them abreast of the incidence of Pierce's disease in their respective regions. Assessment of the incidence of Pierce's disease in vineyards of Cochise, Santa Cruz and Yavapai counties meets the goal described in the expected measurable outcome.

Problems and Delays

First Quarter (Oct 2013 – Dec 2013) Activities:

- Late-season sampling of vineyards and vegetation surrounding vineyards was severely curtailed due to the 2+ weeks shutdown of the federal government. Collections made in late September and stored under refrigeration were also lost because of insufficient time to process and prepare them for freezer storage prior to the shutdown on October 1. After resuming work on October 17, sampling was conducted in six vineyards in the Verde valley, but with difficulty as dormancy in grapevines was well advanced and much of the foliage had already dropped. Similarly, wild and ornamental vegetation surrounding the vineyards was also in the process of shutting down. Combined with the Q4 delay in receiving the Homex 6 homogenizer and inability to fill the lab assistant position, overall assessment of the incidence of Pierce's disease in Arizona vineyards was not as complete as planned. Each of these issues has now been settled, and barring further disruption of national affairs by the Congress, will not be a hindrance in 2014.

Second Quarter (Jan – Mar 2014) Activities:

- There were no unexpected delays or significant challenges to deal with this quarter. The ongoing budget problems are being seriously addressed and will soon be resolved, at least in terms of lining up the numbers and being able to provide ADA with billable invoices.

Third Quarter (Apr – Jun 2014) Activities:

- The 180 day appointment of Charles Cowden expired on June 15. His continued participation on this project has been entirely voluntary. Charles will be eligible to start a new 180 day appointment in mid-September, but this will mean nearly three months of salary that have not been paid out from the Salary category of the Project's budget. It is hoped that a no-cost extension of this project will be possible to make up for the staffing

and equipment-purchase delays in 2013, as well as the current lapse in salary payout due to the expiration of Charles' appointment.

Fourth Quarter (Jul – Sep 2014) Activities:

- As indicated in the report from the previous quarter, the temporary loss of Charles Cowden limited our capacity to run analytical tests on field-collected grapevine samples, especially PCR tests. The earliest date that Charles was allowed to rejoin the lab was September 22, meaning that he missed all but seven working days in the current quarter. An attempt was made to circumvent the furlough as mandated by the rules of his 180 day appointment by temporarily employing Charles at the University of Arizona, but delays in carrying out this procedure prevented this from occurring. Apart from this temporary understaffing problem, there are no other significant problems with the progress of the project.

Future Project Plans

Many of the field samples collected through this quarter have been stored in the freezer and will be analyzed over the next several weeks now that the project is again fully staffed. Other carryover work from the previous quarter includes collections of yellow-sticky cards that will need to be viewed under the microscope to determine presence or absence of vector species. Expertise in the identification of sharpshooter vectors has been sought from a scientist at the University of Illinois. To facilitate the identification process, high magnification photographs of specimens removed from yellow-sticky trap catches are being taken in the event that sight identifications might be possible without having to do the fine-scale microscopic work often required for insect taxonomic identifications.

Funding Expended To Date

A total of $32,257.90 has been expended as of September 30, 2014. The ADA is monitoring this project's budget closely. It is anticipated that spending will get back on track in the next reporting period.

Quantifying Pecan Water Use in Arizona

Activities Performed

First Quarter (Oct 2013 – Dec 2013) Activities:

- Eddy covariance data downloaded regularly by cell phone from both the Sahuarita and Bowie sites.
- PI Brown has creating links for real-time viewing of the data:
- Bowie at http://128.196.12.87:312/
- Sahuarita at http://128.196.12.87:313/
- Photos from the phenocams were downloaded manually from both the Sahuarita and Bowie sites semi-regularly.
- Hired an undergraduate student in the Papuga lab to continue organizing and analyzing the photos from the Sahuarita phenocams to identify green up of the understory and to organize eddy covariance data.

- New undergraduate student has visited Sahuarita site, learned to download eddy covariance data and images from phenocams, and is learning to work with the data and images in MATLAB®.

Second Quarter (Jan 2014 – Mar 2014) Activities:

- Eddy covariance data continue to be downloaded regularly by cell phone from both the Sahuarita and Bowie sites.
- Photos from the phenocams were regularly downloaded manually from both the Sahuarita and Bowie sites.
- Undergraduate student in the Papuga lab continues organizing and analyzing the photos from the Sahuarita and Bowie phenocams to calculate using image analysis the greening of the canopy and visually identify specific phenological phases.
- Undergraduate student in the Papuga lab presented a poster "Digital Image-Derived Greenness as an Indicator of Pecan Phenology: Implications for Irrigation Application Efficiency" at UA Earth Week Student Research Symposium and tied for first place undergraduate student poster in the School of Natural Resources and the Environment (see attached pdf of poster).
- PI Papuga continues to organize and analyze eddy covariance data.
- Co-PI Brown continue to organize and maintain the meteorological data and upload to the AZMET system.

Third Quarter (Apr 2014 – June 2014) Activities:

- Eddy covariance data continue to be downloaded regularly by cell phone from both the Sahuarita and Bowie sites.
- Photos from the phenocams were regularly downloaded manually from both the Sahuarita and Bowie sites.
- Undergraduate student in the Papuga lab continues organizing and analyzing the photos from the Sahuarita and Bowie phenocams to calculate using image analysis the greening of the canopy and visually identify specific phenological phases.
- PI Papuga continues to organize and analyze eddy covariance data.
- Co-PI Brown continue to organize and maintain the meteorological data and upload to the AZMET system.
- Papuga, Co-PIs and undergraduate held a project meeting to discuss results-to-date.
- Co-PI Walworth obtained irrigation records for Sahuarita and Bowie sites.
- PI Papuga accepted an invitation to speak about the project at the Annual AZ Pecan Growers meeting in August.

Fourth Quarter (July 2014 – Sept 2014) Activities:

- Eddy covariance data continue to be downloaded regularly by cell phone from both the Sahuarita and Bowie sites.
- Photos from the phenocams were regularly downloaded manually from both the Sahuarita and Bowie sites.
- Undergraduate student in the Papuga lab continues organizing and analyzing the photos from the Sahuarita and Bowie phenocams to calculate using image analysis the greening of the canopy and visually identify specific phenological phases.

- PI Papuga continues to organize and analyze eddy covariance data.
- Co-PI Brown continue to organize and maintain the meteorological data and upload to the AZMET system.
- Co-PI Walworth continues to obtain irrigation records for Sahuarita and Bowie sites.
- PI Papuga made a presentation about the project at the Annual AZ Pecan Growers meeting in August.

Problems and Delays

First Quarter (Oct 2013 – Dec. 2013) Activities:

- Wiring problem identified and resolved at Bowie site.

Future Project Plans

- In the next quarter of the project we expect to continue to work with our undergraduate student for the project in analyzing the data for fluxes and images for phenology from the Sahuarita and Bowie sites.
- We also anticipate continued maintenance of and collection of data from the sites.
- PI Papuga and Co-PI Brown will continue to work together on gap-filling the eddy covariance data.
- PI Papuga and Co-PI Brown will work together in the development of the empirical crop-coefficient models.
- Undergraduate student in the Papuga Lab will present a poster about the project at the 7th Annual Phenology Research and Observations of Southwest Ecosystems (PROSE) Symposium and the 11th Annual Research Insights in Semiarid Ecosystems (RISE) Symposium.

Funding Expended To Date

A total of $81,839.11 has been expended as of September 30, 2014.

Rapid Detection of Citrus Greening Bacterium

This project was completed on June 30, 2014

Project Summary

Citrus Greening, also known as Huanglongbing (HLB), is an imminent threat to the Arizona citrus industry. The disease has already spread to Florida and Texas, and will likely invade Arizona if vigilance is not taken. The causative agent, bacterium 'Candidatus Liberibacter asiaticus', is transmitted by Asian citrus psyllids, and causes HLB in all citrus varieties, including the highly valued Arizona lemon. Infected trees decline rapidly and may produce green fruit or stop producing completely. HLB is the most feared disease among citrus growers because there are no cures. The best control for this disease is to prevent its introduction and establishment in Arizona. For this to be successful, a rapid and highly sensitive detection method must be developed for the bacterium, as the infested trees and psyllids often carry only a tiny amount of the deadly bacterium. We propose to design and test a real-time polymerase chain reaction assay that is many times more sensitive than the available assays and capable of detecting an extremely low level of the pathogen. The availability of this assay to growers and state regulatory agencies

will strengthen early detection, interception, and eradication of HLB-infested materials and protect Arizona citrus industry from a grave threat.

Project Approach

HLB is the most destructive of all citrus diseases, dubbed as "the green menace" (Callaway, 2008). It is widely believed to be caused by the bacterium "*Candidatus* Liberibacter asiaticus" (Las). Two related bacteria, *Ca*. L. africanus and *Ca*. L. americanus, are also suspects. These Gram-negative bacteria live exclusively in the phloem of the host plants and spread from tree to tree by a sap-sucking insect (Bové et al., 2006): the Asian citrus psyllid, *Diaphorina citri*, in the US and Asia.

The Asian psyllid was first detected in Florida in 1998, but the first outbreak of HLB was not reported until 2005. The disease has since been found in Louisiana, Georgia, South Carolina, and Texas. In 2009, Mexico, Belize, and Jamaica all reported occurrence of HLB. The citrus psyllids are already present in California. The psyllid has already been found in Arizona and California, but the disease has not been reported with the exception of an already eradicated, HLB-positive pummelo tree in the Los Angeles County (CDFA News, 2012).

The goal of this project is to design, test, and validate a rapid and extremely sensitive detection assay for the HLB-causing bacterium, 'Candidatus Liberibacter asiaticus' (Las). This assay, based on the real-time polymerase chain reaction (qPCR), aims to improve the sensitivity of the currently available assays by targeting the *hyp*I gene of Las prophage (Duan et al., 2009). This gene encodes 12 nearly identical tandem repeats; when amplified, these repeats will generate signals 12 times stronger than that of a single-copy gene.

As there is no cure for HLB, exclusion is the best line of defense against the disease. Developing a more sensitive test will help to eliminate any risk of an accidental introduction of Las and to identify Las infection at the earliest possible time. The technique targeting the prophage *hyp*I gene would m a significant improvement over the available qPCR method targeting the 16S ribosomal DNA (rDNA) of Las, three copies of which are present in the Las genome.

To accomplish proposed objectives, we designed and tested qPCR primers targeting the prophage *hyp*I gene and compare the efficacy of this qPCR approach with that targeting the 16S rDNA of Las. Furthermore, we developed and tested a digital PCR (dPCR) assay for the detection of HLB in the infected trees. Our approaches for the project are summarized below:

Designing and testing of qPCR primers. Three sets of primers (see the Table below) were designed after a thorough review of literature and analysis of the genomic sequences of Las and two related bacterial species. Each of these primer sets serves its own purpose. The first set primers targets the twelve repeats in the prophage *hypI* gene. This set of primer is expected to produce the most sensitive test. The second set of primers consists of a common reverse primer and three different forward primers, each specific for a species of Liberibacter bacteria that are suspected to play a role in HLB. The third set of primers consists of three pairs of primers that target variable regions of the LAS bacteria that could help to distinguish different strains or races of the bacterium.

Table 1. Primers used in PCR and qPCR tests to detect HLB

Primer Set	Primer Name	Annealing Temperature	Primer Sequence
1	LJ900f	62°C	GCCGTTTTAACACAAAAGATGAATATC
	LJ900r	62°C	ATAAATCAATTTGTTCTAGTTTACGAC

2	HLBRr	58℃	GCGTTATCCCGTAGAAAAAGGTAG
	HLBasRf	58℃	TCGAGCGCGTATGC**G**AATACG
	HLBafRf	58℃	CGAGCGCGTATTTTATACGAGCG
	HLBamRf	58℃	GAGCGAGTACGCAAGTACTAG
3	Lap5650f	52℃	TCTGTGATGCCGTTTGTAGG
	Lap5650r	52℃	CCAAATCAGCCAGCTCAAAT
	LapGP1f	52℃	GACATTTCAACGGTATCGAC
	LapGP1r	52℃	GCGACATAATCTCACTCCTT
	LasITSAf	52℃	GGGGGTCGTTAATATTTGGTT
	LasITSAr	52℃	GTCGCATACAATGCCAACAT

In the initial tests, all the primer pairs were apparently able to amplify the targeted DNA fragments from both infested citrus and periwinkle under the following PCR conditions: 95℃ for 2 min, followed by 40 cycles of 95℃ for 10 sec; annealing temperature as indicated in the table for 10 sec; and 72 ℃ for 1 min. The PCR is terminated by one more incubation at 72 ℃ for 5 min. The primer pairs of Lap5650f and Lap5650r were only able to amplify expected DNA fragments from the infected periwinkle sample but not from the infected citrus sample, indicating that the Las in the infected citrus is different from that in the infected periwinkle.

Optimization of PCR and qPCR conditions. Temperature gradient PCR tests were carried out to determine the optimal annealing temperature for the primer sets used in this project. The optimal annealing temperatures were determined as 62.5℃ for the primer set HLBBr and HLBasRf, 60℃ for the primer set Lap5650F and lap5650R, and 62℃ for the primer set LJ900F/LJ900R. For the second set of primers, an elongation time of 1 minute and 15 seconds was determined as the best as it produced strong DNA bands and minimum background.

Using the optimum PCR conditions, we determined the detection sensitivities of the PCR assays. DNA from known positive samples were diluted 1:20, 1:100, and 1:1000 in 1ug/ul salmon sperm DNA solution, and 0.5 ul of the diluted DNA was used for each PCR reaction. The optimized PCR assays were capable of detecting LAS-specific DNA in all the dilutions, suggesting a high degree of sensitivity with the primer sets LJ900F/LJ900R and HLBBr/HLBasRf.

Comparative studies of qPCR targeting Las rDNA and qPCR targeting the *hyp*I gene. qPCR tests targeting rDNA and the prophage *hyp*I gene were conducted to compare the detection sensitivity of the two targets. In the Las genome, *hyp*I, contains 12 tandem repeats of 132 nucleotides. These repeats present an attractive target for PCR amplification. Primers designed to amplify these repeats will generate a signal 12 times stronger than that from a single copy gene. In contrast, the Las genome contains only three copies of the rDNA gene, which is the target of the currently available qPCR assay. Therefore, the detection assay being developed in this project will be four times as sensitive as the best current detection method. The sensitivity of this assay can be further improved by including a reverse transcription step. Bacteria, like any other organisms, make many copies of mRNA from a gene. By using the *hyp*I mRNA as a starting material, the RT-qPCR signals will be amplified proportionally based on the number of the bacterial mRNA.

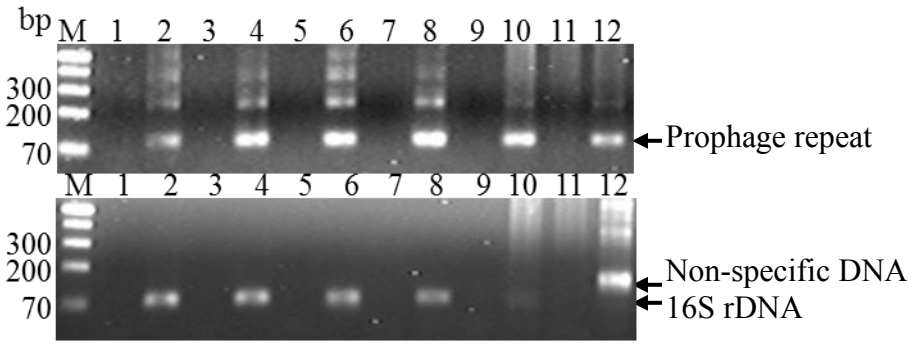
Developing and optimizing a digital PCR detection assay for Las. Using the primer sets designed for qPCR, we carried out tests to optimize the conditions and determine the sensitivity of digital PCR (dPCR) for the detection of Las. dPCR is a recent development in the detection of pathogens and trace amounts of DNA (Baker, 2012). In one single dPCR test, a sample is divided to thousands or millions of micro-chambers, each carrying on a parallel PCR. By counting the

number of positive and negative chambers, the absolute copy number of a HLB DNA can be determined precisely. dPCR offers a number of advantages over qPCR: dPCR directly counts the number of nucleic acid molecules rather than inferring from reference standards or endogenous controls, making absolute quantification of target molecules possible; statistics can be applied to analyze the data and obtain results with a higher confidence because of the large number of repetitions in a single test. Because of these characteristics, dPCR has a great potential to be develop as a more sensitive and reliable assay to detect an extremely low level of the HLB pathogen at the earliest possible time.

We used an Applied Biosystems (ABI) QuantStudio digital PCR machine for this study. The machine essentially carried out 20,000 qPCR reactions in a single run. However, due to the small volume of each reaction (~0.7nanoliter/each reaction), the optimal conditions for dPCR could be different from qPCR and needed to be optimized.

Goals and Outcomes Achieved

Goal 1: Design, test, and validate a real-time PCR test for the HLB-causing bacterium. When the project started, a real-time PCR (qPCR) test already existed for the detection of Las, the causal bacterium for HLB (Li et al., 2006). This test is based on the detection of 16S rDNA genes, three copies of which is are present in the Las genome. To develop a more sensitive real-time PCR assay, we designed and tested five pairs of primers targeting the prophage *hyp*I gene with 12 nearly identical repeats and a phage variable region, and targeting 16S rDNA and ribosomal DNA intergenic regions. After optimization of PCR conditions for the specific primers, all primer pairs could detect HLB bacterium in infected citrus and periwinkle plants with high specificity. Furthermore, the primer pairs (LJ900f/LJ900r) targeting the 12 repeats in the prophage region proved to have 10 to 100 fold higher sensitivity than the previous qPCR assay targeting the 16S rDNA region (primer pairs HLBRr/HLBasRf) (Fig. 1). Therefore we conclude that we have completed the primer goal of this project, i.e., to design, test, and validate a rapid and extremely



sensitive detection assay for the HLB-causing bacterium, '*Candidatus* Liberibacter asiaticus'.

Fig. 1. PCR assay targeting the prophage repeat region is more sensitive than targeting the 16S rDNA region. DNA extracted from healthy citrus (lanes 1, 3, 5, 7,9, 11) and Las-infected citrus (lanes 2, 4, 6, 8. 10. 12) was diluted and amplified with primers specific for the prophage repeats (LJ900f/LJ900r, top panel) and 16S ribosomal DNA (HLBRr/HLBasRf, bottom panel). Dilutions: 1,2, 1:5; 3,4, 1:50; 5,6, 1:500; 7,8, 1:5,000; 9,10, 1:50,000; 10,11, 1:500,000. Lane 12 in the bottom panel contains a non-specific DNA band possibly amplified from the diluting salmon sperm DNA (Xiong et al., unpublished data)

Goal 2. Develop a digital PCR (dPCR)-based test for the detection of the HLB-causing bacterium. A new technology emerged after the initiation of this project. The digital PCR (dPCR) instrument, QuantStudio 3D by Applied Biosystems, carries out 20,000 independent, parallel reactions in a single test. This technology allows statistical analysis of testing results, making the test more reliable and sensitive than the traditional real-time PCR technology. We designed two sets of Taqman assay primers and probes, one targeting the 12 repeats of the prophage region and the other targeting the 16S rDNA region. After optimization of dPCR conditions, we were able to detect *Candidatus* Liberibacter asiaticus bacterium from infected citrus and periwinkle plants using both sets of primer and probes. However, there is no significant difference in the detection sensitivity between the two sets of primers and probes. Additional experiments are required to further optimize dPCR conditions, to compare its sensitivity with that of qPCR, and to validate the assay.

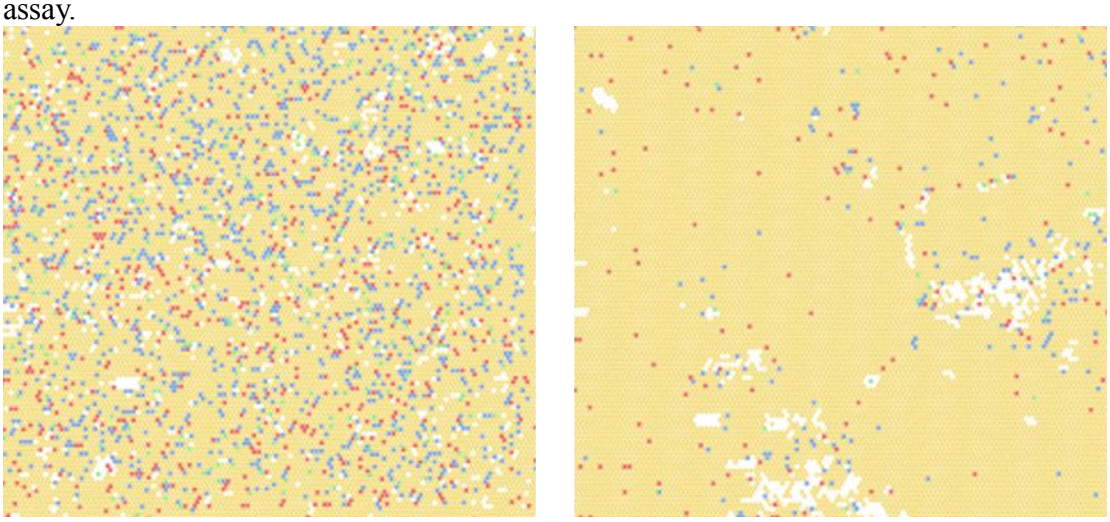


Fig. 4. Development of a digital PCR assay for the detection of *Candidatus* Liberibacter asiaticus. Scanned images of dPCR chips show amplification of Las-specific DNA in each of the 20,000 cells. The reaction of each cell is carried out in a volume of 0.7 nanoliters. The sample at the left contains 100 times more target Las DNA than the sample at the right. Two different fluorophores are used to probe either the Las phage repeat targets or the 16S rDNA target. Red dots represent amplification of phage repeat DNA, blue dots represent amplification of Las 16S rDNA, and green dots represent amplification of both target DNA molecules. (Xiong et al., unpublished data)

Goal 3: Communicate research progresses and results to the public, growers, and scientists. A web page (http://ag.arizona.edu/~zxiong/HLB.html) describing the biology, economic impact, and detection methods for HLB has been created for public viewing. Preliminary results and research progress are also posted at the web site. During the project period, the page has been viewed 1376 times, with an average of 2~3 views daily. Due to a schedule change, a presentation was not made in at the 2013 Arizona Citrus Research Council meeting. Instead, a presentation was made to about 120 high school students in six sessions at the Southwest Ag Summit in Yuma, Arizona, in March 6, 2013. Many of students were either from a farming background or potentially future citrus growers. The presentation covered the technologies (PCR, real-time PCR) for the

detection of the citrus greening bacterium and was well received in a post-presentation evaluation conducted by the organizers. A poster presentation was also made at the APS annual meeting to about 1500 attendees in Austin, Texas from Aug. 10th to Aug. 14th, 2013.

Beneficiaries

The primary beneficiaries are citrus growers in Arizona, and other citrus-producing states. Citrus and its value-added products are a major agricultural industry in the US. As of 2013, citrus production is valued at $3.2 billion (packhouse-door equivalent value) (USDA NAAS, 2013), and the economic impact of the citrus industry is many billion dollars more if value-added products are included in the estimate. The majority of acreage of citrus is planted in Florida (61%), followed by California (33%) with remaining acreage in Texas and Arizona. In Arizona, citrus is grown on some 13,500 acres and is valued at $36 million (farm gate value). Outcomes of this research will benefit 528 individuals involved in the Arizona citrus industry (2012 Census of Agriculture). In addition, implementation of the more sensitive qPCR test developed in this project would help California and Arizona citrus industry avoid billions of dollars in losses due to HLB and help Florida and Texas citrus growers to manage HLB better.

Lessons Learned

Completion of this project made us more appreciative of a well-designed pathogen detection assay and due diligence in research. The specificity and sensitive can be increased substantially with the optimized assay conditions. During our research, we also found that the primers reported in previous research actually contained an error: one nucleotide is missing! This missing nucleotide is marked in red color in Table 1. This was found after our PCR assays did not perform well. Do a thorough research and verify data reported from an even highly reputable journal! We also learned that adapting a new technology is more challenging than expected. During the development of the digital PCR detection method, we encountered delays in the delivery of new products from the manufacturer, components not working as expected, and little resources to depend on when problems arise.

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http://ag.arizona.edu/~zxiong/HLB.html: Citrus Greening (Huanglongbing, HLB).

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User Friendly Fertilizer Recommendations for Vegetables

Activities Performed

First Quarter (October 2013 through December 2013)

- As noted, the fact sheet compilation is limited to our down time in the field. These activities will resume in late March. However, during this period we put out seven demonstrations in grower fields.

Second Quarter (January 2014 through March 2014)

- As noted, the fact sheet compilation is limited to our down time in the field. These activities resumed in late March. However, we put out three more experiment-demonstrations during this quarter. The demonstrations put out the last quarter were completed.

Third Quarter (April 2014 through June 2014)

- Harvested last field demonstrations with broccoli, carrot, onions, and sweet corn in April and May. Worked on bulletins during June. Will continue to work on bulletins through October.

Fourth Quarter (July 2014 through September 2014)

- We worked up data, including analysis from all experiment-demonstrations conducted during fall-winter-spring 2013-2014. We continue to work on bulletins.

Problems and Delays

First Quarter (October 2013 through December 2013)

- No problems or delays. We planned to do most of the data compilation work in the summer when field work is slow.

Second Quarter (January 2014 through March 2014)

- We planned to do most of the data compilation work in the summer when field work is slow. However, we have had delay contracting a programmer for the APPs. Thus, we request a no cost extension.

Third Quarter (April 2014 through June 2014)

- We have had some delays hiring a programmer for APP development. Thus, we requested no cost extension to complete APP development.

Fourth Quarter (July 2014 through September 2014)

- We just identified an individual to work on APPs. Thus, APP work will begin the next quarter.

Future Project Plans

We came to the conclusion that presentations in extension meetings were only marginally effective in technology transfer so we also initiated demonstrations in grower fields. These were not initially planned in the original proposal but we added them based on limited progress in meeting presentation. These demonstrations involved side by side plots using our fertilizer recommendations compared to their standard practices. We conducted seven demonstrations during 2012-2013. These included iceberg lettuce, broccoli, celery, spinach, baby lettuce, and romaine lettuce. We found these were much more effective than meeting presentations in technology transfer so we have continued these in 2013-2014 and rely less on meetings. These included lettuce, broccoli, carrot, onions, and sweet corn. We will conduct additional demonstration during the fall-winter-spring of 2014-2015. In fact, we initiated 3 during October. During these demonstrations we had contacts with 68 producers.

We hope to have most bulletins completed by June. We requested a six month extension and plan to complete APP development during this extension. I have held much of the funding in reserve to pay programmer and cover bulletin publications costs. I do not know these costs at this time and I do not want to overspend.

Project Activity	Responsibility	Timeline
Compile materials for traditional extension publications	This work will be done at the UA by-Sanchez and Nolte.	October 2012 to December 2014
Write extension fact sheets and bulletins with the updated materials	This work will be authored by Sanchez and co-authored by Nolte.	January 2013 to March 2015
In field grower-	The work performed by	October 2012 to March 2015.

demonstrations	Sanchez.	
Grower training workshop on use of use of information in fact sheets and bulletins	Sanchez and Nolte	June 2015.
Compile APP recommendation algorithms	Sanchez	January 2015 to June 2015
Program and test APP applications.	Sanchez	January to March 2015
Grower training workshop on use of APPS	Nolte and Sanchez	March 2015

Funding Expended To Date

A total of $19,264.74 has been expended as of September 30, 2014.

2013 Southwest Ag Summit Survey Addendum A

1. How would you describe your occupation? [Circle 1]

a. Equipment Dealer
b. Grower/Farm Company
c. Marketing/Sales
d. PCA/Chemical Rep.
e. Professional/Support Personnel
f. Seed Representative
g. University/Government Personnel
h. Other_____

2. Does your occupation involve the melon or vegetable industry?

a. Yes b. No

3. How has the SW Ag Summit affected your occupation? [Circle all that apply]

a. Obtained material about desert ag
b. Provided marketing opportunities
c. Obtained material about food safety
d. Developed networking opportunities
e. Gained continuing education units
f. Other_____

4. How did you learn about the SW Ag Summit? [Circle all that apply]

a. Postcard/Flyer in mail
b. SW Ag Summit website
c. Email
d. Social Media
e. Newspaper article
f. Word of mouth
g. Other_____

5. How likely are you to share information you obtained from the SW Ag Summit with others? [Circle a number]

Less Likely Very Likely

1 2 3 4 5

6. If you share the information, with whom will you share it? [Circle all that apply]

a. Staff
b. Coworkers
c. Media
d. Friends/Family

7. Why did you attend the SW Ag Summit? [Circle all that apply]

a. Academic breakout sessions
b. Booth displays
c. Continuing Education Units
d. Keynote addresses
e. Marketing opportunities
f. Networking opportunities
g. Other _____

8. What was the best part of the SW Ag Summit?

9. What part of the SW Ag Summit needs improvement?

10. What topics would you like to see at a future SW Ag Summit?

11. Are you a member of Yuma Fresh Vegetable Association (YFVA)?

a. Yes b. No

12. If you would like information about YFVA, please include the following information:

Name _____

Email/Phone _____

Students taking test

Students with questions

Students watching Veggie Man video

Fill Your Plate with Veggies Quiz
Arizona Farm Bureau's Fillyourplate.org

(Instructional Note: Pre-test should be on Blue copy paper; Post-test should be a different color)

1. Does Arizona grow vegetables and fruits? ____ Yes ___ No
2. Which one below is not a fruit or vegetable?
    - Watermelon
    - Broccoli
    - Cabbage
    - Beef
    - All the Above
3. What % of fruits and vegetables should you have on your plate?
    - 20%
    - 75%
    - 0%
    - 50%
4. What Arizona County produces the majority of our vegetables during the winter?
    - Apache
    - Yavapai
    - Yuma
    - La Paz
    - Maricopa
5. Water is essential to growing fruits and vegetables. How do Arizona farmers water their crops?
    a. Drip
    b. Furrow
    c. Sprinkler
    d. All the Above
6. What % of lettuce comes from Yuma, Arizona in the winter?
    a. 10%
    b. 35%
    c. 60%
    d. 90%

Veggie Quiz

① 29 correct, 1 Blank	① 26 correct, 4 blank
② 29 correct, 1 wrong	② 28 correct, 2 wrong
③ 12 correct, 18 wrong	③ 6 correct, 24 wrong
④ 13 correct, 17 wrong	④ 27 correct, 3 wrong
⑤ 14 correct, 16 wrong	⑤ 26 correct, 4 wrong
⑥ 2 correct, 28 wrong	⑥ 25 correct, 5 wrong

Tables

Table 1. Computed total nitrogen application rates and uniformity indices for data set I

			Upstream end test-plot							Middle test-plot							Downstream end test-plot						
			Rain gage index parallel to mainline							Rain gage index parallel to mainline							Rain gage index parallel to mainline						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
			Application rate (g/m^2)							Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index parallel to laterals		1	2.4	0.8	1.0	1.5	2.1	1.8	1.1	1.8	0.3	1.5	1.7	-	-	0.7	1.3	1.2	1.0	-	1.8	-	1.7
		2	1.1	1.3	0.9	1.5	1.9	1.9	0.5	1.3	1.1	0.3	-	-	1.4	0.8	1.0	0.9	1.2	1.7	1.7	-	1.7
		3	1.0	1.3	1.9	1.2	1.6	1.8	-	2.0	0.5	0.8	1.7	-	0.9	0.4	0.6	1.0	1.2	1.8	2.2	2.0	2.2
		4	1.3	1.3	1.0	1.5	1.7	1.7	1.2	1.2	1.1	1.1	1.2	-	0.6	0.8	0.3	1.0	1.7	1.5	2.3	-	2.7
		5	0.8	1.8	1.5	2.3	1.7	1.5	1.5	1.7	1.4	1.4	1.1	-	0.5	0.3	0.3	0.7	1.8	1.3	2.1	2.3	1.8
		6	0.7	1.3	1.5	2.2	1.8	1.5	1.0	0.0	0.9	1.2	1.5	1.5	1.0	1.1	0.7	0.6	1.4	1.5	2.0	2.2	1.7
		Unit																					
Average wind speed during fertigation test		*m/s*	1.2																				
Duration of test irrigation event/fertigation event		*h*	3.0/3.0																				
Dimension	Test-plot	*ft*	30.0×35.0							30.0×35.0							30.0×35.0						
	Farm block	*ft*	210.0×430.0							210.0×430.0							210.0×430.0						
Test-plot Scale	Average rate	*g/m^2*	1.4							1.1							1.5						
	UCC	-	0.755							0.655							0.665						
	DU_{lq}	-	0.607							0.416							0.459						
Field scale	Minimum rate	*g/m^2*	0.3																				
	Maximum rate	*g/m^2*	2.7																				
	Average rate	*g/m^2*	1.3																				
	UCC	-	0.692																				
	DU_{lq}	-	0.494																				

Based on irrigation depth and nitrogen concentration measured on 02/23/2013, Yuma Valley Irrigation Districts

Table 2. A summary of the average, maximum, and minimum water depths, total nitrogen concentrations, and application rates along with uniformity indices at test-plot and field scales: data sets I, II, III, and IV

		Data set I									Data set II								
		Test-plot scale data									Test-plot scale data								
		Upstream end test-plot			Middle test-plot			Downstream end test-plot			Upstream end test-plot			Middle test-plot			Downstream end test-plot		
		Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate
		mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2
Test-plot Scale	Average	13.1	110.3	1.4	12.4	94.0	1.1	13.3	104.7	1.5	14.8	43.5	0.700	14.3	35	0.5	14.0	24.8	0.4
	UCC (-)	0.883	0.799	0.755	0.847	0.679	0.655	0.864	0.700	0.665	0.869	0.757	0.666	0.818	0.714	0.607	0.851	0.645	0.613
	DUlq (-)	0.820	0.656	0.607	0.731	0.492	0.416	0.803	0.507	0.459	0.791	0.587	0.475	0.716	0.598	0.498	0.777	0.450	0.493
Field-scale		Field-scale data									Field-scale data								
		Depth			Conc			Applic. rate			Depth			Conc			Applic. rate		
		mm			mg/L			g/m^2			Mm			mg/L			g/m^2		
	Average	12.9			102.9			1.3			14.4			34.4			0.5		
	Minimum	7.6			22.1			0.3			7.2			1.6			0.1		
	Maximum	19.1			220.3			2.7			19.1			80.3			1.5		
	UCC (-)	0.864			0.726			0.692			0.846			0.705			0.629		
	DUlq (-)	0.784			0.552			0.494			0.761			0.545			0.489		
Test-plot Scale																			
		Data set III									Data set IV								
		Test-plot scale data									Test-plot scale data								
		Upstream end test-plot			Middle test-plot			Downstream end test-plot			Upstream end test-plot			Middle test-plot			Downstream end test-plot		
		Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate
		mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2
	Average	6.6	299.1	2.0	7.0	280.2	1.9	8.5	250.9	2.2	12.6	204.1	2.5	14.3	223.4	3.2	12.6	231.6	2.8
	UCC (-)	0.728	0.808	0.648	0.645	0.773	0.614	0.728	0.805	0.680	0.744	0.872	0.759	0.776	0.898	0.770	0.724	0.874	0.774
	DUlq (-)	0.605	0.626	0.487	0.488	0.611	0.509	0.619	0.670	0.500	0.583	0.796	0.666	0.614	0.844	0.625	0.549	0.787	0.654
Field-scale		Field-scale data									Field-scale data								
		Depth			Conc			Applic. Rate			Depth			Conc			Applic. rate		
		mm			mg/L			g/m^2			Mm			mg/L			g/m^2		
	Average	7.4			276.7			2.0			13.2			219.7			2.8		
	Minimum	1.9			68.2			0.3			4.8			144.8			1.2		
	Maximum	19.1			426.4			5.7			19.1			305.9			5.3		
	UCC (-)	0.700			0.795			0.647			0.748			0.881			0.767		
	DUlq (-)	0.571			0.636			0.499			0.582			0.809			0.648		

Table 3 Computed total nitrogen application rates and uniformity indices for data set II

			Test-plot 1							Test-plot 2							Test-plot 3						
			Rain gage index parallel to mainline							Rain gage index parallel to mainline							Rain gage index parallel to mainline						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
			Application rate (g/m^2)							Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index parallel to laterals		1	1.1	-	0.7	0.8	0.6	0.4	0.2	0.3	0.3	0.6	0.4	0.4	0.6	0.2	0.6	0.4	0.1	0.2	0.2	-	0.4
		2	1.2	1.1	0.9	0.4	0.6	0.3	0.3	0.3	0.5	0.6	0.2	0.2	0.3	0.4	0.6	0.6	0.2	0.2	0.1	0.4	-
		3	0.7	1.1	0.9	0.4	0.6	0.6	-	0.4	0.4	0.3	0.4	0.4	0.6	-	0.4	0.4	0.3	0.2	0.5	0.6	0.3
		4	0.7	0.4	0.6	0.6	0.7	-	0.7	0.3	0.3	0.6	0.5	0.7	1.1	-	0.3	0.2	0.3	0.2	0.7	0.5	-
		5	0.7	0.5	0.3	0.6	0.8	1	1.1	0.8	0.2	0.4	0.5	-	1.5	0.5	0.2	0.4	0.2	0.4	0.4	0.5	0.8
		6	-	1.1	0.5	0.6	0.3	0.6	0.2	-	0.9	0.5	0.5	1	-	0.9	-	0.4	0.2	0.3	0.5	0.3	0.2
		Unit																					
Average wind speed during fertigation test		*m/s*	4.5																				
Duration of test irrigation event/fertigation event		*h*	3.0/3.0																				
Dimension	Test-plot	*ft*	30.0×35.0							30.0×35.0							30.0×35.0						
	Farm block	*ft*	140.0×430.0							140.0×430.0							140.0×430.0						
Test-plot Scale	Average rate	g/m^2	0.7							0.5							0.4						
	UCC	-	0.666							0.607							0.613						
	DU_{lq}	-	0.475							0.498							0.493						
Field scale	Minimum rate	g/m^2	0.1																				
	Maximum rate	g/m^2	1.5																				
	Average rate	g/m^2	0.5																				
	UCC	-	0.629																				
	DU_{lq}	-	0.489																				

Based on irrigation depth and nitrogen concentration measured on 02/28/2013in the Yuma Valley Irrigation Districts

Table 4. Computed total nitrogen application rates and uniformity indices for data set III

			Upstream end test-plot							Middle test-plot							Downstream end test-plot						
			Rain gage index parallel to mainline							Rain gage index parallel to mainline							Rain gage index parallel to mainline						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
			Application rate (g/m^2)							Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index parallel to laterals		1	2.0	3.3	3.3	2.9	2.4	2.6	1.2	5.7	3.0	2.8	1.8	1.9	1.4	1.9	4.9	5.4	2.8	2.7	2.8	1.9	3.6
		2	1.2	2.7	3.2	2.1	0.7	0.9	1.3	4.2	2.9	2.3	1.5	0.9	1.5	0.7	2.8	2.2	2.4	2.1	1.3	2.2	-
		3	1.7	2.7	1.8	1.9	1.3	-	1.1	2.5	2.4	2.3	1.2	1.1	0.8	0.9	0.9	2.8	1.9	1.9	1.2	1.4	1.6
		4	1.6	2.3	2.4	1.7	1.6	1.6	1.0	1.9	2.3	1.5	1.1	-	1.2	1.0	1.5	2.0	2.0	1.3	1.2	0.3	0.7
		5	2.8	2.4	-	1.1	0.4	1.6	1.8	2.4	1.8	1.2	1.2	1.5	1.1	1.5	2.2	2.2	2.7	2.0	1.0	1.8	2.0
		6	5.5	3.1	-	2.4	1.6	-	2.0	3.6	2.2	2.5	1.9	1.1	3.1	-	3.7	3.3	2.0	1.9	2.2	1.7	2.1
		Unit																					
Average wind speed during fertigation test		*m/s*	3.3																				
Duration of test irrigation event/fertigation event		*h*	3.4/3.4																				
Dimension	Test-plot	*ft*	30.0×35.0							30.0×30.0							30.0×35.0						
	Farm block	*ft*	105.0×410.0							105.0×410.0							105.0×410.0						
Test-plot scale	Average rate	g/m^2	2.0							1.9							2.2						
	UCC	-	0.648							0.614							0.680						
	DU_{lq}	-	0.487							0.509							0.500						
Field scale	Minimum rate	g/m^2	0.3																				
	Maximum rate	g/m^2	5.7																				
	Average rate	g/m^2	2.0																				
	UCC	-	0.647																				
	DU_{lq}	-	0.499																				

Based on irrigation depth and nitrogen concentration measured on 03/01/2013 in the Yuma valley Irrigation Districts

Table 5. Computed total nitrogen application rates and uniformity indices for data set IV

			Upstream end test-plot							Middle test-plot							Downstream end test-plot						
			Rain gage index parallel to mainline							Rain gage index parallel to mainline							Rain gage index parallel to mainline						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
			Application rate (g/m^2)							Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index parallel to laterals		1	3.2	-	2.4	2.1	1.6	2.6	3.3	3.2	2.8	3.3	1.8	1.8	2	2.5	4.2	3.4	2.1	1.8	2.3	2.1	3.3
		2	2.8	3.7	2	1.7	1.2	1.2	2.7	3.6	4.1	2.8	1.7	1.6	2	1.9	2.7	3	2	1.5	1.4	1.3	2
		3	2.2	2.4	2.4	1.7	2	1.9	3.1	2.7	3.5	2.8	2.7	2.3	3.2	2.7	2.7	2.4	2.4	2.3	2	2.3	2.5
		4	1.7	2	2.2	2.9	3.1	3.8	3.8	2.6	3.3	4.1	3.8	3.5	4.2	3.8	2.5	3.6	4.5	3.5	4.1	3.2	2.2
		5	1.8	2.1	3	2.3	3.9	4	-	3.3	3.8	3.9	4.1	4.2	5.3	-	2.9	3.2	4.2	3.4	3.3	3.1	2.7
		6	2.6	3.1	2.2	1.9	2.1	2.7	2.9	2.2	3.5	3.9	3.5	4.2	4.1	3.6	3.9	3.8	2.7	3.3	2.6	2.9	2.8
		Unit																					
Average wind speed during fertigation test		*m/s*	2.2																				
Duration of test irrigation event/fertigation event		*h*	3.0/3.0																				
Dimension	Test-plot	*ft*	30.0×35.0							30.0×35.0							30.0×35.0						
	Farm block	*ft*	81.7×200.0							81.7×200.0							81.7×200.0						
Test-plot scale	Average rate	*g/m^2*	2.5							3.2							2.8						
	UCC	-	0.759							0.770							0.774						
	DU_{lq}	-	0.666							0.625							0.654						
Field scale	Minimum rate	*g/m^2*	1.2																				
	Maximum rate	*g/m^2*	5.3																				
	Average rate	*g/m^2*	2.8																				
	UCC	-	0.767																				
	DU_{lq}	-	0.648																				

Based on irrigation depth and nitrogen concentration measured on 03/02/2013 in the Yuma Valley Irrigation Districts

Table 6. Computed total nitrogen application rates and uniformity indices for data set V

			Upstream end test-plot							Middle test-plot							Downstream end test-plot						
			Rain gage index parallel to mainline							Rain gage index parallel to mainline							Rain gage index parallel to mainline						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
			Application rate (g/m^2)							Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index parallel to laterals		1	1.2	2.4	2.2	1.6	1.1	1.1	1.6	0.9	1.2	2.1	2.3	1.9	1.1	0.9	1.0	1.1	1.4	1.2	1.1	1.4	1.2
		2	1.1	1.3	0.8	1.6	1.9	1.3	1.2	0.7	1.3	1.3	2.6	1.5	1.3	1.0	1.3	1.0	1.3	1.2	1.5	1.4	1.2
		3	1.4	0.9	1.4	1.3	1.3	0.9	1.0	2.0	1.3	0.9	2.3	1.7	1.4	1.3	2.2	2.3	1.1	1.5	2.0	1.3	1.0
		4	1.3	1.1	1.2	1.5	1.4	1.3	1.0	3.0	1.1	1.0	0.8	1.7	2.2	2.5	2.0	2.1	1.1	2.1	1.1	1.2	1.1
		5	1.0	2.0	1.2	1.4	1.4	1.0	1.0	2.0	1.9	1.7	0.9	1.4	1.7	2.0	1.9	0.0	1.8	1.0	1.2	1.6	1.2
		6	0.9	1.0	2.3	0.9	1.3	1.5	1.0	1.9	2.0	2.1	1.6	1.5	1.7	2.4	1.2	1.0	1.0	1.1	1.0	1.4	2.3
		Unit																					
Average wind speed during fertigation test		*m/s*																					
Duration of test irrigation event/fertigation event		*h*	3.0/3.0																				
Dimension	Test-plot	*Ft*	30.0×35.0							30.0×35.0							30.0×35.0						
	Farm block	*Ft*	70.0×400.0							70.0×400.0							70.0×400.0						
Test-plot scale	Average rate	*g/m^2*	1.3							1.6							1.4						
	UCC	-	0.788							0.717							0.768						
	DU_{lq}	-	0.714							0.574							0.740						
Field scale	Minimum rate	*g/m^2*	0.7																				
	Maximum rate	*g/m^2*	3.0																				
	Average rate	*g/m^2*	1.4																				
	UCC	-	0.758																				
	DU_{lq}	-	0.676																				

Based on irrigation depth and nitrogen concentration measured on 03/04/2014 in the Yuma Valley Irrigation Districts

Table 7. A summary of the average, maximum, and minimum water depths, total nitrogen concentrations, and application rates along with uniformity indices at test-plot and field scales: data sets V, VI, VII, and VIII

		Data set V									Data set VI								
		Test-plot scale data									Test-plot scale data								
		Upstream end test-plot			Middle test-plot			Downstream end test-plot			Upstream end test-plot			Middle test-plot			Downstream end test-plot		
		Depth	Conc	Applic. Rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate
		mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2
Test-plot Scale	Average	9.1	144.3	1.3	9.7	168.4	1.6	9.2	154.5	1.4	9.8	206.9	2.0	9.8	182.0	1.8	7.6	200.3	1.5
	UCC (-)	0.948	0.795	0.788	0.897	0.733	0.717	0.920	0.734	0.768	0.757	0.896	0.721	0.826	0.867	0.808	0.783	0.860	0.721
	DUlq (-)	0.921	0.727	0.714	0.855	0.643	0.574	0.891	0.731	0.740	0.690	0.837	0.622	0.756	0.753	0.675	0.616	0.792	0.611
Field-scale		Field-scale data									Field-scale data								
		Depth			Conc			Applic. rate			Depth			Conc			Applic. rate		
		mm			mg/L			g/m^2			mm			mg/L			g/m^2		
	Average	9.3			155.7			1.4			9.1			196.4			1.8		
	Minimum	7.6			84.9			0.7			3.5			102.6			0.7		
	Maximum	12.4			276.3			3.0			16.7			321.4			3.7		
	UCC (-)	0.922			0.754			0.758			0.789			0.874			0.750		
	DUlq (-)	0.889			0.700			0.676			0.687			0.794			0.636		
Test-plot Scale																			
		Data set VII									Data set VIII								
		Test-plot scale data									Test-plot scale data								
		Upstream end test-plot			Middle test-plot			Downstream end test-plot			Upstream end test-plot			Middle test-plot			Downstream end test-plot		
		Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate	Depth	Conc	Applic. rate
		mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2	mm	mg/L	g/m^2
	Average	11.1	230.8	2.5	12.1	241.5	2.9	11.3	218.5	2.5	9.8	211.3	2.0	10.9	208.0	2.3	9.0	159.5	1.5
	UCC (-)	0.870	0.806	0.826	0.877	0.872	0.790	0.881	0.821	0.772	0.632	0.787	0.641	0.652	0.743	0.533	0.697	0.705	0.495
	DUlq (-)	0.794	0.690	0.716	0.793	0.755	0.665	0.802	0.726	0.685	0.497	0.704	0.569	0.532	0.596	0.415	0.613	0.552	0.410
Field-scale		Field-scale data									Field-scale data								
		Depth			Conc			Applic. rate			Depth			Conc			Applic. rate		
		mm			mg/L			g/m^2			mm			mg/L			g/m^2		
	Average	11.5			230.2			2.7			9.9			192.9			1.9		
	Minimum	7.6			113.0			1.2			3.8			56.5			0.4		
	Maximum	167.			291.4			4.5			19.1			358.1			5.2		
	UCC (-)	0.876			0.833			0.796			0.660			0.745			0.556		
	DUlq (-)	0.796			0.724			0.689			0.548			0.617			0.465		

Table 8. Computed total nitrogen application rates and uniformity indices for data set VI

			Upstream end test-plot							Middle test-plot							Downstream end test-plot						
			Rain gage index parallel to the mainline							Rain gage index parallel to the mainline							Rain gage index parallel to the mainline						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
			Application rate (g/m^2)							Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index, parallel to laterals		1	1.3	1.4	0.9	1.4	1.5	2.4	3.4	1.1	2.3	1.9	1.8	2.5	2.9	1.6	1.1	1.0	1.5	2.0	3.1	1.7	2.1
		2	2.6	1.8	1.3	1.2	1.6	1.8	2.0	1.9	2.0	1.5	1.8	-	2.0	2.7	1.6	1.6	-	1.6	1.4	1.2	1.4
		3	3.1	1.6	1.7	1.5	1.7	1.6	1.4	2.1	2.2	1.6	1.6	1.7	1.1	0.8	1.6	1.7	1.4	1.4	1.1	1.2	-
		4	3.3	3.4	2.1	2.0	2.4	1.8	0.9	2.0	1.9	1.5	1.9	2.1	1.2	1.0	1.4	1.2	1.3	1.1	2.0	1.2	-
		5	3.4	2.6	1.4	2.0	2.5	2.2	2.3	1.3	1.6	1.4	1.8	1.9	1.9	1.7	1.1	0.8	0.7	1.6	2.5	3.0	-
		6	2.4	2.0	1.6	1.7	2.6	3.7	2.3	1.2	1.7	1.8	1.6	2.1	3.0	1.8	1.4	0.8	0.7	1.3	2.4	2.3	-
		Unit																					
Average wind speed		*m/s*	2.9																				
Duration of test irrigation/fertigation event		*h*	3.0/1.0																				
Dimension	Test-plot	*ft*	30.0×35.0							30.0×35.0							30.0×35.0						
	Farm block	*ft*	70.0×460.0							70.0×460.0							70.0×460.0						
Test-plot scale	Average rate	*g/m^2*	2.0							1.8							1.5						
	UCC	-	0.721							0.808							0.721						
	DU_{lq}	-	0.622							0.675							0.611						
Field scale	Minimum rate	*g/m^2*	0.7																				
	Maximum rate	*g/m^2*	3.7																				
	Average rate	*g/m^2*	1.8																				
	UCC	-	0.750																				
	DU_{lq}	-	0.636																				

Based on irrigation depth and nitrogen concentration measured on 02/28/2014 in the Yuma Valley Irrigation Districts

Table 9. Computed total nitrogen application rates and uniformity indices for data set VII

			Upstream end test-plot							Middle test-plot							Downstream end test-plot						
			Rain gage index parallel to the mainline							Rain gage index parallel to the mainline							Rain gage index parallel to the mainline						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
			Application rate (g/m^2)							Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index, parallel to laterals		1	2.5	3.7	3.6	2.5	2.3	3.2	2.4	2.1	3.1	2.4	3.9	3.7	2.0	1.8	3.1	2.6	2.2	2.8	2.6	3.3	2.6
		2	3.1	2.9	3.2	2.9	2.3	3.3	2.4	2.1	2.9	3.6	4.2	3.8	2.6	1.8	1.4	1.9	1.9	1.6	1.9	3.4	1.3
		3	2.4	2.2	2.1	1.8	1.9	2.6	2.4	3.0	2.1	3.7	4.1	3.6	2.7	1.5	4.1	2.0	1.6	2.0	1.9	3.2	2.1
		4	1.6	3.2	3.2	1.9	2.6	2.5	2.3	3.2	2.2	4.0	3.8	2.8	3.1	1.8	4.5	3.1	2.3	2.2	2.8	1.7	2.3
		5	1.2	2.9	3.1	1.8	1.8	2.5	2.0	2.6	2.2	3.7	4.0	2.4	2.9	2.6	2.9	2.1	2.9	2.3	3.0	2.7	2.5
		6	2.7	2.6	2.9	3.0	2.0	2.5	2.1	2.6	3.4	2.8	3.1	3.1	3.2	3.6	1.8	2.4	2.2	2.0	3.1	2.1	3.8
		Unit																					
Average wind speed		*m/s*	0.6																				
Duration of test irrigation/fertigation event		*h*	3.0/1.0																				
Dimension	Test-plot	*ft*	30.0×35.0							30.0×35.0							30.0×35.0						
	Farm block	*ft*	70.0×460.0							70.0×460.0							70.0×460.0						
Test-plot scale	Average rate	*g/m^2*	2.5							2.9							2.5						
	UCC	-	0.826							0.790							0.772						
	DU_{lq}	-	0.716							0.665							0.685						
Field scale	Minimum rate	*g/m^2*	1.2																				
	Maximum rate	*g/m^2*	4.5																				
	Average rate	*g/m^2*	2.7																				
	UCC	-	0.796																				
	DU_{lq}	-	0.689																				

Based on irrigation depth and nitrogen concentration measured on 02/27/2014 in the Yuma Valley Irrigation Districts

Table 10. Computed total nitrogen application rates and uniformity indices for data set VIII

			Upstream end test-plot							Middle test-plot							Downstream end test-plot						
			Rain gage index parallel to the mainline							Rain gage index parallel to the mainline							Rain gage index parallel to the mainline						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
			Application rate (g/m^2)							Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index, parallel to laterals		1	3.0	2.7	1.2	1.0	1.9	2.5	1.8	2.2	2.7	1.3	0.7	0.8	1.0	1.4	4.3	1.4	0.6	1.3	1.3	1.1	1.9
		2	3.1	3.1	1.2	1.3	1.2	2.3	2.1	4.4	2.0	1.0	1.1	1.1	0.9	0.9	3.9	2.4	0.4	1.0	1.0	1.0	0.5
		3	2.5	1.4	1.4	1.2	1.7	3.1	1.4	5.0	-	1.4	1.6	1.6	1.8	1.8	2.1	1.4	0.7	0.7	0.9	1.1	0.7
		4	1.5	1.4	0.9	1.2	2.3	2.0	2.3	3.9	1.4	1.9	1.6	1.8	4.7	4.7	5.2	1.2	1.1	0.8	1.4	-	2.4
		5	1.3	1.7	1.1	1.2	1.5	3.8	3.8	2.5	2.0	1.9	3.1	4.2	4.5	3.1	3.0	1.1	0.4	1.3	1.6	2.0	2.4
		6	2.8	3.8	2.0	1.3	1.6	1.0	3.1	4.8	3.5	1.7	0.8	2.6	2.8	2.7	1.4	0.8	1.0	0.7	0.7	1.2	2.6
		Unit																					
Average wind speed		*m/s*	6.5																				
Duration of test irrigation/fertigation event		*h*	3.0/1.0																				
Dimension	Test-plot	*Ft*	30.0×35.0							30.0×35.0							30.0×35.0						
	Farm block	*Ft*	70.0×400.0							70.0×400.0							70.0×400.0						
Test-plot scale	Average rate	g/m^2	2.0							2.3							1.5						
	UCC	-	0.641							0.533							0.495						
	DU_{lq}	-	0.569							0.415							0.410						
Field scale	Minimum rate	g/m^2	0.4																				
	Maximum rate	g/m^2	5.2																				
	Average rate	g/m^2	1.9																				
	UCC	-	0.556																				
	DU_{lq}	-	0.465																				

Based on irrigation depth and nitrogen concentration measured on 02/28/2014 in the Yuma Valley Irrigation Districts

Table 11. A summary of field-scale nitrogen application rates: data sets I to VIII

	Application rate (g/m^2)		
	Minimum	Maximum	Average
Data set I	0.3	2.7	1.3
Data set II	0.1	1.5	0.5
Data set III	0.3	5.7	2.0
Data set IV	1.2	5.3	2.8
Data set V	0.7	3.0	1.4
Data set VI	0.7	3.7	1.8
Data set VII	1.2	4.5	2.7
Data set VIII	0.4	5.2	1.9

Summary of average field-scale application rates (g/m^2)		
Minimum	Maximum	Overall average
0.5	2.8	1.8

Table 12. A summary of nitrogen application rate uniformity indices: data sets I to VIII

Data ID	Type of uniformity index	Irrigation uniformity		
		Test-plot scale		Field-scale average
		Minimum	Maximum	
Data set I	*UCC*	0.655	0.755	0.692
	DU_{lq}	0.416	0.607	0.494
Data set II	*UCC*	0.607	0.666	0.629
	DU_{lq}	0.475	0.498	0.489
Data set III	*UCC*	0.614	0.680	0.647
	DU_{lq}	0.487	0.509	0.499
Data set IV	*UCC*	0.759	0.774	0.767
	DU_{lq}	0.625	0.666	0.648
Data set V	*UCC*	0.717	0.788	0.758
	DU_{lq}	0.574	0.740	0.676
Data set VI	*UCC*	0.721	0.808	0.750
	DU_{lq}	0.611	0.675	0.636
Data set VII	*UCC*	0.772	0.826	0.796
	DU_{lq}	0.665	0.716	0.689
Data set VIII	*UCC*	0.495	0.641	0.556
	DU_{lq}	0.410	0.569	0.465
Uniformity indices		Field-scale average *UCC* and DU_{lq} summary		
		Minimum	Maximum	Overall average
UCC		0.556	0.796	0.700
DU_{lq}		0.465	0.689	0.575

Table 13. Computed test-plot scale bromide application rates: data sets IX, X, XI, and XII

		Data set IX							Data set X						
		Rain gage index parallel to the mainline							Rain gage index parallel to the mainline						
		1	2	3	4	5	6	7	1	2	3	4	5	6	7
		Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index, parallel to laterals	1	1.3	1.1	0.9	0.9	1.0	0.8	1.0	1.4	1.6	1.5	1.1	1.0	1.2	1.5
	2	1.0	1.0	1.0	1.0	0.9	0.8	0.8	1.3	1.5	1.2	1.0	1.0	1.0	1.2
	3	1.0	0.9	1.0	1.0	1.0	0.8	0.8	1.5	1.4	1.2	1.1	1.0	1.0	1.1
	4	1.0	0.9	1.0	1.0	0.9	0.8	0.8	1.5	1.6	1.1	1.2	1.1	0.9	1.3
	5	0.9	1.1	0.9	0.8	0.9	0.9	0.8	1.4	1.3	1.3	1.2	1.1	1.1	1.2
	6	1.1	0.9	0.7	0.8	0.8	0.7	1.0	1.5	1.5	1.3	1.1	0.7	0.7	1.4
		Data set XI							Data set XII						
		Rain gage index parallel to the mainline							Rain gage index parallel to the mainline						
		1	2	3	4	5	6	-	1	2	3	4	5	6	-
		Application rate (g/m^2)							Application rate (g/m^2)						
Rain gage index, parallel to laterals	1	1.2	1.4	1.6	1.3	1.7	1.3	-	1.6	1.8	2.0	2.0	1.8	1.6	-
	2	1.4	1.5	1.6	1.5	1.2	1.5	-	1.6	1.8	1.9	1.7	1.7	1.3	-
	3	1.1	1.2	1.3	1.2	1.2	1.1	-	1.5	1.8	1.5	1.6	1.5	1.4	-
	4	0.9	1.2	1.4	1.2	1.1	1.1	-	1.3	1.4	1.8	1.7	1.6	1.3	-
	5	0.8	1.0	2.4	1.5	1.3	1.0	-	1.3	1.6	1.5	1.8	1.2	1.2	-
	6	1.2	1.3	1.9	1.7	1.6	1.1	-	1.6	1.3	1.6	1.4	1.5	1.6	-

Based on irrigation depth and bromide concentration measured on 03/28/2014, 03/31/2014, 04/03/2014, and 04/04/2014 in the Maricopa Agricultural Center of the University of Arizona. Note that data sets IX, X, XI, and XII were collected in test-plots I, II, III, and IV (Figure 9), respectively.

Table 14. A summary of the test-plot scale average, maximum, and minimum water depths, bromide concentrations, and application rates along with uniformity indices: data sets IX, X, XI, and XII

		Data set IX			Data set X		
		Test-plot scale data			Test-plot scale data		
		Depth	Conc	Applic. rate	Depth	Conc	Applic. rate
		mm	mg/L	g/m^2	mm	mg/L	g/m^2
Test-plot Scale	Average	10.3	88.3	0.9	10.2	119.3	1.2
	Minimum	8.1	78.8	0.7	7.6	72.8	0.7
	Maximum	14.3	100.3	1.3	14.3	140.3	1.6
	UCC (-)	0.903	0.954	0.895	0.853	0.932	0.852
	DU_{lq} (-)	0.867	0.932	0.853	0.792	0.880	0.771
		Data set XI			Data set XII		
		Test-plot scale data			Test-plot scale data		
		Depth	Conc	Applic. rate	Depth	Conc	Applic. rate
		Mm	mg/L	g/m^2	mm	mg/L	g/m^2
Test-plot Scale	Average	12	111.6	1.3	12.6	125.1	1.6
	Minimum	8.1	80.8	0.8	9.5	98.3	1.2
	Maximum	14.3	208.8	2.4	14.3	145.8	2.0
	UCC (-)	0.899	0.885	0.830	0.894	0.913	0.890
	DU_{lq} (-)	0.822	0.840	0.771	0.855	0.861	0.824

Data sets IX, X, XI, and XII were collected in test-plots I, II, III, and IV, respectively

Figures

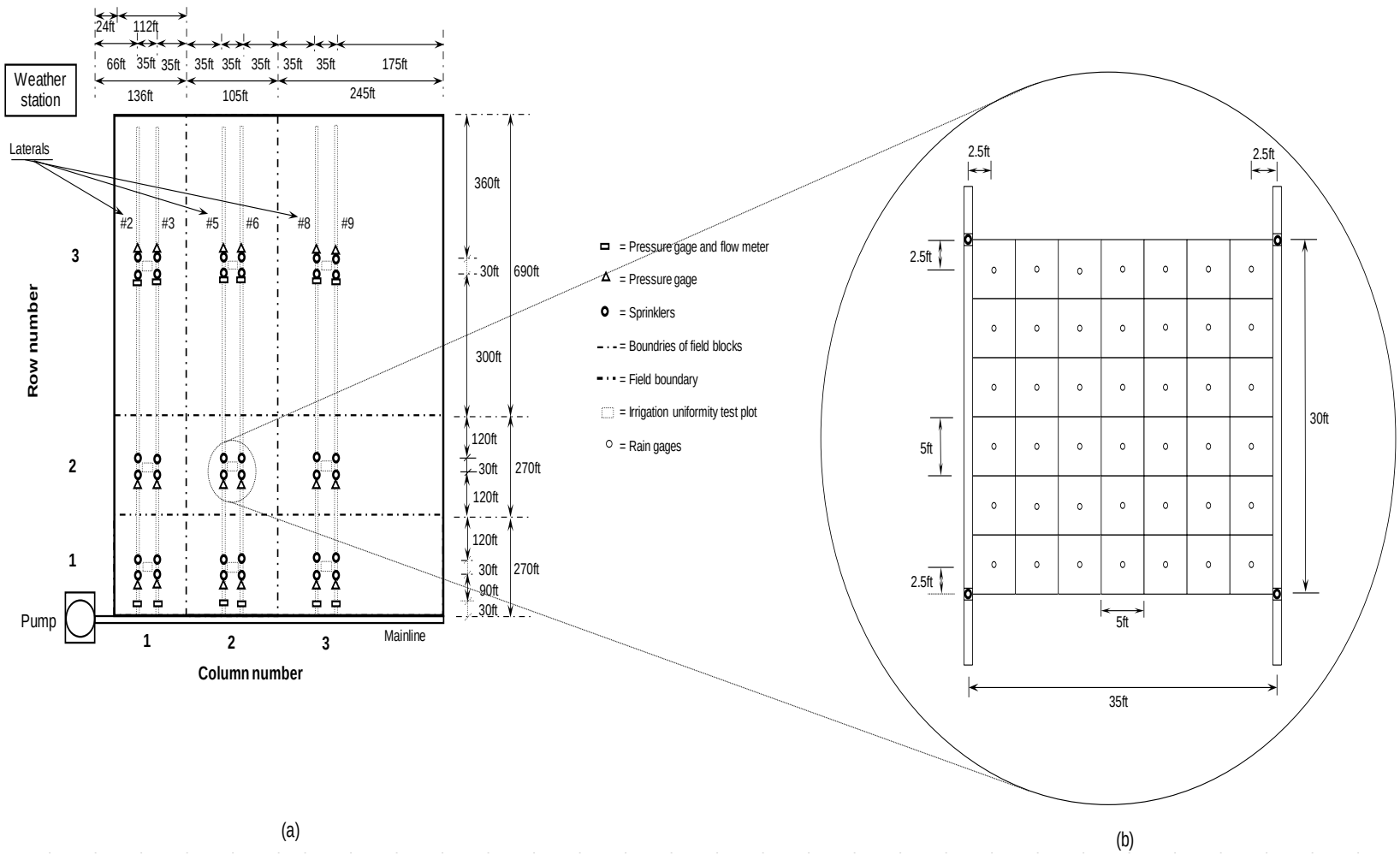

Figure 1. Field-scale irrigation uniformity evaluation (Zerihun et al., 2011): (a) Spatial distribution of uniformity evaluation plots and associated field blocks and (b) Layout of an irrigation uniformity evaluation plot

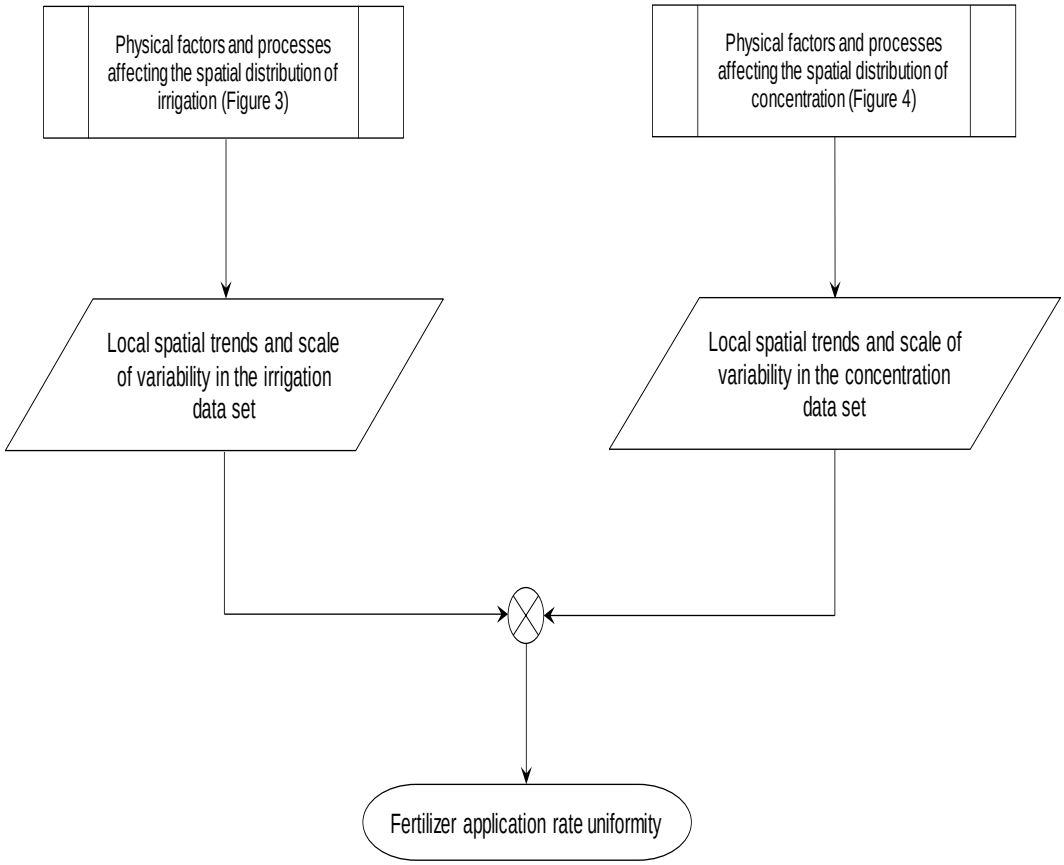

Figure 2. Flow diagram depicting the dependence of fertilizer application rate uniformity on the spatial variability of irrigation and concentration data sets

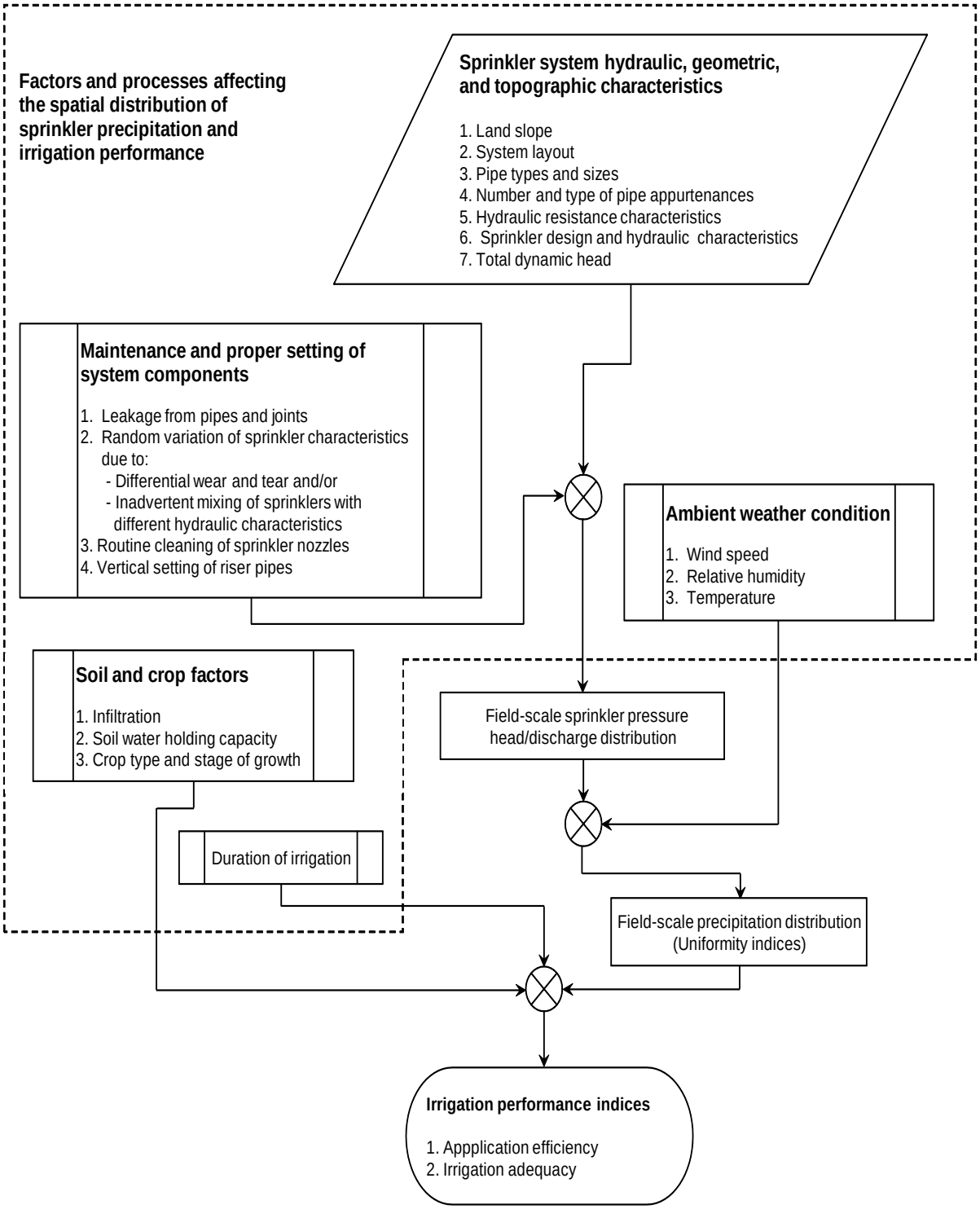

Figure 3. Flow diagram depicting the interplay of factors and processes affecting the field-scale spatial distribution of sprinkler precipitation and irrigation performance

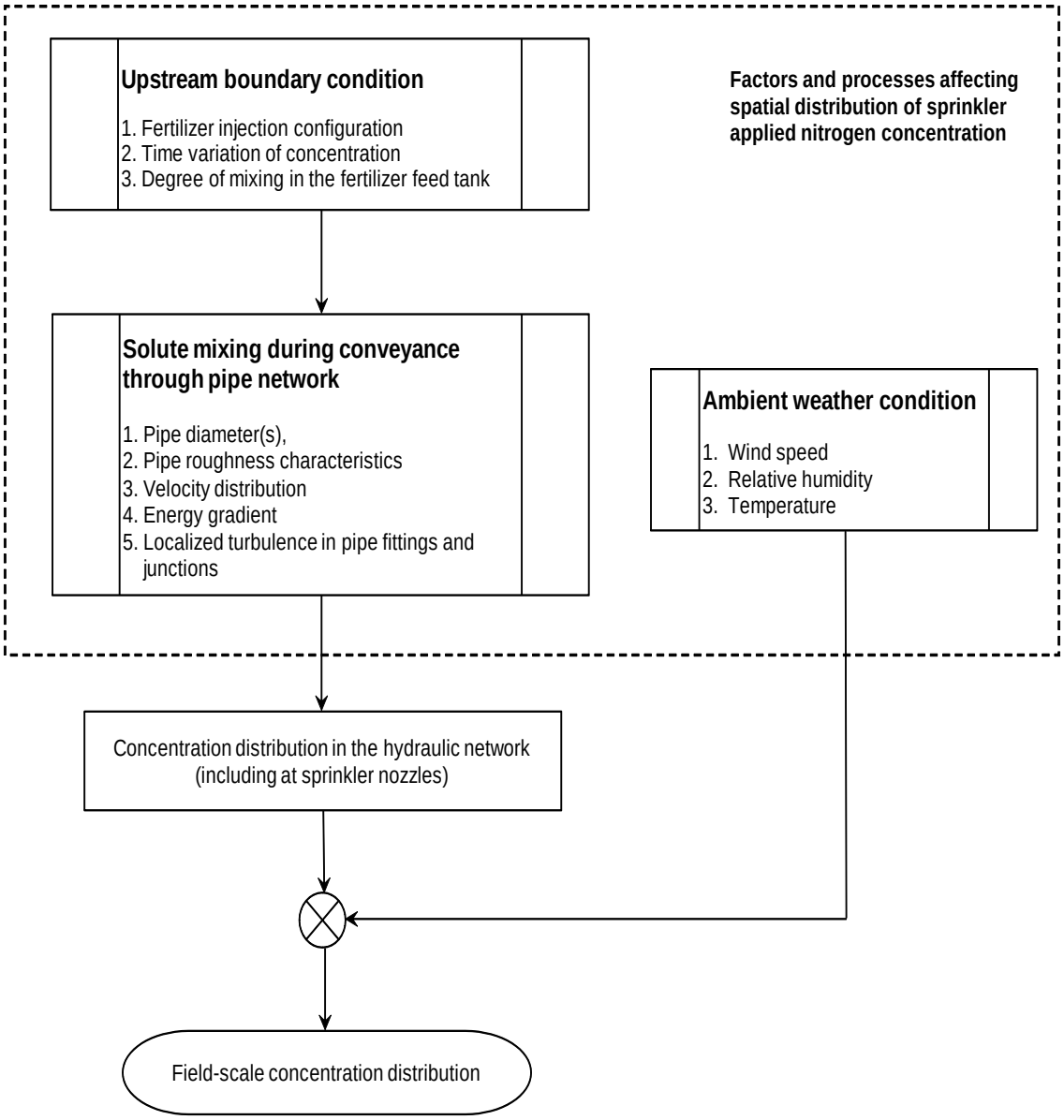

Figure 4. Flow diagram depicting factors and mechanisms affecting the field-wide spatial distribution of the concentration of sprinkler applied nitrogen fertilizer

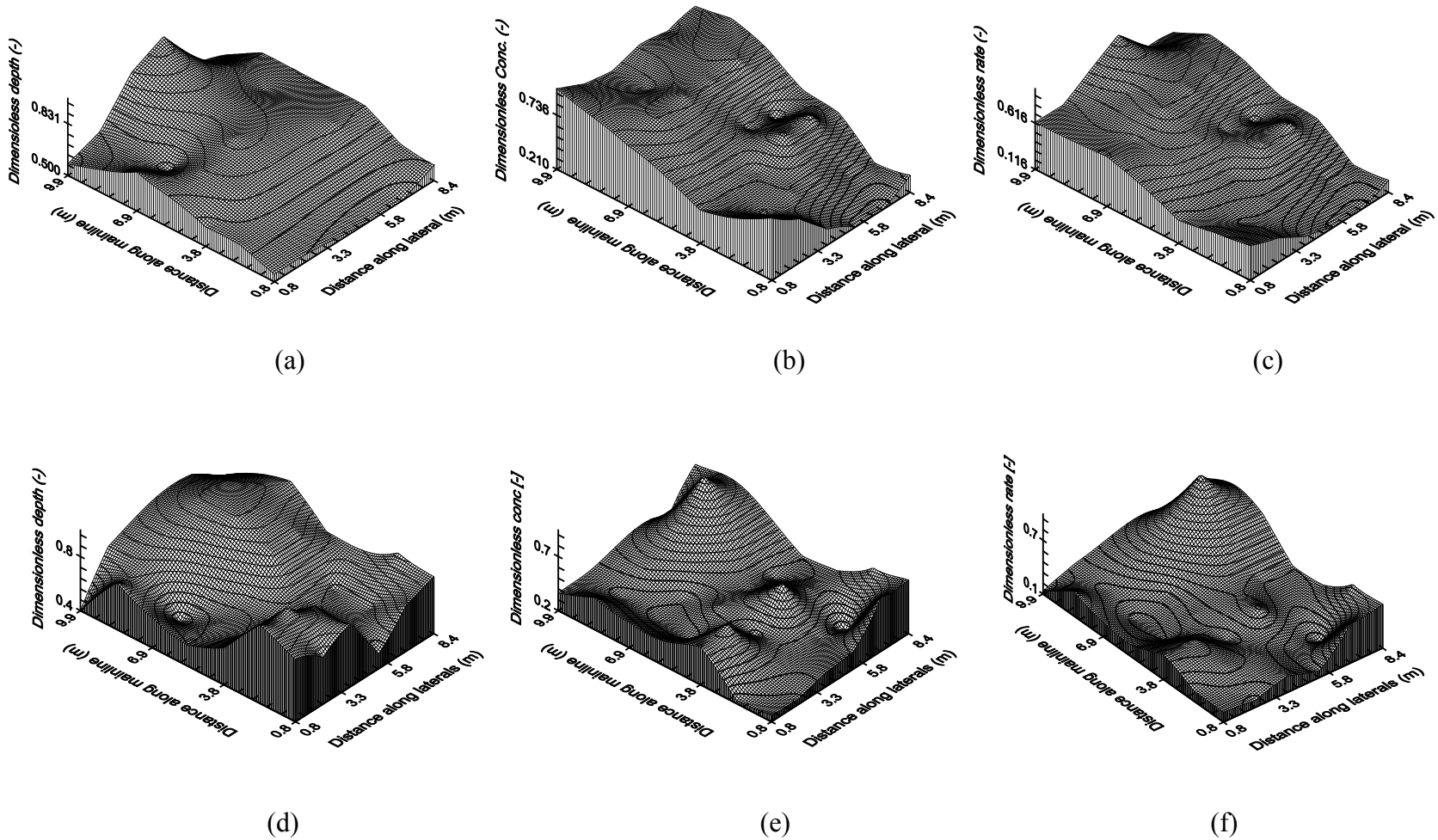

Figure 5. Dimensionless spatial distribution of (a) Irrigation depth (data set I, downstream end test-plot), (b) Nitrogen concentration (data set I, downstream end test-plot), (c) Nitrogen application rate (data set I, downstream end test-plot), (d) Irrigation depth (data set II, middle test-plot), (e) Nitrogen concentration (data set II, middle test-plot), and (f) Nitrogen application rate (data set II, middle test-plot)

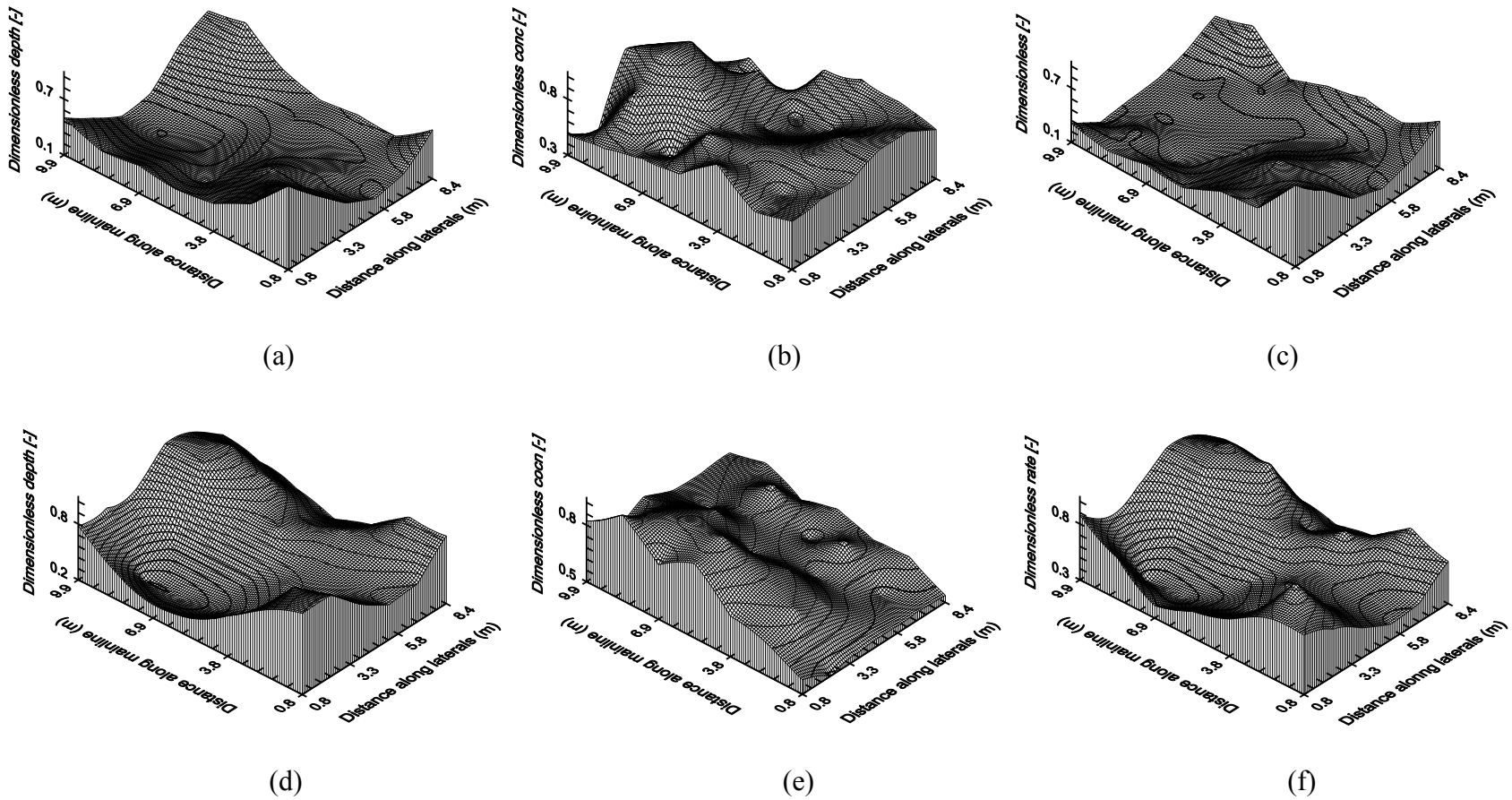

Figure 6. Dimensionless spatial distribution of (a) Irrigation depth (data set III, middle test-plot), (b) Nitrogen concentration (data set III, middle test-plot), (c) Nitrogen application rate (data set III, middle test-plot), (d) Irrigation depth (data set IV, upstream end test-plot), (e) Nitrogen concentration (data set IV, upstream end test-plot), and (f) Nitrogen application rate (data set IV, Upstream end test-plot)

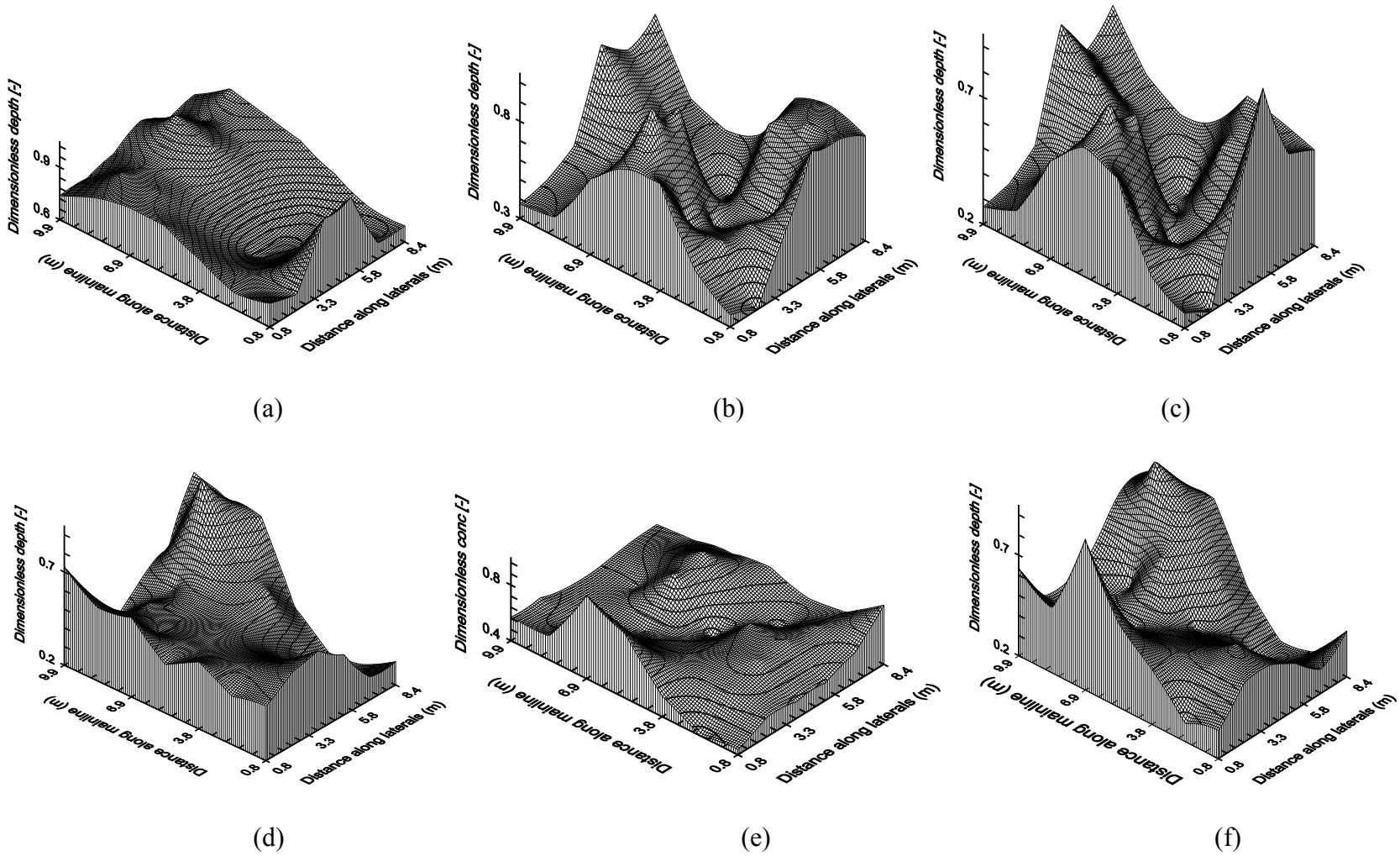

Figure 7. Dimensionless spatial distribution of (a) Irrigation depth (data set V, middle test-plot), (b) Nitrogen concentration (data set V, middle test-plot), (c) Nitrogen application rate (data set V, middle test-plot), (d) Irrigation depth (data set VI, downstream end test-plot), (e) Nitrogen concentration (data set VI, downstream end test-plot), and (f) Nitrogen application rate (data set VI, downstream end test-plot)

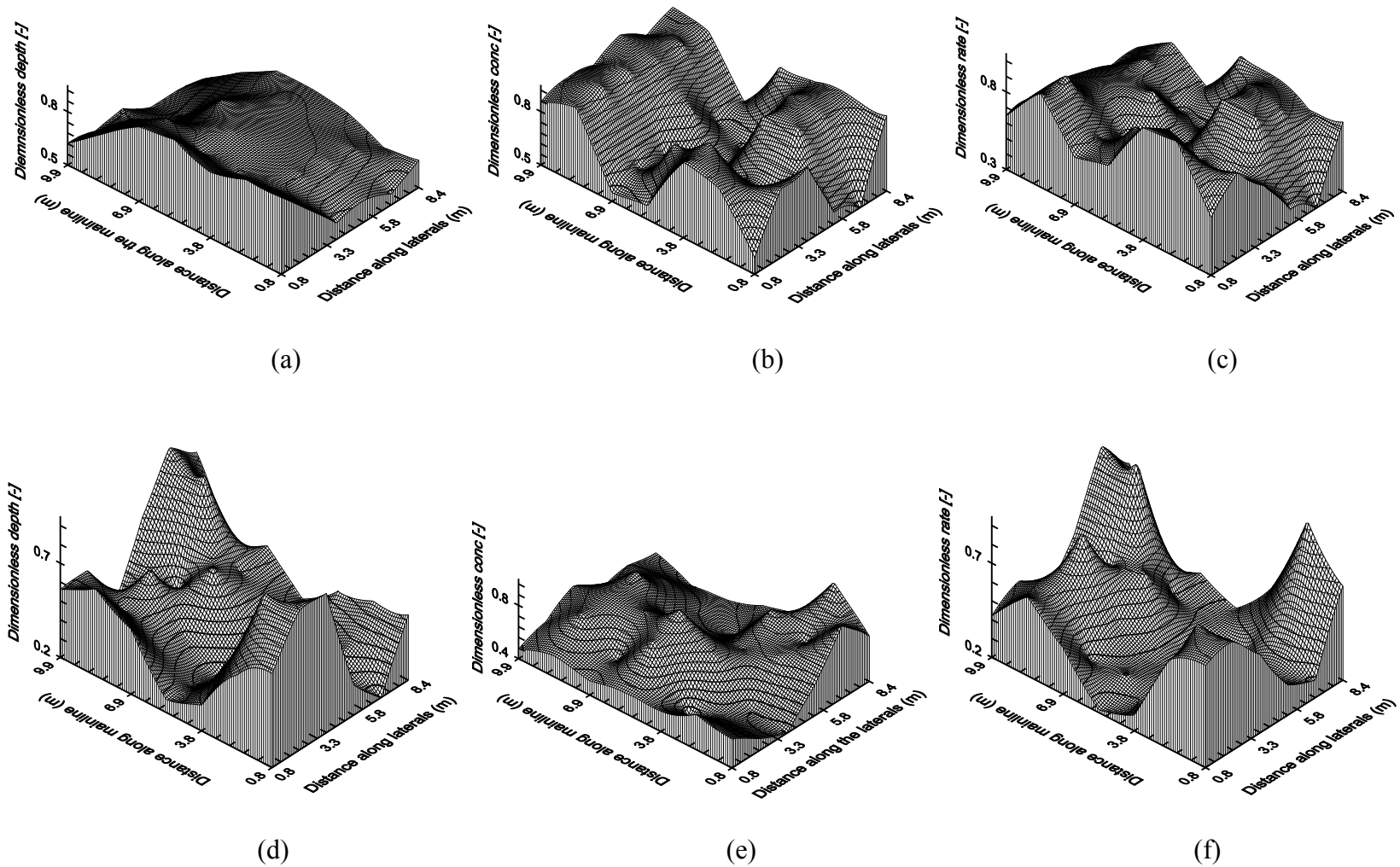

Figure 8. Dimensionless spatial distribution of (a) Irrigation depth (data set VII, upstream end test-plot), (b) Nitrogen concentration (data set VII, upstream end test-plot), (c) Nitrogen application rate (data set VII, upstream end test-plot), (d) Irrigation depth (data set VIII, upstream end test-plot), (e) Nitrogen concentration (data set VIII, upstream end test-plot), and (f) Nitrogen application rate (data set VIII, upstream end test-plot)

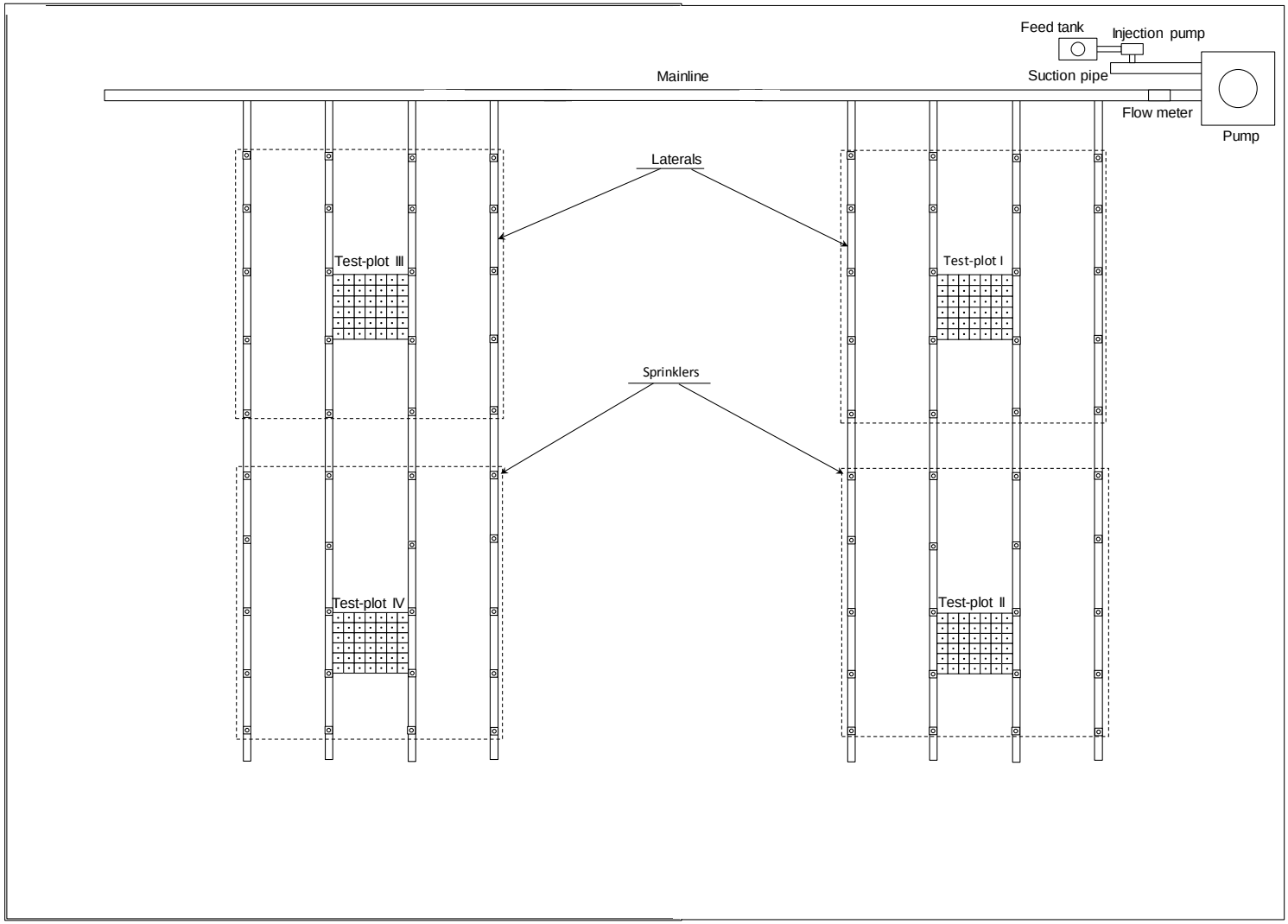

Figure 9. Layout of test-plots for the Bromide tracer study, Maricopa Agricultural Center (Note that fertilizer application configurations 1, 2, 3, and 4 were implemented in test-plot I, II, III, and IV, respectively)

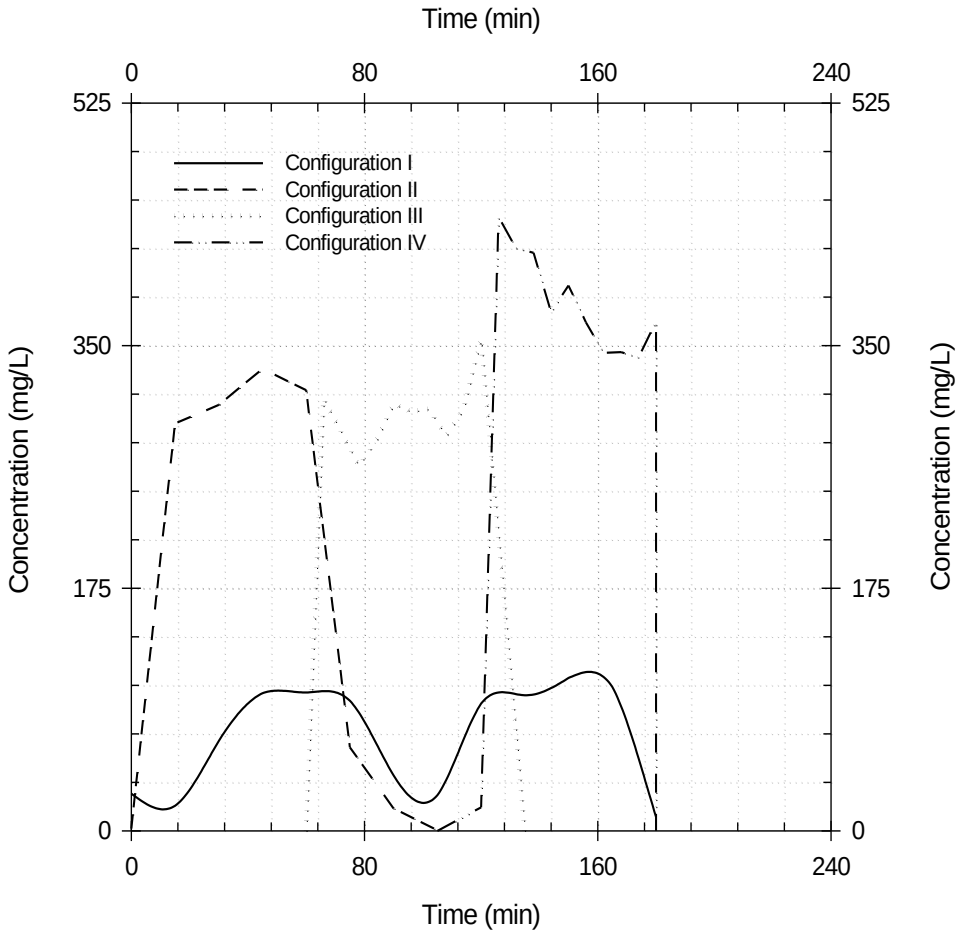

Figure 10. Measured bromide breakthrough curves at the sprinkler system inlet corresponding to the four solute application configurations