Arizona Department of Agriculture

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Introduction

On September 24, 2014, 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 $1,105,843.55 in FY14 Specialty Crop Block Grant Program – Farm Bill funds to fund eighteen 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, six education projects and ten research projects and are one to three years in duration. The expiration of the grant period is September 29, 2017.

2014 Arizona Edible School Gardens

This project was completed on September 30, 2016

Project Summary

Today's children may be the first generation of Americans whose life expectancy will be shorter than that of their parents. Seventy-five percent (75%) of Americans eat less than two servings of fruits and vegetables per day. Connecting people to their food source and educating them about the importance including 5 – 13 servings of nutritious fruits, vegetables and nuts into their diet – every day – is paramount to arresting this unhealthy trend.

The purpose of this project is to create 50 edible school gardens in Arizona in order to provide access to fruits and vegetables, teach children the importance of good nutrition and increase the demand for specialty crops.

Project Purpose

The Western Growers Foundation's objective is to plant and sustain a fruit and vegetable garden in every willing Arizona school. Edible school gardens give children the opportunity to learn where their food comes from and the importance of good nutrition.

This project was important because it helps children to learn about the fruits and vegetables that they eat, improves healthy eating, and builds awareness among the general public. This is timely because of the obesity epidemic that is plaguing our nation.

These funds allowed us to reach more schools and further build out the network of school garden programs, reaching more students, and re-reaching some students.

Project Activities

School gardens were established in 50 schools, and we collected 1535 survey responses from students that participated in the gardens.

First Quarter (Oct. 2014 – Dec. 2014) Activities:

- Updated online grant application to fix bugs, add garden budget template and update questions

- Worked with Arizona Department of Education and other organizations to solicit applicants via e-newsletters and social media
- Fielded questions from grant applicants via phone and email; followed-up with applicants with incomplete applications to offer assistance

Second Quarter (Jan. 2015 – Mar. 2015) Activities:

- Fielded questions from grant applicants via phone and email; followed-up with applicants with incomplete applications to offer assistance
- Extended the application deadline to February 3rd to allow applicants with incomplete applications to finish them and had 155 applications in total
- All applications were reviewed and scored based on proposed garden plans and budgets, school and community support and overall need.

Third Quarter (Apr. 2015– June 2015) Activities:

- Announced 50 grant winners and distributed grant packages (including a copy of Arizona Gardens for Learning book, Producepedia bookmarks and seeds) in April http://www.csgn.org/news/2015-arizona-school-garden-grant-winners
- Began collecting Commitment Statements from grant recipient schools
- Earned media: http://svherald.com/content/bisbee-news/2015/06/27/397134

Fourth Quarter (July 2015 – Sept. 2015) Activities:

- Collected Grant Commitment Statements from grant recipients; fielded questions regarding grant purchases
- Began working on the creation of benchmark survey(s) to measure Expected Measurable Outcomes

First Quarter (Jan. 2016 – Mar. 2016) Activities:

- Fielded questions from grant applicants via phone and email; followed-up with applicants with incomplete applications to offer assistance
- Received and compiled data from student surveys

Second Quarter (Apr. 2016– June 2016) Activities:

- Assisted grant recipients with follow up documentation

Goals and Outcomes Achieved

The goals of this project were to create 50 edible school gardens and increase the number of children with an understanding of good nutrition and where food comes from. WGF was able to meet the goal of 50 edible school gardens by giving out 50 $1500 grants to K-12 schools in Arizona. The other project goal was largely successful with over 1,500 student surveys returned. Of the 1,535 students, we found that 75% of students worked in the garden at least once a week. Their work included planting seeds (65%), pulling weeds (55%), and harvesting (40%).

In addition to meeting the project goals, WGF was able to collect some valuable and interesting statistics about the use of these edible gardens. According to the survey submissions, WGF found that all schools used the school garden program to advance their STEM curriculum.

Beneficiaries

All specialty crop growers in AZ benefited from increased awareness of their products among school age children. A total of 50 schools in AZ benefited from the project. The grant recipients were able to use their funds to plant and sustain a fruit and vegetable garden, giving children the opportunity to learn where their food comes from.

Lessons Learned

School gardens can be incorporated to support the STEM curriculum. We found that schools were using the garden to teach lessons in multiple subjects considering that a successful garden requires buy-in from the entire school. WGF has found that the interest and need for school gardens is continuing to grow in support of the STEM curriculum. Additional benefits include engaging the children through physical activity and encouraging healthier eating habits.

Next time we will implement a more quantitative and rigorous survey methodology to more clearly demonstrate changes in student behavior and attitudes towards fresh fruits and vegetables. We will also look at ways to measure longer term interest and engagement in growing fruits and vegetables. And we would like to engage more of the faculty to better understand the breadth of the garden benefits thought the site.

Contact Person

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2015 SWAS – An Collaborative Educational Conference

This project was completed on February 29, 2016

Project Summary

The 2015 Southwest Ag Summit was held on February 25 and 26, on the Arizona Western College (AWC) campus on the outskirts of Yuma Arizona. We brought together people, knowledge and equipment and presented it to the agriculture workforce operating in this arid region of the Southwest. This year in partnership with the University of Arizona Cooperative Extension, Yuma County Farm Bureau, AWC and the Yuma Fresh Vegetable Association we made available to the attendees the demonstration of new and refitted equipment and irrigation techniques. Our presenters brought forth information on laws and regulations, Integrated Pest Management, plant nutrition, food safety updates, as well as, marketing. This was all centered around the Specialty Crop Business. Our ongoing drought has our water supply becoming a critical issue so we added a water panel this year made up of the major water districts and managers of the southwest. This included the Central Arizona Project, Salt River Project, Metropolitan Water district as well as the Wellton Mohawk Irrigation District and the Yuma County Water Users Association. As a bonus, the International Spinach Symposium chose to hold their event in conjunction with our Summit.

Project Purpose

Our objective and purpose have been the same since the inception of the Southwest Ag Summit. To make available to the growers and producers of specialty crops, new and vital information on

research, cutting edge technology and hands on demonstrations of equipment and technology crucial for the production of produce here in the desert southwest.

The 2015 SWAS set goals to expand our target audience by increasing the attendance of produce and melon growers. We wanted to measure the increase of outreach of our information by surveying attendees as to how likely they would share this information amongst friends, co-workers amd industry acquaintances. Also with this being our second year of holding the field demos on the AWC Land Lab, we wanted to increase the attendance at this very equipment and preparation heavy portion of our event.

Our Summit is held in February of each year because we are starting to wind down in our production of specialty crops but still have a full workforce engaged and living in Yuma. Those people critical to production can take time to attend and participate. This information can not only be taken north to California's specialty crop production areas and utilized extensively but also for next fall in the next Yuma growing cycle.

Out water panel and breakout was most critical for Yuma and California due to the extensive drought that has taxed our water systems. River system management, urban use and future planning were of great interest and importance to the attendees.

This is our 9th annual event. Recently, the grant has allowed us to reach out further to an interested audience enabling us to find quality speakers and move into areas like marketing and water that attracts more and more diversified attendees. Putting money into the AWC Land Lab allows us to offer more in the way of field demonstrations.

Project Activities

Planning – We start almost as soon as the Summit is over but prior to the grant time period. However, once October hits we start with meeting and planning of all the pieces that need to come together for a successful Summit:

- We spend many hours discussing content of the summit. Big question is what will attract a large attendance. Being a SCBGP recipient we take great care to stay on the target of specialty crops. We do include a few commodity breakouts due to this diverse area that we farm in. Utilizing the expertise of the University of Arizona Research Farm, specifically Dr. John Palumbo, we look for and get speakers to address current problems and sometime future issues looming on the horizon.
- AWC has become the venue of choice due to the classrooms, auditoriums, IT expertise and state of the art electronics that are so necessary for great presentations. Rooms have to be booked in advance, Land Lab discussions, meal planning, and logistics.
- Marketing is a must if you want people to attend. WEB site changes, social media, a booth at the Farm Bureau Annual Meeting, advertisements, and the Insider Magazine are all directed in bringing more people to the event.
- Land Lab required pre-plant work so that the thinners have something to thin. Mulching, disking, listing, bed shaping and irrigation all came together in a timely fashion.
- Registration, name tags and signage all were ready on opening day.

This year in anticipation of non-grant qualified events we sat down with AWC and asked them to do two billings: one for non-qualified and one for qualified. This included room rent, IT,

security, registration etc. In those areas where the general audience experienced our event we took only 80% of the monies from SCBGP. 80% was derived from a survey we take during lunch to gauge who our audience is and where they take this information after they leave the Summit.

Goals and Outcomes Achieved

First Expected Measurable Outcome

- Increase the attendance of the 2015 SWAS Academic Programs by vegetable and melon industry members (Goal) by 10% from 600 (Benchmark) to 660 (Target) measured by surveys, registration and attendance lists (Performance Measure).

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

Value Label	Frequency	Percent	Valid Percent
(Blank)	1	.34	
Yes	250	84.18	84.46
No	46	15.49	15.54
Total	297	100	

84.46% of the 296 people who answered question 2 of the survey indicated that their occupation involves the melon or vegetable industry. Applying that percentage to the total number of paid participants (841), it is estimated that **711 participants** whose occupations involve the melon and vegetable industry attended the Academic Programs of the 2015 SWAS. This exceeds our goal considerably.

Second Expected Measureable Outcome

- Increase the reach of the SWAS by measuring how likely attendees are to share materials with coworkers and/or staff unable to attend the SWAS (Goal) by 10%, from 288 people (Benchmark) to 320 people (Target) measured by survey questions about participants' sharing SWAS materials (Performance Measure).

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

3. "If you share the information, with whom will you share it?"
Multiple Answers – Notes people who circled any way they will share in the materials.

	Share with Whom?	
Melon or Vegetable Occupation?	*Yes*	*No*
Staff	*112 (44.8%)*	*138*
Coworkers	*222 (88.8%)*	*28*
Media	*34 (13.6%)*	*216*
Friends/Family	*130 (52%)*	*120*

*Note: Only includes those who said their occupation involves the melon or vegetable industry.

Of those who answered "Yes" to question number 2 of the survey indicating that their occupation involved the melon or vegetable industry **112 or 44.8%** indicated they would share their materials with **Staff**. Of those who answered "Yes" to question number 2 of the survey indicating that their occupation involved the melon or vegetable industry **222 or 88.8%** indicated they would share their materials with **Coworkers**.

Applying those percentages to the total estimated number of participants (**711) participants** whose occupations involve the melon and vegetable industry, it is estimated that **319 or 44.8%** will share the materials with staff and **631 or 88.8%** will share the materials with coworkers. In analyzing the survey answers, we realize that survey question #7 could have been written better by combining "Staff/Coworkers". However, whether one uses the estimate for sharing materials with "staff" or "coworkers" or both, it is safe to say the goal was met or exceeded.

Third Expected Measureable Outcome
Increase the attendance to the 2015 SWAS Field Demonstration by vegetable and melon industry members (Goal) by 25% from 105 (Benchmark) to 131 (Target) measured by surveys, registration and attendance lists (Performance Measure).

4. "Does your occupation involve the melon or vegetable industry?" crossed with
5. "Did you attend the Field Demonstration?"

Total Answers: 294

		Attended Field Demo?	
		Yes	*No*
Melon or Vegetable Occupation?	*Yes*	*123*	*126*
	No	*15*	*30*

Of those who answered "Yes" to question number 2 of the survey indicating that their occupation involved the melon or vegetable industry **89.19%** of those people answered "Yes" to question number 3 indicating that they attended the Field Demonstration. Applying that percentage to the total number of 195 people who attended the Field Demonstration (320 minus 125 students), it is estimated that **174 participants** whose occupations involve the melon and vegetable industry attended the 2015 SWAS Field Demonstration. Once again, we exceeded our goal.

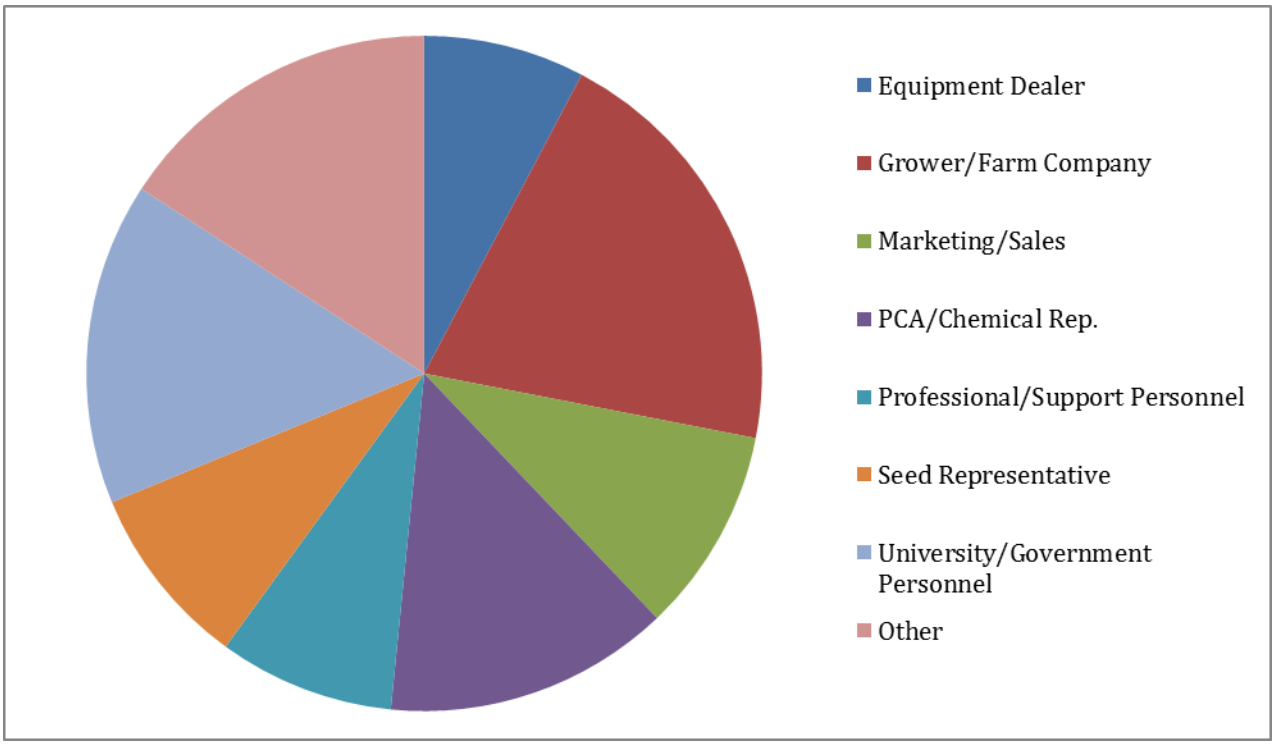
Below are the results and statistical analysis of our survey that we used to measure our goals performance:

Southwest Ag Summit 2015 Survey Statistics

1.) How would you describe your occupation?

Label	**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
(Blank)	12	4.04		
Equipment Dealer	22	7.41	7.72	7.72

Label	Frequency	Percent	Valid Percent	Cumulative Percent
Grower/Farm Company	58	19.53	20.35	28.07
Marketing/Sales	28	9.43	9.82	37.89
PCA/Chemical Rep.	39	13.13	13.68	51.58
Professional/Support Personnel	24	8.08	8.42	60.00
Seed Representative	25	8.42	8.77	68.77
University/Government Personnel	44	14.81	15.44	84.21
Other	45	15.15	15.79	100
Total	297	100	100	



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

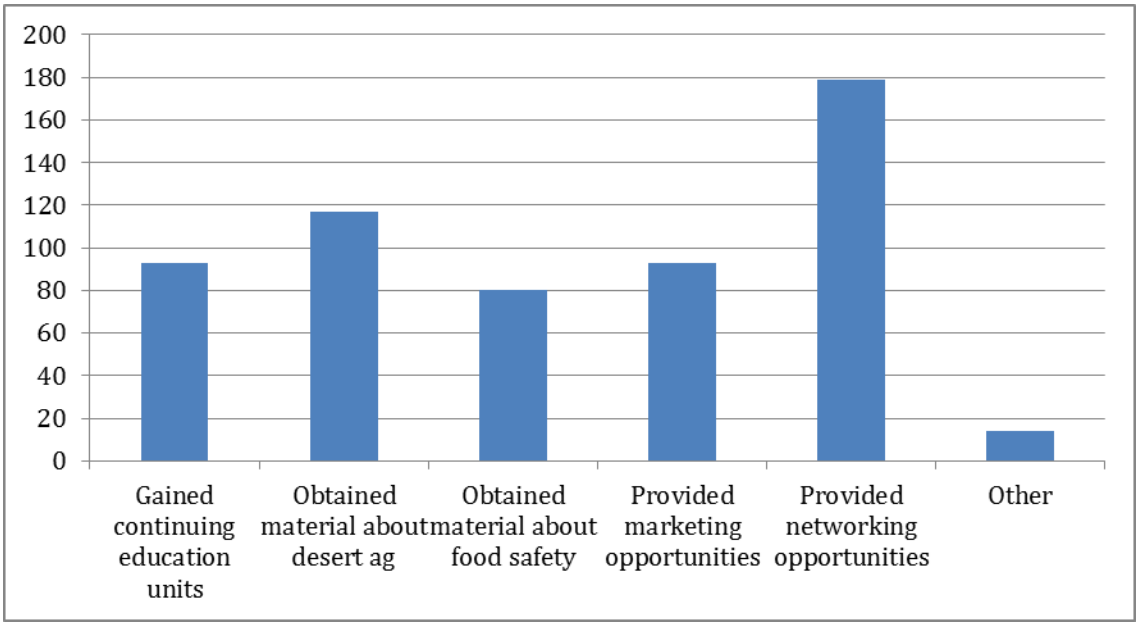
Value Label	Frequency	Percent	Valid Percent
(Blank)	1	.34	
Yes	250	84.18	84.46
No	46	15.49	15.54
Total	297	100	

3.) Did you attend the Field Demonstration?

Value Label	Frequency	Percent	Valid Percent
(Blank)	2	.67	
Yes	139	46.80	47.12
No	156	52.53	52.88
Total	297	100	

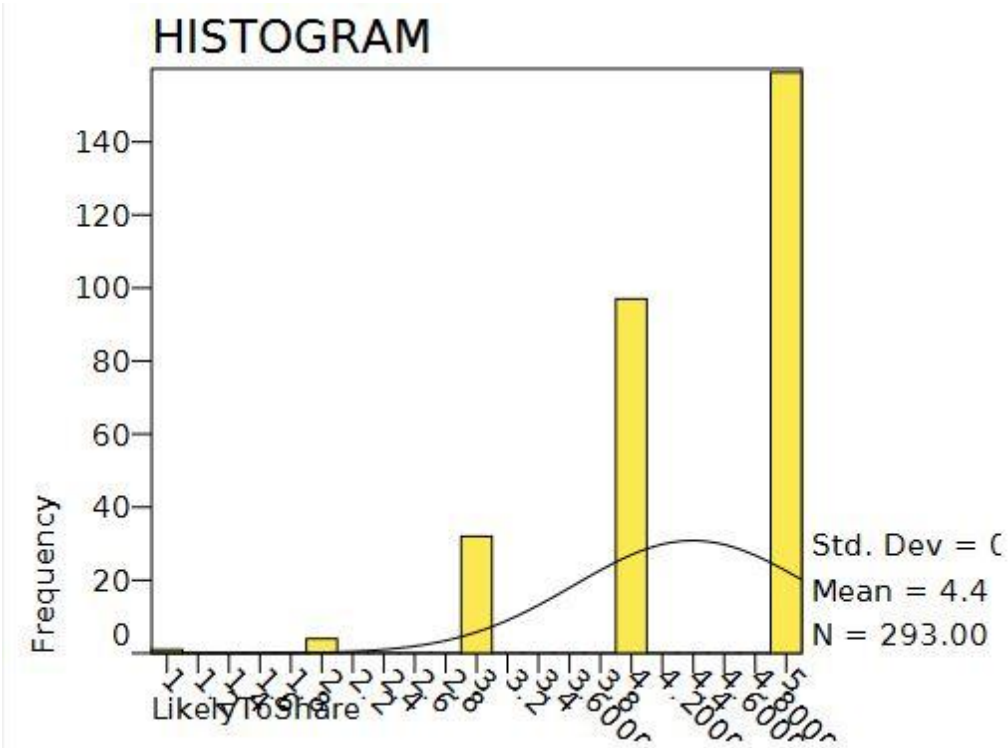
4.) How has the SW Ag Summit affected your occupation? (Multiple overlapping answers)

Label	Frequency	Percent
Gained continuing education units	93	31.31
Obtained material about desert ag	117	39.39
Obtained material about food safety	80	26.94
Provided marketing opportunities	93	31.31
Provided networking opportunities	179	60.27
Other	14	4.71



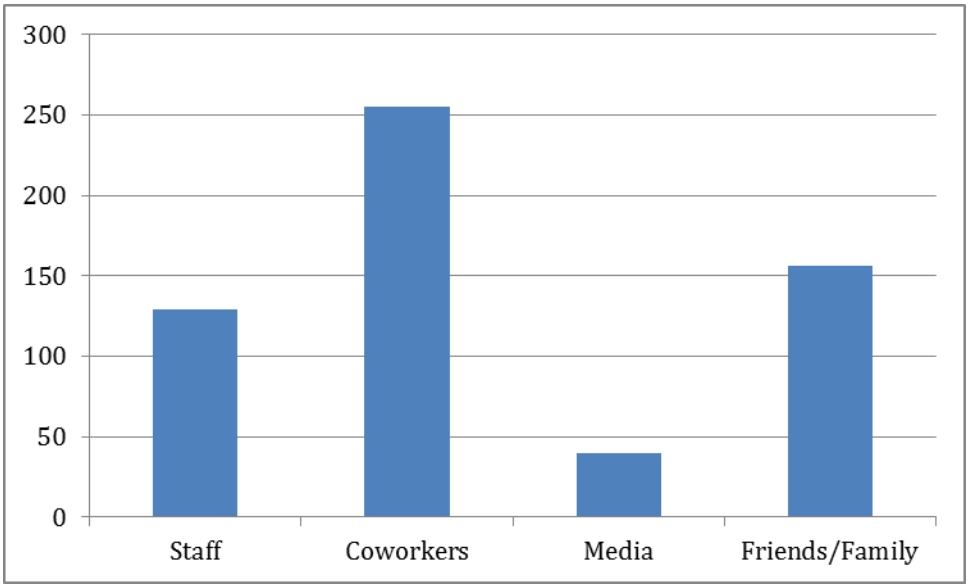
5.) How likely are you to share information you obtained from the SW Ag Summit with others? Distribution of answers from "1 Less Likely" to 5 "Very Likely"

Information Sharing	
Mean	4.40
Standard Error	0.04
Median	5.00
Mode	5.00
Standard Deviation	0.76
Sample Variance	0.58
Kurtosis	1.19
Skewness	-1.18
Range	4
Minimum	1
Maximum	5
Sum	1288
Count	293



6.) If you share the information, with whom will you Share it? (Multiple overlapping answers)

Label	Frequency	Percent
Staff	129	43.43
Coworkers	255	85.86
Media	40	13.47
Friends/Family	156	52.53



What this all boils down to is our audience is consistently above 80% for people associated with the vegetable and melon industry. Our ongoing objective is to keep the content aimed at the specialty crop group and our results will continue to grow and maintain the levels that have achieved.

Beneficiaries

The Yuma Fresh Vegetable Association is made up of growers, Packers/Shippers and Associate members. The event attracts members and non-members alike and many in the specialty crop business. Our attendance was around 841 and our survey indicated about 711 were associated with the specialty crop business.

In addition to the specialty crop growers, the attendees ranged anywhere from seed to agricultural chemicals to Pest Control Advisors (PCA) to Certified Crop Advisors (CCA) to fertilizer people and not to mention tire companies and tractor businesses. Our information presented on Specialty crops directly affects the growers with new and innovative ideas. PCA's earn Continuing Education Units (CEU) while increasing their knowledge of insects, pathogens and weeds. Fertilizer people are getting the latest on fertilizer research while earning CCA CEU's to maintain their certificates. Food safety people increase their knowledge and learn abut new safety training materials.

At our field demonstrations even the tractor and equipment people learn about the new equipment the University of Arizona rolled out this year. Two years ago they unveiled their automatic thinner and the last two years they were demoing their fertilizer wheel applicator that reduces the pruning of roots via the old shank method.

The Specialty Crop Block Grant Program benefits twice when researchers, who receive Specialty Crop Block Grants, present their data at the Southwest Ag Summit to the primary beneficiaries of their research, the members of the specialty crop industry.

Lessons Learned

The Southwest Ag Summit keeps growing each year because we deliver a consistent content of information about specialty crops in an arid land environment to make our subjects are valuable and timely. In other words, we are finding answers and solutions to current growing issues.

We are also delivering ideas that potentially can sometimes intercept problems of the future. For example, we presented drones and how they might be used for growing specialty crops. It is a lot of speculation on just how valuable it is to spot some growing issue based on an infrared signature. But is is being talked about and demonstrated in real time at our Summit.

Contact Person

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Additional Information

Gross income attributed to specialty crops is estimated at $74,512 and comes from registration fees and sponsors. Gross income is utilized to fund expenses not covered by the Specialty Crop Block Grant such as $13,887.50 for meals for this two day event as well as another $13,276.50 for expenses not covered by the grant. The estimated net income for the 2015 SWAS of $46,147.00 will be reinvested into the 2016 SWAS helping us to sustain this event.

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

This project was completed on September 30, 2015

Project Summary

Prior to the development of the Food Safety Projects Coordinator (FSPC) position of the Arizona Department of Agriculture's (ADA) Agricultural Consultation and Training (ACT) there was no one the industry could turn to for information about USDA's Agricultural Marketing Services' Good Agricultural Practices/Good Handling Practices (GHP/GAP) Audit Verification Program, or how to begin to develop a program that would comply with the program's requirements. The FSPC, once on board, was able to fill the gaps (no pun intended) between the auditor and the industry. This position gave the industry the "green light", as one grower stated, to become certified to sell their produce.

A local grower, previously certified in the Arizona and California Leafy Greens Marketing Agreement (LGMA) became concerned that smaller growers had no food safety programs. A food borne illness outbreak originating from one of these smaller farms would negatively affect his operation. ACT was contacted to begin a dialogue to develop training in a leafy greens food safety program which developed into the ADA/U of A GHP/GAP Food Safety Training Program and the FSPC position.

A grant from USDA, SCBGP, enabled the development and maintenance of this training program. During scheduled training classes a manual and flash drive containing forms and blank records, which may be used by the grower for their own GHP/GAP program, are issued to attendees. The FSPC will contact the attendees of the training classes to offer assistance, if needed or desired, to develop a food safety program for the GHP/GAP audit.

Arizona Revised Statues (ARS) §§ 3-561, 562, 563 allow growers to sell their produce without restriction, licenses or fees. But the Arizona Department of Health Services (ADHS) and each County Environmental Service and Health Departments require that restaurateurs and markets obtain food from approved source. At this time, the term "approved source" is ambiguous, but ADHS and the counties agreed that GHP/GAP certification would allow a grower to reach these goals. CHD authority covers marketplaces and restaurants; they do not regulate or monitor farm conditions. By attending our training, a better understanding of the conditions and requirements are delivered.

Project Approach

The FSPC is involved in many areas of food safety from telephone conversations and contacts to presentations for small and large groups to personalized consultations:

- One-on-one consultations; as of September 2015 more than 54 consultations
- GHP/GAP Training assistant and co-presenter
- Meet growers and potential growers to assist and guide them in developing their programs prior to audit
- Consult and assist with the Arizona Department of Health Services
- Consult and assist with County Health Departments and Environmental Services in each of Arizona's counties.
- Food Safety Presentations and discussions to any group requesting a presentation.
- Phone contacts to training attendees
- Review food safety programs prior to audit
- Participate and assist in Arizona Farm to School Steering Committee; consulting and assisting
- Participate and assist in Arizona School Garden Program, training and food safety.
- Submit food safety blogs for the Arizona Farm Bureau

Our most significant partner in the GHP/GAP training project is **Dr. Kurt Nolte** of the University of Arizona Cooperative Extension, Yuma County. Dr. Nolte has developed the training program and manual used in our Arizona statewide training based on the USDA's AMS GHP/GAP Verification Program. Dr. Nolte is the presenter for each scheduled training class, with the FSPC assisting as the co-presenter.

Goals and Outcomes Achieved

The goals, or outcome measures, developed at the beginning of the program have been revised to capture actual information from the growers. These questions were posed to the attendees of the GHP/GAP classes as not all those attending would request one-on-one consultations. The wording of the questions or responses may be revised, or may target a different audience (those requesting consultations).

Five questions were posed to the most recent 100 attendees of the most recent GHP/GAP training classes.
These questions were:

1. To what extent do you feel you have learned from the program?
2. To what extent has your understanding of GHP/GAP improved or increased as a result of the program?
3. To what extent have your skills in GHP/GAP improved or increased as a result of this training?
4. What is your overall rating of this training program?
5. I will be able to use what I learned in this training.

The responses were worded to allow the growers to express their satisfaction with our training classes:

A. Learned nothing
B. Learned very little
C. Learned some
D. Learned some but still confused
E. Learned enough to start a GHP/GAP program

23% of the growers/attendees responded:

	A	**B**	**C**	**D**	**E**
Q. 1	0	0	8.7	17.39	**73.91**
Q. 2	0	0	9.09	13.64	**77.27**
Q. 3	0	0	18.18	9.09	**72.73**
Q. 4	0	0	9.09	13.64	**77.27**
Q. 5	0	0	19.05	9.52	**71.43**

This is the first survey and response and will be used as a base line for future surveys. On average almost 75% of those attending the classes were provided enough information and materials to start a GHP/GAP program, while 100% responded that they left the training with more knowledge than they had at the beginning.

- **ONE-ON-ONE CONSULTATIONS:** The main function of the FSPC is to assist growers who decide to pursue the audit by helping, on a one-on-one basis, to develop their food safety programs. The FSPC has contacted 100% of those attending the training classes. In many cases, where there is no initial contact, a voice mail message is left by the FSPC for the attendee to respond to the call, with very few responding. A small percentage of those contacted will request a consultation. A very small percentage elects to go on to certify.

- **GHP/GAP TRAINING CLASSES:** As of 30SEP2015, there have been 20 scheduled GHP/GAP training classes throughout Arizona with more than 325 people attending. From January 2015 to September 2015 there was one GHP/GAP training class with 24 growers attending.

The GHP/GAP Training Project was designed to educate, assist and guide growers and producers within Arizona to the USDA GHP/GAP On-Farm Verification Audit. ACT and the U of A CE have met that goal by offering and presenting training classes, consulting with growers to develop their food safety programs and review those programs and plans, as described above, where and when the growers want.

The FSPC's detailed one-on-one consultations have been very popular with growers around the state, for several reasons:

- They are free.
- The FSPC gives current and precise advice on their food safety programs. The growers know exactly what to expect during an audit and exactly how to develop their manual, what documents the auditor will ask for and how to respond to questions. Rule number one: Never Lie!
- The FSPC will travel to the grower, not the grower to the FSPC. Meeting on the home ground of the grower is a positive for the grower as they feel more comfortable.

Beneficiaries

All growers, farmers, greenhouses want to provide a safe food product for their customers. If their products are not safe, they will not have any customers, and potentially lose everything they have worked for. Additionally any food borne illnesses that are sourced from a specific crop or commodity will affect all growers of that crop. During a GHP/GAP one-on-one consultation, the FSPC and the grower discuss growing techniques, protocols, records etc. If the grower decides to pursue the GHP/GAP Certification, the entire circle of grower/supplier to buyer/customer/consumer will benefit from the completion of the GHP/GAP project. Many growers have desire to audit, but did not know how to begin or once begun did not know how to develop their program. The FSPC's expertise in food safety, auditing, and program development was just what the industry needed.

The FSPC has held consultations and meetings in Arizona with traditional farms, greenhouses, aquaponics operations, Arizona State government agencies, Arizona County Health Departments, university academics, wholesale and retail food industry, Arizona Farm Bureau, and other states' programs to increase food safety awareness and protocols.

The FSPC has accompanied the department's Public Information Officer (PIO) to discuss the food safety programs with two Arizona State Senators.

There have been 14 food safety and GHP/GAP presentations to The University of Arizona Cooperative Extension's Beginning Farmers and Master Gardeners Classes, 5 during the period of January 2015 to September 2015.

Once growers decide to increase their food safety protocols, even without the benefit of a USDA GHP/GAP audit, everyone benefits from their increased knowledge of food safety and handling, and increased monitoring of their operation.

During the tenure of the FSPC, since August 2011, there have been more than 57 one-on-one consultations with growers and farmers to develop a GHP/GAP food safety program. Several have audited and have been certified. But the majority has not pursued the audit. Each of the consultations have been positive and resulted in an increase in food safety protocols for growing, harvesting, or packing their produce.

There have been revised quantitative data developed to support the benefits of the FSPC and the GHP/GAP training with the U of A Cooperative Extension.

From January 2015 to September 2015 there was one GHP/GAP training class with 24 attending. During this same time frame there were 13 one on one consultations.

From October 2015 to September 2015 there were 6 growers that had attended the GHP/GAP training classes and assistance from the FSPC who successfully completed the USDA GHP/GAP audit. After all this is the point of the program.

Lessons Learned

- Target the correct audience for classes. Targeting and inviting those that are not producers will not request and audit and will not certify. While it is important to discuss and teach food safety protocols in the garden, this may not be the correct venue for personal gardens.
- The personalized attention is a great positive. The FSPC while visiting each consultee is always impressed with the warmth, hospitality and openness that is shown to him.
- When we have an excellent product (the GHP/GAP Training Classes and Materials) other groups want to copy them. We have had many people (corporate and private consultants) try to copy our program and training materials, but the Arizona Department of Arizona's GHP/GAP training program is the only one of its kind in the US.
- All growers of food products are interested in food safety, whether or not they pursue the certification audit. Many do not want government intrusion into their businesses, while others welcome the attention.
- Due to the Food and Drug Administration redesigning the Food Safety Modernization Act (FSMA) after the comment period was closed, many growers and producers are taking a "wait and see" attitude and approach to what will be required. Since certification is not required by statute for selling their products, the growers are not "jumping on the bandwagon" as one grower stated. If food safety certification becomes a regulatory requirement and mandated, growers and producers will develop their plans with the assistance of ADA and U of A CE.
- The GHP/GAP food safety plan is in essence a business plan. Many of the attendees to our training program are hobby growers and are not considering their growing as a business. Others have stated that this type of plan is too complicated and complex, even with the FSPC assisting. In order to fully engulf themselves into the GHP/GAP audit, they must approach this as a business and develop a business plan.

- Unexpected outcomes:
  - the few numbers of growers that actually audit and become certified, that 6 during this time frame completed their audit.
  - That growers and producers embrace the one-on-one consultations with the FSPC. Those that do request a consultation are very satisfied with their plans, even if they decide not to pursue an audit.
  - The openness which growers discuss their operations and protocols with the FSPC
- Expected Outcomes:
  - ADA and the U of A CE did not know what to expect during this initial project. Whether the training and consultations were to be embraced or shunned was unknown.

The goals, or outcome measures, developed at the beginning of the program have been revised to capture actual information from the growers. These questions were posed to the attendees of the GHP/GAP classes as not all those attending would request one-on-one consultations. The wording of the questions or responses may be revised, or may target a different audience (those requesting consultations).

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Additional Information

By providing food safety training and consultations, the Arizona Department of Agriculture assists Arizona growers and farmers in providing a food to the public that has been grown with a HACCP-like program. Steps are taken to assure that water, soil, manure (if used) and worker hygiene are all monitored and assessed for hazards. Those growers that have been certified are competing, as one growers stated, “with one step ahead of the pack”.

It’s All About the Fruits and Veggies

This project was completed on December 31, 2015

Project Summary

The *It’s All about the Fruits and Veggies* Grant Project developed standards-based curriculum and resources highlighting fruits and veggies that are produced in Arizona and the seasons in which they grow. Teachers and students across the state now have access to the Arizona Fruits and Veggie Ag Mag, 20 Arizona Specialty Crop Lessons, the What’s in Season Classroom Poster Series, and the Arizona Greetings Booklet. Resources from the grant were also used as part of the Farm Friday Fun with Arizona Agriculture Program. This program provides nearly 150 Arizona teachers with a digital curriculum package that includes the Arizona Crop of the Month Fact Sheet, Lesson Plan and Farmer Profile.

Project Purpose

The purpose of the *It's All about the Fruits & Veggies* project was to complete a project-based learning curriculum package that will enable teachers to easily use agriculture, specifically specialty crops that are also grown in most school gardens, to reach CCRS and classroom learning goals. Science, Technology, Engineering and Math (STEM) have become the focus of school districts across the state; across the country. Agriculture is a perfect fit for this new educational focus as it encompasses all of these disciplines while remaining applicable and relatable to the students.

At this time, it is important that the agricultural industry steps up to the plate and provides teachers with resources that not only teaches the consumers (teacher, students and parents) about our food and fiber industry, but also helps them reach their educational goals so that they can be more prepared to enter college and or the workforce upon graduation. While providing this service, consumers will also be educated about the importance of agriculture, especially specialty crops, to our own state's economy. The addition of these resources 1) *Fruit and Veggie Ag Mag*,) update and reprint to the *Greetings* brochure and 3) 30 Specialty Crop Lesson Plans to the 2009 Specialty Crop supported Fruit and Veggie Curriculum Kit and the 2012 Specialty Crop supported Specialty Crop Videos, will make a complete project-based learning curriculum package that can be used by teachers with little outside volunteer support.

Not only will the *It's All about the Fruits & Veggies* project be beneficial to teachers in the classroom, but also to farmers in the fields. There is a huge disconnect between the consumer and farmers today. Consumers want to know where their food is coming from and they are not always turning to the correct sources. This project will allow consumers to get answers from the experts that are out in the fields: the farmers themselves.

Project Activities

The *It's All about the Fruits and Veggies* project allowed for the development of 20 teacher written Specialty Crop Lessons that can be found in hard copy and are also available on the web.

Also created through this project was the Arizona Fruits and Veggies Ag Mag, an agricultural magazine that was designed to show students the difference between fruits and veggies, the parts of the plant, crops through the seasons and careers associated with the production of fruits and vegetables in our state. A total of 100,000 Fruit and Veggie Ag Mags were produced. To date 4,500 Ag Mags have been distributed through our Farm Friday Fun with Arizona Agriculture Program, an additional 1,000 have been distributed through classroom presentations and nearly 6,000 have been given out through County Fairs and other community events across the state.

The Arizona Greetings Booklet was also updated and reprinted as a result of this project. Of the 20,000 copies that were produced over 5,000 have been distributed through community events. Later this month an additional 3,000 copies will be distributed as classroom sets (35) to each of the High School Ag Programs. This resource will continue to be used with the Arizona Ag Presentation (High School) and distributed to consumers across the state.

The continuity of the resources developed throughout this project allowed for the introduction of a curriculum project known now as Farm Friday Fun with Arizona Ag. The resources from this project were lumped together to create a curriculum package for teachers across the state. On the 1st of each month teachers that have signed-up to participate (nearly 150) receive an email that contains facts about the specialty crop of the month, a lesson plan to be used in the classroom and a farmer profile from an Arizona producer that grows that month's crop. This curriculum

was a direct result of the materials created through the *It's All about the Fruits and Veggies* project.

Goals and Outcomes Achieved

It was a goal of this project to *increase consumer awareness of specialty crops (GOAL) by distributing 2,000 Greetings brochures to high school classrooms across the state. Prior to the classroom presentation students will take a pre-survey asking specific questions about Arizona crop production. After the presentations and receiving the Greetings brochure, students will receive a follow-up survey (PERFORMANCE MEASURE) to determine if knowledge about Arizona Specialty Crops increased by 25% (TARGET) from the pre-survey results (BENCHMARK).* We fell short of the goal to distribute 2,000 Arizona Greetings Brochures to high schools in conjunction with the Arizona Ag Presentation and were only able to distribute 940 copies in this manner. We had a higher rate of elementary scheduling this semester which allowed for less available dates for High School Presentations. A pre and post assessments was given to the High School Students to assess their change in knowledge after using the resource. The results showed that on average students scored a 1.13 out of 6 on the pre assessment and a 5.75 out of 6 on the post assessment. The average increase in knowledge was 80%.

Another goal of this project was *to Increase consumer awareness of specialty crops (GOALS) by distributing 20,000 Fruit and Veggie Ag Mags to schools with school gardens. Students will receive a pre and post assessment (PERFORMANCE MEASURE & BENCHMARK) to garner information about what was learned and to assess if there was a 25% increase (TARGET) in knowledge of specialty crops.* Although we did not meet the 20,000 mark, we were able to distribute 11,500 Fruit and Veggie Ag Mags to students and consumers across the state. Eighty-eight elementary students participated in a pre and post assessment with this resource. The average pre assessment score (2.5 out of 10) increased after the introduction of the resource producing an average score of 9 out of 10 on the post assessment. The average increase in knowledge was 65%.

Assessments will continue to be given as classroom presentations are scheduled.

Beneficiaries

A variety of Specialty Crop growers benefitted from resources developed through this project, as their crops were highlighted and introduced to consumers. Growers include head lettuce, romaine lettuce, cantaloupe, leaf lettuce, spinach, broccoli, watermelon, cauliflower, cabbage and carrots to name a few. Arizona agriculture across the board was a direct beneficiary as students and consumers were introduced to the diversity and importance of agriculture in our state. In total, 150 teachers, 9,440 students and over 11,000 other consumers have been impacted and had their knowledge about Arizona Specialty Crops increase as a result of the resources from this grant project. With the remaining materials to be distributed these numbers will only continue to rise.

Lessons Learned

One lessoned that was learned through this grant project was that persuading teachers to submit lesson plans is a harder sell than was originally thought. We had hoped to gather 30 teacher lesson plans as a result of the Grant project, but were only successful in collecting 20 lesson plans. After talking with teachers, we discovered that the time of year is extremely important. It

is better to catch teachers right before a school break. While school is in session they have too many other things on their plate and adding lesson plan development was not something most were willing to do.

When setting our goals for outcomes we did not take into account the time it would take to distribute, fill out and collect the pre and post assessments in conjunction with the classroom presentation. The time required for this process greatly exceed the 55-minute time frame that classes are schedule for. To remedy this issue, we had teachers give the pre and post assessment independently from the presentation.

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Additional Information

What's in Season Classroom Posters

POWer PLAY'te/National Nutrition Month

This project was completed on December 15, 2015

Project Summary

The POWer PLAY'te National Nutrition Month program was designed to take the POWer PLAY'te program to 200 Arizona schools in order to encourage Arizona students to eat more fruits and vegetables. The grant allowed POWer PLAY'tes to reach 100,000 Arizona students by distributing POWer PLAY'tes, fruit and vegetable materials for the cafeteria, fruit and vegetable nutritional information for the parents, and encouraging them to logon to the POWer Track on www.powerplayte.com

Project Purpose

Children are not eating sufficient quantities of fruits and vegetables, nor are parents buying and cooking sufficient quantities of fruits and vegetables. Schools have increased fresh produce options for both school breakfast and school lunches under the new USDA guidelines; however, they need additional support to ensure children are eating the fresh fruits and vegetables provided. This project was essential and timely because there is sufficient evidence to support the need for a new approach in encouraging children to eat fruits and vegetables. POWer Fresh Kids has a proven track record with the POWer PLAY'te program. By introducing fruits and

vegetables in a fun, kid-friendly way, using proven teaching techniques, children will eat more fruits and vegetables. In this manner, nutrition education can be compared to literacy education. Young children learn to read through a variety of techniques: colorful pictures, characters, roleplaying and making a connection to the reader's life are all proven ways to introduce and encourage students to read. The same techniques should be used when introducing fruits and vegetables to children. Before children are able to understand the lifelong value of eating fruits and vegetables, students will develop a love for fruits and vegetables, understanding where they came from and eventually their benefits.

This project aimed to (1) introduce fruits and vegetables in a kid-friendly way; (2) encourage children to fill half their plate with fruits and vegetables at all meals; (3) educate parents on the importance of feeding their families fruits and vegetables, so that they will purchase and serve more fruit and vegetables to their families; and (4) increase the number of media stories regarding fruit and vegetable consumption for elementary school children.
This week-long program encouraged schools to continue this unique approach to nutrition education. The week-long events gained media attention, as well. Press releases were sent to local, state and national media. Media coverage and stories are highlighted on the www.powerplayte.com and www.jvsmithcompanies.com websites as well as both companies' Facebook sites. The project did not educate, highlight or focus on non-specialty crops. The parent outreach piece highlighted specialty crops and encouraged purchase and consumption of specialty crops.

Project Activities

First Quarter (Oct. 2014 – Dec. 2014) Activities:

- In October, 2014 we developed outreach materials for 400 schools; we made phone calls to more than 200 schools and we mailed sample materials to elementary school district nutrition directors with the goal of registering 200 schools across the five regions. We created a registration form for schools to use to sign up for the program.
- In November, 2014 we followed up with schools. Kristan Sheppeard traveled to Casa Grande, Oro Valley and the Tucson area to visit with schools in person. Susan Sternitzke traveled to Quartzsite, Parker, Lake Havasu City, Kingman and Bullhead City. Kristan returned to Tucson at the request of the school nutrition manager and registered 13 schools during that trip in January, 2015.
- We calculated power track usage on www.powerplayte.com between October, 2014 and December, 2014 in order to create a baseline for growth.
- Susan Sternitzke traveled to Somerton, AZ to meet with their school nutrition manager to sign their schools up for the program.
- In December, 2014 we met with a non-biased team to interview them to be the team that will administer the survey and collecting data in the five regions.
- We created the outline for changes/renovations of the website
- We created the weekly activities that will be sent to all of the schools
- We placed a full page ad in the AZ School Nutrition Association's quarterly newsletter
- We inventoried the POWer PLAY'tes and moved them to the warehouse we will utilize when the distribution begins.

- We met with the Arizona Department of Education to request their assistance in reaching schools.
- We met with the Yuma area schools and were successful in signing up 19 schools.
- We created and printed parent materials.
- We submitted a press release to our local newspaper. A front page story ran on November 9, 2014.http://www.yumasun.com/news/local-healthy-eating-program-set-to-expand/article_dfc1c12c-6863-11e4-b679-63fd8cd41220.html
- A story also ran in an agriculture industry publication The Packer http://www.thepacker.com/fruit-vegetable-news/Power-Playte-introduced-in-Yuma-schools-169641216.html
- We also promoted the press release and story on the POWer PLAY'te Facebook page.
- JV Smith Companies promoted the story on their Facebook page.

Second Quarter (Jan. 2015 – Mar. 2015) Activities:

- In January, we sent an e-mail blast to Arizona School District Nutrition Directors.
- In January, Kristan visited Tucson to present to principals of Ampitheater School District.
- In January, Kristan also visited Flagstaff school districts.
- In January, Susan visited Phoenix area school districts.
- In January, we followed up with phone calls to interested school districts from the first call back in October.
- In January, 2015 we created crop of the day sheets; veggie character cafeteria posters. We used Brett Frame to design these items.
- In January, we sent a large mailing that included outreach materials and sample materials to all school nutrition directors across the state.
- In January, 2015 we submited a Request for Proposal to three design/printing services companies for all of our printing needs.
- In January and February, 2015 we secured the remainder of the schools in order to meet our goal of 100,000 students.
- In February, 2015 we updated the website to include all schools that have signed up. We used MGM Studios for this service.
- In February, 2015 we created downloadable marketing materials that will be on our website for parents to use at home.
- In February, 2015 we sent the POWer PLAY'te weekly activities and surveys via email to all schools.
- In February, 2015 we printed the parent materials; crop of the day sheets and cafeteria posters. We used Jon Perry for printing.
- In February and March, we answered any concerns or questions from elementary school staff; supplemented marketing with POWer PLAY'te social media sites; and collected photos and stories from elementary schools for social media sites.
- In February, we sent a survey to the Nutrition Managers at each school.
- In February, we created a measuring tool for the 10 schools we will monitor more closely.

- In February and March, our non-biased team administered the pre-measurement tool and collected data at the 10 chosen schools.
- In February, we calculated power track registrations in order to create baseline for measurement.
- In March, we placed an advertisement in the Healthy Somerton initiative newsletter.
- We worked with website designer on update and changes.
- We sent several e-mails to schools reminding them of the week-long plan and measurement plan.
- We also sent schools ideas to expand on the program and gave them website password to access password protected section on powerplayte.com.
- In February and March, we boxed and mailed the program for each school including plates, crop of the day sheets, parent flyers and cafeteria posters. In addition, we included survey and week-long plan suggestion sheet. School spreadsheet is included.
- We met with Arizona Head Start and signed up preschools for the program as well. We distributed materials to them that will be used in Head Starts along the Colorado River in Arizona.
- We submitted a press release to our local newspaper and media outlets. We also submitted a press release to the newspaper, television and radio contacts in Tucson, Phoenix, Sedona, Prescott, Mesa, Chandler, Queen Creek, Scottsdale, Flagstaff, Maricopa and Lakeside.
- KAWC aired a POWer PLAY'te National Nutrition month story on "Arizona Edition" on March 30, 2015.
- Healthiest County in America newsletter also featured a story on the POWer PLAY'te grant program in the March 25th, 2015 edition.
- Yuma school districts also highlighted POWer PLAY'te on their menu for parents and the community to view.
- We also promoted the press release and story on the POWer PLAY'te Facebook page and Twitter.
- JV Smith Companies promoted the story on their Facebook page.

Third Quarter (Apr. 2015 – June 2015) Activities:

- In April and May, we created and sent e-mail blasts to Arizona School District Nutrition Directors.
- In April, May and June, we updated the POWer PLAY'te website to showcase the grant and encourage kids to register for the POWer Track. We also adjusted the site so the POWer Track would be more easily accessible through mobile devices.
- In April and May, we resent the surveys to all the participating school districts.
- In April, May and June, we highlighted the grant project through press releases and social media.
- In April and May, 2015, we sent the press releases to regional media in all of the cities that participated in the grant project.
- In May, 2015, The Packer ran a story about the grant project.

- JV Smith Companies promoted the story on their Facebook page.
- In May, we held a POWer PLAY'te assembly in Crane School District and in Somerton School District.
- In May and June, we compiled info and photos from our measurement days in 10 schools.
- In June, Alex Trujillo, an executive chef, reviewed the measurement photos and provided data for the dietician.
- In June, Christine Winters, a registered Dietician, reviewed the measurement information and created a summary.
- In June, we reserved an ad in the Arizona Farm Bureau publication highlighting the grant project.
- In June, we reserved an ad in the SNA publication highlighting the grant project.

Fourth Quarter (July 2015 – Sept. 2015) Activities:

- In July, 2015-September, 2015 we continued to promote on POWer PLAY'te social media.
- In July, 2015-September, 2015, we continued to update website to post information regarding National Nutrition Month program including data and photos.
- In July, 2015-September, 2015, we continued to reach out to school districts in hopes to receive more surveys back from the Nutrition Managers.
- In September, 2015 we went to Mesa School District to hold the assembly at the winning school from the POWer Track contest.
- In September, 2015 we sent a press release announcing the winning school and documented our visit to Mesa. We shared through social media outlets, as well.

Extension Activities (Oct. 2015 – Dec. 15th 2015)

- In October, we placed a POWer PLAY'te ad directing readers to the website to learn about grant program in Arizona Parenting.
- In December, we placed two ads on Facebook promoting the use of the POWer Track on www.powerplayte.com (one ad was placed on POWer PLAY'tes page and the other on JV Smith Companies page.)

Goals and Outcomes Achieved

- Expected Measurable Outcome #1: Increase fruit and vegetable consumption at 200 elementary schools (GOAL) during National School Nutrition month by 20 % (TARGET) from current consumption which will be measured prior to launching National School Nutrition Month. (BENCHMARK) Benchmark numbers of current fruit and vegetable consumption will be found previous to National School Nutrition Month by looking at the quantity of fruits and vegetables taken from salad bars and quantity of fruits and vegetables eaten on POWer PLAY'tes. Performance measures will include measuring 10 schools in detail chosen from a variety of locations representing the state and areas of low, medium, and high income. In addition, all school nutrition managers will be surveyed (PERFORMANCE MEASURE) prior to the National School Nutrition

Month and then again directly after and in weeks following National School Nutrition Month regarding their student's fruit and vegetable consumption rate.

Goals and Outcomes Achieved: We provided the POWer PLAY'te grant program to 188 Arizona schools. Because of their number of students enrolled, we met our goal with the 188 schools because the total number of students participating was 100,410 Arizona student. We did see an increase in fruit and vegetable consumption during National Nutrition month by 15.75%. We measured 10 schools in detail prior to National Nutrition Month and then again during National Nutrition Month. Our executive chef reviewed the measurement photos and provided data for the dietician. The registered dietician created a summary based on measurement data. The registered dietician confirmed the increase in fruit and vegetable consumption at the participating elementary schools.

- Expected Measurable Outcome #2: Increase parental awareness of the importance of eating fruits and vegetables by distributing 120,000 pieces of informational materials. (GOAL) Two months after distribution, parental logins (PERFORMANCE MEASURE) will increase by 20% (TARGET) to determine if parents accessed the POWer PLAY'te website after receiving the informational materials from the level of parental logins before distribution of marketing materials. (BENCHMARK)

  Goals and Outcomes Achieved: We did increase parental awareness of the importance of eating fruits and vegetables by distributing 120,000 pieces of informational material. Parental logins increased by 152 %.

Beneficiaries

The beneficiaries of this project are many. First, the growers and all those involved with growing, distributing and selling specialty crops will benefit by increased consumption. As children learn more about fruits and vegetables and consume more, all those involved with the specialty crop industry will benefit. As the program gained national media coverage, the specialty crop industry benefits from the positive public relations stories. The program demonstrates the agriculture's genuine interest in encouraging children to eat fruits and vegetables for their health. In addition to the industry benefitting, the 100,000 plus children, reached during the POWer PLAY'te grant week, will drastically benefit by eating more fruits and vegetables. Their health depends on it.

Lessons Learned

Our goals were achieved but that did not come without challenges. Here are a few:

- We had challenges gathering a non-biased team to handle the measuring in the 10 schools. We interviewed several groups. We did finally settle on a team that we felt confident would complete the task properly.
- In visiting with Tucson areas schools, we learned that many of them are run by food service management companies instead of managing them in-house. The majority of these companies are not in a position to make a decision about participating in the program. They don't have the "ownership/buy-in" that the other schools have.

- The holiday season made it difficult to get positive answers from many schools. We were asked to follow up after the holidays.
- One of the schools we met with has an existing grant so they are not allowed to utilize our grant. They felt it would be competing.
- We met our goal of 100,000 students prior to enrolling 200 schools because 188 schools had a total enrollment of 100,410 students.
- We worked on the measuring tool for quite a while. We spoke with experts in measuring and data and collaboratively decided the best way to measure was to take photos pre eating and post eating both before POWer PLAY'te week and during/after that week. We then decided to hire a nutritionist to analyze the photos and provide us with the measurement data.
- We had one district that really wanted us to present to each of their schools. We explained that since there is just two of us, that isn't possible. However, we did send e-mails with extra information to help them with their launch and offered our services via phone at any time.
- We did have three schools that wanted to do their week in April because of their 2 week Spring Breaks. We allowed them to do that.
- We had a difficult time receiving surveys back from the school districts. We sent three e-mail blasts to the schools as well as called each director to explain the importance of getting them back.
- We had difficulty getting the schools to promote the POWer Track to their kids. We recognize they are very busy and focused on academics. In hindsight, we would have budgeted more money to create a campaign to reach kids and parents from the participating schools directly rather than relying on the schools to disseminate the information. We did run a social media advertising campaign that drastically increased the parental logins on the POWer Track.
- We struggled to get final ad placed by deadline so we filed for extension. We were able to place the ad within the extension timeframe.

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School Garden Food Safety On-Line Training

This project was completed on September 30, 2015

Project Summary

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 Measurement of Educational Readiness to Inform Teaching (AzMERIT) and the AIMS (Arizona's Instrument to Measure Standards Science) tests that students are required to pass.

The need to develop a school garden program including a food safety component is extremely important. 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 Online 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 increase in schools' interest to educate students on the benefits of consuming 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

This grant was written as a follow-up to SCBGP-FB10-42 and SCBGP-FB13-25. At that time there were no food safety guidelines for schools and school grown produce was not allowed to be prepared or served in the school cafeteria. SCBGP-FB10-42 implemented coordination with the AZ Department of Health Services (ADHS), AZ Department of Education (ADE), and AZ Department of Agriculture (ADA) in the development of School Garden Food Safety Guidelines that are now an official publication of the University of Arizona College of Agriculture and Life Sciences. Through the implementation of the Guidelines, ADHS will now certify a school garden as an approved source allowing its produce to be served in the school cafeteria. A series of live trainings that educated school personnel on the Guidelines in addition to an introduction to AZ Specialty Crop Lessons for the classroom were conducted under the previous two grants. These live trainings met the demand of school community members who were able to attend in person; however, many interested participants were constrained by logistics of their profession to travel great distances within the state in order to attend.

SCBGP-FB14-37 was designed to provide online trainings for school district personnel with research-based strategies to implement a garden safety program as well as introduce agricultural concepts into their current curriculum. The Online School Garden Food Safety Program developed a series of online video modules that reflects the nine successful live trainings that were conducted in various regions of the state. The online training provides: 1) Instruction on the curriculum for school garden food safety which were specifically developed for school gardens and were mirrored after the GHP/GAP industry trainings; 2) Makes available the use of hands-on

lessons from the school's garden using the Arizona Specialty Crop Lessons which were developed by Arizona teachers; and 3) Links to online video instructions of step-by-step procedures for growing a successful produce garden which were developed by the Agroecology Program of the University of Arizona College of Agriculture and Life Sciences Cooperative Extension in Maricopa County.

Monica Kilcullen Pastor, Associate Area Programmatic Agent, UA College of Agriculture and Life Sciences Cooperative Extension (UA CALS CE): Served as PI on the grant overseeing the script of the training videos to ensure the integrity of information related to the School Garden Food Safety Guidelines and marketing the program at various meetings and community events.

Brandon Moak, Program Coordinator, Sr., UA CALS CE: Served as Program Manager to coordinate day-to-day logistical functions of the program, assisted in writing training scripts, coordinated production with video voice-over, developed website content, assisted with marketing the trainings, developed reporting system for trainees, and facilitated communications with educators as needed.

Kathryn Mathewson, School Garden Sanitarian, ADHS: Provided department input on the supplementary videos related to the certification of school gardens through ADHS.

Goals and Outcomes Achieved

Prior research conducted under SCBGP-FB10-42 revealed the high interest Arizona schools have in developing or properly cultivating school gardens and being able to serve that produce in their school's cafeteria. This grant, SCBGP-FB14-37, sought to make trainings available to all of Arizona's school personnel through an online training platform and established a goal of 50 educators completing the trainings. Of these, a goal was established that 25 educators would provide reports on the lessons they used to help increase their knowledge about Arizona's Specialty Crop industry.

The online trainings consist of nine videos that teach components of the School Garden Food Safety Guidelines and six supplementary videos related to the certification of school gardens through ADHS. The nine videos include 1) Introduction which explains the need for and the development of the Guidelines; 2) Organizing a Food Safety Plan which discusses the purpose of a food safety plan, the importance of documentation, and the role of garden managers; 3) Land History & Garden Location which emphasizes health considerations related to choosing a garden location and its construction; 4) Maintenance & Growing – Water which emphasizes health considerations related to the garden's water source; 5) Maintenance & Growing – Soil Amendments which emphasizes health considerations related to the garden's soil amendments, such as fertilizers and compost; 6) Maintenance & Growing – Uninvited Guests which discusses acceptable actions to reduce weeds and animals from invading the garden and how to keep it secure; 7) Before Entering the Garden which outlines the need to train garden workers and emphasizing health and hygiene practices; 8) Maintaining the Garden which focuses on the Guidelines as it pertains to working in the garden prior to harvest; and 9) Harvesting which discusses harvesting procedures as it relates to the Guidelines. The six supplementary videos provide explanations related to the required documents that are submitted to ADHS for certification. These include 1) Certification Overview which explains the general process for having the school garden certified; 2) Develop a Food Safety Plan which explains the purpose of

documents related to a Food Safety Plan; 3) Ensure Water Safety which explains the documents to submit related to water testing including harvested rainwater; 4) Ensure Soil Safety which explains ADHS documents related to soil testing including compost; 5) Establish Your Garden which explains the need for a garden map to be included in the certification application; and 6) Request a Site Visit which explains the ADHS application for certification.

The online training portion of the website was launched in July 2015. This was four months later than anticipated. Delays are attributed to a more lengthy time investment in the scripting of the voiceover content. Initial efforts were placed in making the content highly engaging with the plan to only have one training video. This process was abandoned due to the significant length of the video, and it was determined that a series of more succinct videos would be appreciated by the participants and increase the percentage of participants who completed each video. This change in script content also lead to a change in the video platform from Panopto to a static PowerPoint slide with voiceover from a professional. Delay in the timetable was further compromised by conflicting responsibilities with Moak's commitment to other programs. Had the website been launched in March, Moak would have been able to appropriately balance time between the two programs; however, with the perpetual delay from changing script content, he was unable to give this program the needed focus to launch the website any sooner. Furthermore, as the online trainings were launched in the summer, this made it likely that teachers were unable to see the announcement until their return to school since many provided their school email for the Listserv. A second announcement was given in September at the completion of the supplementary videos.

The online-training videos are made available without restriction to the public. All visitors to the website are encouraged to register in order to track progress and obtain demographic data. However, this registration is not required, and it is conceivable that some participants may benefit from the trainings without our knowledge. All visitors were also informed about the 30 Arizona Specialty Crop Lessons that were developed by Arizona teachers and their alignment to state standards. Participants were encouraged to provide feedback regarding the lessons they used in conjunction with the trainings.

A total of 18 people have registered for the online trainings, 32 people short of the goal of 50 people. As the online training is designed for participants to complete at their own pace, of the 18 registrants, 44.4% (8 people) completed the training videos regarding the Guidelines, and 11.1% (2 people) completed the supplementary training videos regarding the application process. Although these numbers are well short of the anticipated goal, they are respectable representations of interest considering the short amount of time educators have been able to participate.

Unfortunately, none of the registered participants chose to provide feedback regarding their use of the 30 Arizona Specialty Crop Lessons. However, this does not mean that none of them used the lessons. Analysis of website data through Google Analytics indicates that lesson downloads increased by an average of 10.89% per month since the initial launch of the online trainings with a total of 213 downloads since. It is reasonable to concluded that this increase in lesson downloads may be related to the announcements of the online trainings.

Comparison of actual accomplishments with the goals established for the reporting period:

- Benchmark: no School Garden Food Safety online training for educators
- Goal: develop School Garden Food Safety online training for educators (accomplished)
- Target: at least 10% of the educators who complete the training will have their school's garden certified (ongoing)
- Performance Measure: a minimum of 50 teachers will complete the online training (approached; 8 of the 18 registrants completed)
- Benchmark: teachers will document student knowledge about specialty crops
- Goal: teachers will utilize Specialty Crop lessons (approached; 213 lessons downloaded, zero reported)
- Target: at least 50% of educators who complete the training will report on lessons taught to increase students' knowledge about Arizona's Specialty Crop industry (unsuccessful)
- Performance Measure: all educators who complete the trainings will report on the lessons used to increase students' knowledge about Arizona's Specialty Crop industry (unsuccessful)

A verbal report from the ADHS School Garden Sanitarian indicated that 19 schools have been certified by ADHS and the school's garden produce can now be used in the school cafeteria. Advertising of the Online Trainings will be ongoing. Advertising postcards were developed and are distributed at teacher events and garden programs. The trainings have been posted on the national edWeb daily digest, in the USDA Farm to School network, through the AZ Department of Education's school garden program, on various teacher listserves and as links from other pages. The PI has also been accepted to present on the program at the national Professional Agricultural Workers Conference in Alabama in December.

Beneficiaries

The beneficiaries of this project are the 18 teachers and school personnel who participated in the online trainings as well as the 3,762 students they reported that they teach. The teachers benefited because they enhanced their curriculum using lessons that are educationally appropriate and aligned to required standards. They also benefited because they participated in a professional development program that allows them to add the credits to their required teacher certification.

Students and teachers both benefited because they increased their exposure to the specialty crop industry in Arizona. This has impacted the practices used in their school gardens to ensure safe food production. The lessons also incorporated a nutrition component that encourages healthy consumption by eating Arizona products.

Lessons Learned

The most important lesson learned was the continued desire by schools to implement food safety practices in their school garden. Whenever educators responded about the announcements related to the online trainings, they expressed appreciation for making them aware of the resources that they weren't able to access when the live trainings were available.

A major setback was the estimation of time to script and produce the training videos. Although much of the content was already created from the live trainings, providing information in a scripted format proved more meticulous than anticipated. Live trainings allowed for

extemporaneous explanations of content which is more easily understood by participants as they interact with the dialogue as opposed to a stagnant presentation from an online training format.

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Additional Information

Attached is a copy of the postcard created. (**Appendix A**)

Arizona Grown Marketing Efforts Phase 4

This project was completed on September 30, 2017

Project Summary

Phase 4's efforts focused on new ways to continue to increase awareness of the AZ Grown brand for Arizona Grown specialty crops. These efforts increase the overall understanding and importance of the brand while continuing to build value and loyalty in our ongoing efforts in the Arizona market through four areas; Social Media, Public Relations, Research and AZ Grown leave behind materials and vendor display.

With Facebook having such a strong presence and having served as the anchor for the AZ Grown efforts over the last two years, this continued to be a key component of this project as well as an electronic market survey to determine brand recognition in the market. These will help influence strategy as AZ Grown continues to move forward in the future. A collateral piece that can be left behind at meetings, events as well as a vendor display to use at stores or events was developed to promote the effort.

Project Purpose

Most consumers are unaware of the benefits of purchasing local produce and plants, although we have been making progress with our Arizona Grown marketing projects. They need to understand these needs in order to increase the competitiveness of the Specialty Crop industry.

Since its inception, the Arizona Grown Facebook page has drawn over 1,850 likes and has reached an average of 3,000 consumers per week. The purpose of this project is to increase sales of Arizona specialty crops and drive awareness of the benefits of purchasing local produce and plants by utilizing media and social media platforms. Phase 4 of the AZ Grown marketing efforts builds upon the most successful parts of the first three phases.

Phase 4 objectives were in the Social Media, Research and AZ Grown leave behind materials and vendor display areas. An electronic market survey to determine brand recognition in the market was funded. This will help influence strategy as AZ Grown continues to move forward in the future. This phase was designed to help us determine how the AZ Grown label and Phase 1 - 3 marketing efforts helped increase sales for those using them on their packaging or plants with a funded research project.

This project differed from previous grants by utilizing leave behind materials, a vendor display and research which have not been completed before. This grant continued to build upon the social media aspect of previous grants.

Project Activities

Phase 4's activities focused on our continued outreach to promote AZ Grown specialty crops through AZ Grown Facebook posts, a website refresh, a vendor display, leave behinds and a research project.

Since Phase 1, Facebook has been a huge part of reaching consumers and providing them with information about specialty crops such as where to purchase, recipes to make, facts about Arizona specialty crops, etc. Content was created by R&R Partners and reviewed by members of the specialty crops industry and program staff. Different content was posted 5 days out of each week of the month. At the beginning of this phase 1,850 people had liked the Arizona Grown Facebook page, by the end of the project we had 4,615 likes.

As a part of this phase we had planned to do a refresh to the Arizona Grown website. This was to originally take place at the beginning of this project but unfortunately our website was hacked. While we did refresh some of the look of the website we mostly focused on making the website more secure to prevent any future hacking. So far our security update has been successful.

The Arizona Department of Agriculture worked with the Arizona Nursery Association and Western Growers Association to develop Arizona Grown leave behinds. These leave behinds were created to educate consumers and the general public about the benefits of buying Arizona Grown specialty crops. Some of the benefits in the leave behinds included: increase in Arizona's economy, getting truly fresh produce, and investing in plants that thrive. The vendor display highlighted both Arizona Grown plants and produce. The display has been used at industry meetings and events alongside the leave behinds. Leave behinds have also been distributed with the Arizona Department of Agriculture's Arizona Grown Specialty Crop Guide.

One big part of this phase was to dig a little deeper and see what impact the AZ Grown marketing campaign was having on consumers by conducting a research project. R&R partners developed and administered the survey. The research was fielded from September 23, 2015 thru October 2, 2015 to 401 people. Qualified respondents were full time or part time residents, at least 18 years of age and were the primary or shared person responsible for household purchases. Below were the questions asked and responses:

1. When was the last time you shopped for produce (fresh fruits and vegetables)?
    - Majority of respondents who had shopped for produce in the past week did so at a grocery store, farmer's market or local farm.
2. When was the last time you shopped for live plants (trees, shrubs, flowers etc)?
    - Respondents who had shopped for plants in the last week were spread out among grocery store, local farm or garden, farmers market and somewhere else.

3. Where do you typically look for when you are shopping for produce or live plants?

Plants	Produce
74% - Grocery Store	100% - Grocery Store
64% - Farmer's Market	81% - Farmer's Market
62% - Local Farm or Garden	66% - Local Farm or Garden
80% - Somewhere Else	70% - Somewhere Else

4. What is the MOST important consideration when shopping for produce and live plants?
    - The highest responses were seasonality, lowest cost, organic and locally grown
5. What signs or stickers do you typically look for to help educate you purchase decision?
    - The highest responses where for organics, maintenance and price with locally grown following close behind.
6. Have you seen the Arizona logo on signs or stickers when shopping for produce or live plants? Where have you seen it?
    - 60% said yes they have seen the logo with majority seeing the logo at grocery stores and farmers markets. While others have seen it at nurseries and local gardens.
7. All else being equal, what does the Arizona Grown logo have on your decision to purchase?
    - 93% are much more or somewhat more likely to purchase AZ Grown/local/fresh produce and plants.
8. What would you say is the MOST compelling reason to buy locally grown produce and plants?
    - The highest responses were that it's better for the economy and a higher quality product.

Below are some key findings of the survey:

- The majority of the people shop for produce at the grocery store, whole live plants are purchased at a variety of outlets

- When shown the logo, most (6-10) say they have seen it at the grocery store or farmers market.

- All things being equal, the Arizona Grown logo has a significant impact on product selection.

- Arizonans want to hear about the economic and environmental impact of buying local, and then about quality.

- Though not at the top of the consumer's mind, the Arizona Grown logo can have a significant influence on product choice for produce and plants.

- Arizonans prefer that their dollars go to local farmers and stay in the local economy. Additionally, they feel that local growers have a smaller footprint and yield high quality products.

A follow up survey will be conducted in Phase 5 after running billboards and social media promoted posts to see what impact the campaign had on consumers.

Goals and Outcomes Achieved

The goal of this project was to continue to increase the amount of visitors to the Arizona Grown website. We estimated that we could add another 300 unique visitors per month. We believe we were successful in achieving this goal. As you can see in the chart below there were months where we were under our 300 unique visitors but also months where we exceeded the 300 unique visitors.

AZ Grown Website Visitors		
	2014 - 2015	**2015-2016**
October	193	351
November	205	324
December	181	337
January	285	521
February	283	313
March	598	292
April	443	1,169
May	448	15,982
June	360	9,425
July	310	522
August	298	435
September	316	368

While we did fall below or 300 goal in the beginning months of 2014, we still find these numbers to be impressive as the only marketing effort during this time was our Facebook posts. This means these visits were solely from our Facebook page.

In 2015 we reached and exceeded our goal of 300 every month aside from one with a huge increase in May and June. We do believe much of this increase was due to our AZ Grown leave behind, display and Facebook posts but we also ran our Phase 5 banner ads, billboards and promoted posts which contributed to the huge spike in visits during April – June.

Beneficiaries

The biggest beneficiary is the consumer and the ability to educate and connect them to locally grown plants and produce.

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 in the state.

Contact Person

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Plant Something Campaign Marketing Support

This project was completed on September 30, 2016

Project Summary

The Arizona Nursery Association (ANA) was awarded this grant for the continuation of the Plant Something campaign, especially for marketing endeavors. The goal with the grant was to expand promotion, sale and use of Arizona grown landscape plants and trees. These grant funds creating additional marketing arenas for the Plant Something campaign, targeted specifically at consumers through the use of media and public events. These grant funds allowed the use of media to target the general public to increase awareness of the campaign which promotes purchasing plants and trees therefore increasing the sales of ornamental nursery stock. Since the program had been well-established with previous grant funds, it was vitally important to have another grant to expand the public's awareness of the Plant Something campaign.

This grant specifically funded radio advertising, digital billboards, theatre advertising, web advertising and exposure at public events from July 2015-September 2016.

Project Purpose

The purpose of this grant is to specifically increase the awareness of the Plant Something campaign through various media outlets. This was important because sending a consistent message to consumers makes them take notice of the advertisements. This project did build on the previously funded Plant Something grants which the Arizona Nursery Association has received. This is also an advantage as creative costs are kept at a minimum since we can reuse advertisement and videos.

All components work toward the central goal of increasing the competitiveness and long term sustainability of the Arizona nursery industry.

Project Activities

Advertising

ANA had previously developed digital billboard ads and a Public Service Announcement (PSA) which were both used in this campaign. For the theatre pre-movie advertising, we used the 30 second animated video asking viewers to imagine the world without plants and trees called "Imagine". The animation depicts a beautiful world with trees and plants and then takes them away. The last panel of the PSA shows the Plant Something website as the source for more

information about planting trees and plants and where to purchase them. The digital billboards featured a large path of soil with two different sets of copy. One digital billboard said "Do Something Shady….Plant Something" and the other said "Do Something Dirty…..Plant Something". Both then encouraged viewers to go to the Plant Something website. Radio advertisements were also aired during the spring and fall and we re-used our radio commercials from the previous grant.

Web Presence
Social media and Facebook advertising was utilized during fall of 2015 and spring of 2016.

Public & Trade events
A Plant Something booth was purchased at a National Nursery & Landscape Association meeting in April 2016 to promote the Plant Something movement.

Goals and Outcomes Achieved

Sales in Retail Nurseries:
Arizona grown low water use plant sales will increase by at least 10% during the promotional period.
ANA emailed surveys to retail nurseries to report plants sales during same month cycles in 2014 compared to 2013 to measure the effectiveness of the promotion. In the same survey, ANA gathered results for 2015 compared to 2014.

Reported results were as follows:
Comparing ANA member retail nursery sales in 2014 to 2013, an average decrease of 4.5% was reported.
Comparing ANA member retail nursery sales in 2015 to 2014, an average increase of 13.6% was reported.
Radio Advertising:
Fall 2015 (Sept - Nov) paid radio advertisements aired were: 279 paid ads including 30 & 60 second spots. The spots are the same commercial we have previously aired. Arizona statewide listeners are estimated at 100,000 – 250,000 per spot depending on day and time.

Digital Billboards:
Spring 2016 – 12 freeway billboards with an 8 second spots rotating every 64 seconds resulting in total estimated impressions of 641,719.

Theatre Pre-roll Ads:
A 3 week flight of valley wide Phoenix theatres was utilized to place 30 second blocks of the Imagine video in theatres suitable for our demographic resulting in total estimated impressions of 375,000.

Beneficiaries

The project benefited the entire Arizona nursery crop industry. This industry, according to the 2007 survey, has total sales of $644 million and includes the 200 members of the Arizona Nursery Association as well as an estimated 1000 landscapers in Arizona. Educating consumers

of the environmental benefits of planting landscapes has resulted again in an increase in sales on the retail level which will in turn, increase Arizona grower sales. Because the grant met a need of each level of the Arizona industry as well as the general public, an actual number cannot be quantified.

Lessons Learned

We learned that utilizing the skills of an experience advertising agency is key in selecting theatres and billboards. The details are very important to get the most exposure from your dollars invested.

We also learned that "stretching your comfort zone" and utilizing copy which gets the consumers attention on billboards is quite effective.

Contact Person

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Additional Information

We believe the Plant Something promotional campaign has increased awareness of the competitiveness and consumption of ornamental plants in Arizona. Through our previous surveys, a 10% increase in sales was reported by the retail nurseries. However, a decrease was reported for this first time since the inception of the program. We would argue this had more to do with the economy and weather related issues rather than the success of our program.

We believe that an indicator of the popularity and success of this Plant Something promotion is that many other states are applying for Plant Something grants for their states from the Specialty Crop Block Grant program.

Copies of any and all promotional materials, radio advertisements, theatre ads and videos are available upon request. Website is www.plant-something.org and Facebook page is under Plant Something.

Creation of Self-Sterilizing Harvesting Tools

This project was completed on September 30, 2016

Project Summary

A safe and sustainable food supply is of paramount importance in Arizona and thus, improved harvesting methods and materials aimed at reducing the risk of pathogen presence on food crops, while protecting crop yield and viability, are of intense interest to growers of specialty crops. Recently, multiple formulations of quaternary ammonium compounds (QACs) have been introduced as household and commercial cleaning agents. This project tested the use of QACs in

maintaining sterility of harvesting tools and packaging materials, and compared these results to a traditional method of maintaining sterility (10% bleach solution). Though QACs were effective under certain conditions, they were not more effective than bleach in maintaining sterility during the harvesting process.

Project Purpose

According to manufacturer literature, QACs form a long-term hydrophobic and biologically-resistant film on target surfaces. Ammonium molecules within the film destroy bacteria and viruses that come in contact with the surface, highlighting the possibility that these compounds could prove to be effective in sterilizing harvesting tools and produce packing equipment. The capability for long-term sterilization of harvesting materials would be of great value to growers, but limited information is available on how effective these compounds actually are for tool sterilization, or how often re-application of QACs to tools would be necessary during harvesting. Perhaps even more importantly, no information is available on the potential for negative crop impacts (e.g., yield reductions, discoloration) that could arise from the use of these products, and nothing is known regarding the efficacy of treatment on different packing/growing materials (e.g., metal vs. plastic vs. wood surfaces). As a result, growers have been reluctant to embrace the use of QACs in food harvesting and processing.

QAC's were introduced for use as industrial sanitizing agents in the 1930s. Since that time, QAC formulations have undergone successive improvements to enhance efficacy and reduce their toxicity to users, to the point where hundreds of QAC-based disinfectants are now available in over-the-counter formulations. The most recent improvements include the additions of QACs to a silicone polymer, such that once applied, the compound sticks to metal and plastic surfaces, forming an effective "self-sterilizing" hydrophobic and biologically-resistant film on target surfaces. Ammonium molecules within the film destroy bacteria and viruses that come in contact with the surface.

Harvesting materials, e.g., cutting knives, packing crates, plastic pallets, and processing tables, are under constant exposure to soil and other bacterial-laden environments and as such, present a challenge for maintaining produce safety. It is simply not economically feasible, nor is it safe for the food crop, to re-sterilize a harvesting knife following each use. And yet, current methods for cleaning harvesting equipment are cumbersome, at times requiring several hours to sterilize a single piece of machinery (personal observation). Thus, the capability for long-term sterilization of harvesting equipment would be of great value to growers, but they lack the information needed that would enhance the potential for their adoption of these methods for tool sterilization.

The specific objectives of this project are:

- Establish the effectiveness of QACs relative to current methods for use in sterilization of field harvesting and crop processing equipment for harvesting of leafy greens, accounting for their ability to control/eliminate bacterial indicators as well as any effects on marketable yield of the crop.
- Effectively communicate these results to Arizona specialty crop producers.
- Provide graduate student training in field, laboratory, and extension methodology.

In order to meet the stated objectives, this work conducted laboratory studies to assess the long-term efficacy of QACs on harvesting tools, and examined QAC influences on sterility of harvesting aides and QAC-related crop impacts under field conditions over two growing seasons. These results were compared to control sites without QAC; controls included non-treated harvesting and packing materials (treated with water only) and materials treated using conventional methods (a dilute bleach solution), to assess the benefits and/or harm of QAC use in food production. The project also included surveys of growers of fresh produce to assess time and materials currently spent on sterilization of harvesting materials, and the development of extension and outreach events to convey results to the grower community.

Project Activities

This project included laboratory and field studies to determine the feasibility of introducing QAC-based sterilization practices to producers. Phase I of the stated **Work Plan** involved laboratory studies to examine the efficacy of QACs (at 100% strength and 50% strength) vs. traditional sterilization methods (dilute bleach solution) and a water control against indicator bacteria (*E. coli*) applied to harvesting tools and packing materials. Materials tested included stainless steel, aluminum, wood, and plastic (Figure 1). Following treatment of surfaces with *E. coli* bacteria at a concentration of 500 colony forming units (CFU) per square inch, sterile techniques were used to swab smooth surfaces and joint areas of the materials to assess survival of indicator bacteria. Presence of viable *E. coli* on swabs was ascertained using MI agar (Becton Dickinson, Inc., Franklin Lakes, NJ). Swabs were collected at Time 0 (immediately after treatment of surfaces with *E. coli*); Time 1 (1 minute following application of QACs, bleach, or water); and Time 2 (5 minutes following application of QACs, bleach, or water). This work was repeated six times using various swiping methods and different material configurations (e.g., metal bowls, metal tables, metal knives). Figure 1 shows the results of one of the repetitions, where bowls made of different materials were treated with 10% bleach (red columns), 100% QAC (green), 50% QAC (purple), or water (blue).

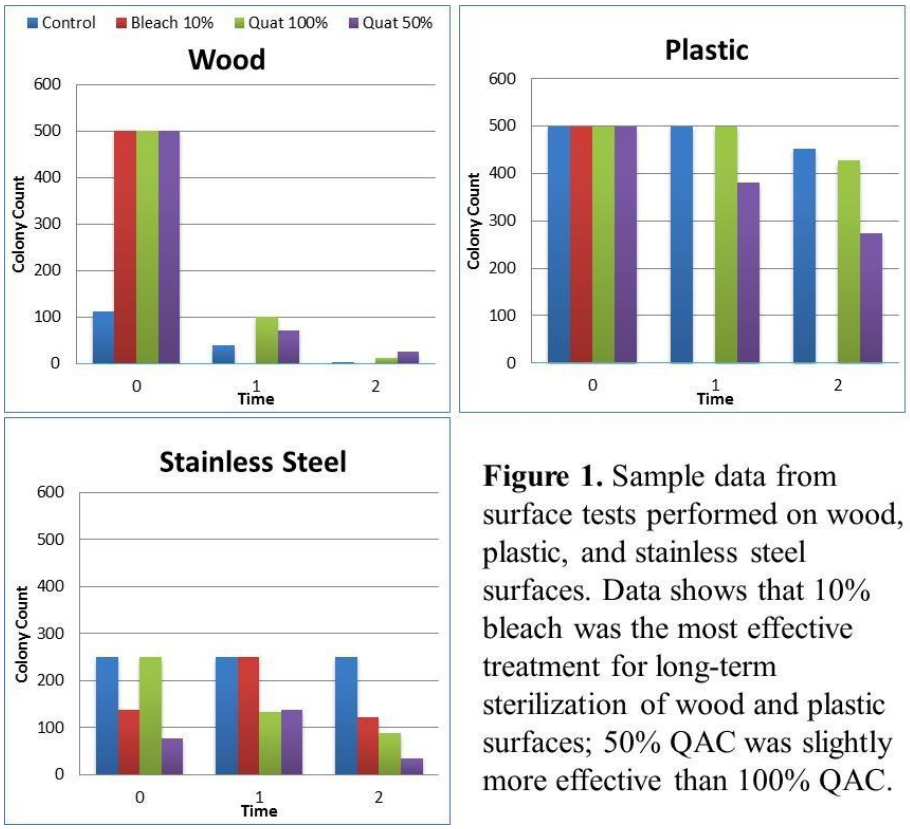

Figure 1. Sample data from surface tests performed on wood, plastic, and stainless steel surfaces. Data shows that 10% bleach was the most effective treatment for long-term sterilization of wood and plastic surfaces; 50% QAC was slightly more effective than 100% QAC.

Over all repetitions of this work, chlorine bleach showed the highest efficacy for surface sterilization of materials, while wood was the material that showed highest levels of sterility following treatment (Table 1). Though the objective of this work was to identify the QAC concentration most effective for maintenance of tool sterility over the longest period of time, bleach was by far the most effective sterilization tool.

Table 1. Effects of different treatments (blue rows) on *E. coli* counts over time; and effects of surface materials (orange rows) on treatment efficacy over time.

Treatment	***E. coli* (CFU per square inch)**		
	Time 0	**Time 1**	**Time 2**
10% Bleach	443	384	0
QAC (100%)	500	0	298
QAC (50%)	414	341	160
Water	403	276	352
Wood	403	53	10
Plastic	500	315	238
Stainless Steel	357	260	186
Aluminum	500	375	375

Phase II of the stated **Work Plan** consisted of field trials conducted over 2 growing seasons (Winter 2014/2015 and Winter 2015/2016) on a ¼-acre plots of leafy greens (e.g., romaine and greenleaf lettuce) at the Yuma Agricultural Center. Following a full growing cycle of the crop

using established methods, greens were sprayed with *E. coli*, then harvested the following morning (Figure 2) and placed on metal processing tables. During the harvesting and processing, harvesting knives and tables were treated with either 10% bleach, 100% QAC, or water (control). Harvesting tools were swabbed every 5 cuts, and were freshly treated with the sterilizing agent (or water control) every 50 cuts. Swabs were analyzed to estimate viable of *E. coli* (as in Phase I) throughout the harvest. Field trials were performed four times throughout the length of the project.

Figure 2. Setup of field experiments. The evening before harvest, all plots were sprayed with an *E. coli* solution to "contaminate" the crop (a). The following morning, all harvesting tools were treated with water (control), bleach, or 100% QAC (b). After cutting 5 heads of lettuce, tools were swabbed and assayed for presence of viable *E. coli* (c).

Results of the field trials confirmed that both bleach and QACs were equally effective in sterilizing harvesting materials in a field situation (Figure 3). However, an unexpected result was that the QAC and bleach treatments were most effective over time (after 4 or 5 cuts), whereas our hypothesis was that sterility of the tools would be highest over the first cuts, and would decrease thereafter. This pattern was found repeatedly during all reps of this experiment.

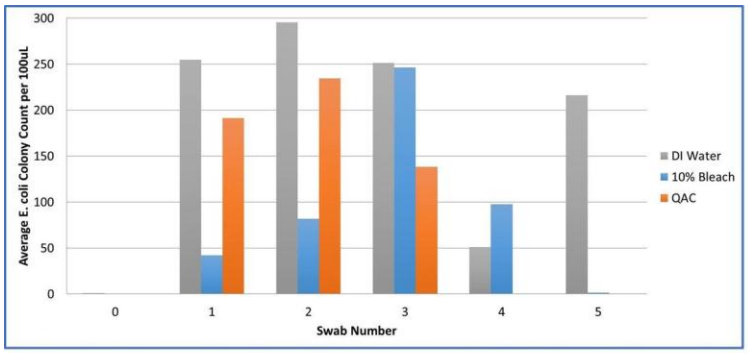

Figure 3. Results of Spring, 2015 rep of field harvesting experiment, showing viable *E. coli* on swabs of harvesting tools treated with QAC (orange), 10% bleach (blue), or water (control; grey). Initial swab of tool (before cut, time 0) showed no viable *E. coli,* with successive swabs after cutting 5 heads showing *E. coli* contamination transferred from the crop to the harvesting tool.

Treatment of stainless steel harvesting tables also occurred during all field experiments. Stainless steel tables are often used in field situations during the harvest of specialty crops, necessitating the addition of this treatment to the field assays. As the *E. coli*-contaminated lettuce heads were harvested, they were placed on stainless steel harvesting tables that had been pre-treated with either 10% bleach, 100% QAC, or water (control). Tables were swiped five times, each swipe following the processing of 10 *E. coli*-contaminated lettuce heads. During these experiments, no viable *E. coli* were detected, regardless of treatment used to sterilize the table. We hypothesize that, because all of these experiments occurred in the winter or spring in full sunlight, that the sun (ultraviolet radiation and heat) produced the most effective sterilizers of the stainless steel tables.

The third and final phase of the stated **Work Plan** was to perform an economic analysis of the use of QACs, to ascertain if growers would be willing to adopt the use of this product as a sterilizing agent, despite the higher cost than traditional methods (e.g., bleach). This economic analysis would have been useful if indeed the QACs had proven to be a far more effective sterilization method than bleach. However, this was not the case. Nevertheless, leafy greens producers in Yuma were asked to complete a detailed questionnaire on procedures and cost for sterilization of harvesting equipment. During two producer meetings (Yuma Lettuce Days, winter 2014 and 2015), cooperating growers completed a total of 38 questionnaires, with the major results summarized in Table 2.

Table 2. Results of questionnaire completed by cooperating growers at producer meetings.

Question	**Response**
What supplies/methods do you use for sterilization of harvesting tools?	Bleach (92%); UV/sunlight (66%); Soap and water (75%)
Would you consider the use of another cleaning agent if it were effective?	Yes (75%); Maybe (25%)
What information would you require about a new cleaning agent?	Efficacy (92%); Cost (100%); Potential for damage to crop (85%)
How many person hours do you estimate are spent each week during harvesting season on the cleaning/sterilization of harvesting tools?	0-10 (5%); 10-20 (65%); 20-30 (10%); 30-40 (20%); 40+ (0%)

Table 2 indicates strongly that growers are very open to the idea of using alternative methods for sterilization of harvesting tools. What is also clear is that well-controlled, replicated studies with conclusive results would be needed before growers are willing to adopt new measures.

Goals and Outcomes Achieved

The Expected Measurable products of this project stated in the proposal included:

- **Goal 1:** Rank the effectiveness of QACs relative to current methods for sterilizing field harvesting equipment (GOAL) over two Arizona leafy green growing seasons (Winter 2014/2015 and Winter 2015/2016) (TARGET). As no such ranking of disinfecting systems and protocols is currently available (BENCHMARK), this project would provide the first known, unbiased collection of field level, food safety guidelines for sanitizing harvest tools and equipment in Arizona (PERFORMANCE MEASURE). Through

laboratory and field assessments of the efficacy of QACs relative to bleach and water in sanitizing harvesting equipment and food packing materials over multiple replications, this goal was achieved. Because the QACs were not more effective than established methods for sanitation of harvesting equipment (10% bleach), food safety guidelines have not been changed or updated.

- **Goal 2:** Increase awareness of harvest tool sanitization practices among Arizona specialty crop producers (GOAL). Dissemination of key recommendations that establish best management practices in harvest tool disinfection will be presented to over 250 growers (GOAL) at the 2015 and 2016 preseason fresh produce safety workshop in Yuma, the 2016 Southwest Ag Summit, and Arizona Good Agricultural and Good Handling Practice Workshops. Final results, including economic analyses, will be summarized in a Cooperative Extension Bulletin at the conclusion of the project (TARGETS). The success of the project will be measured by attendance and participant exit assessments (PERFORMANCE MEASURES) at these meetings and overall grower adoption of the guidelines over time (PERFORMANCE MEASURE).

  The second goal of this project has been partially met. Distribution and completion of surveys by specialty crop producers increased understanding of current practices in sanitation of harvesting tools, and the current interest of growers in testing and adopting updated methods of sanitation. Because the QACs did not present any improvement over current methods used to sanitize harvesting tools, the Cooperative Extension Bulletin is not going to be completed as part of this work. Though the bulletin will not be submitted, the results of this project are contributing strongly to the design and successful completion of a follow-up project, SCBGP-FB15-07, "Creation of self-sterilizing irrigation pipelines." Though the irrigation pipelines project had proposed to test QACs, bleach, and water within irrigation pipelines, the newer project has been expanded to test two additional novel sterilization compounds, heightening the potential of success.

  Results of this project have also been distributed to growers during several events. In 2015, undergraduate students from Central Arizona Community College presented the results of the laboratory project in two posters at the USDA-ARS and Maricopa Agricultural Center Field Days. In November, 2016, master's student Juli Simons presented her results in a poster at the ASA-CSSA-SSSA International Annual Meetings in Phoenix, Arizona.

- **Goal 3.** Development of human resources (GOAL) through training of one UA Master's level student for a period of two years (TARGET). The student will become fully trained in laboratory and field methods, economic analysis, and extension/outreach (PERFORMANCE MEASURE).

  Goal 3 has been successfully realized. This project has resulted in laboratory and field training for three undergraduate students: Isadora Garcia, Alexa Brown (South Mountain Community College), and Emily Gudvangen (University of Arizona). The project has also resulted in the training of a master's student, Juli Simons (University of Arizona). All students have become adept in laboratory methods, field sampling, and reporting of results.

Beneficiaries

This research builds on our expertise in Extension and contributes to a growing body of knowledge related to pathogenic bacteria and their relation to food safety. To date, few studies have been conducted that assess the potential for harvesting tools to pass bacteria into crops, and the efficacy of sterilization methods. In preliminary studies, we have collected data which demonstrates that current methods used to sterilize harvesting tools and packing materials are extremely effective, and perhaps more effective than newly developed methods. The testing of QACs came at the behest of growers, who had received marketing materials on these new compounds expounding their efficacy in tool sterilization. Yet the specialty crop producers had no information on these materials, their efficacy in field situations, or their potential to cause crop damage. Our original hypothesis was that QACs would be more effective in tool sterilization, but this was not proven.

The results of this project will be of extreme interest to stakeholders and growers, whose primary interest is the production of a high-quality, safe end product. We consider these stakeholders, who have been integral in the conception, proposal, and design on this project, the primary beneficiaries of this information. Over the length of the project, we documented 325 specific instances where information from this project were beneficially transferred to stakeholders. Benefits were realized in several ways. First, surveys to understand time and materials spent on sanitizing harvesting tools and equipment were distributed to specialty crop producers at grower meetings in fall 2015 and winter 2016. Twenty-two (22) completed surveys were collected. Results of this project were also distributed to growers during two poster events. In 2015, undergraduate students from Central Arizona Community College presented the results of the laboratory project in two posters at the USDA-ARS and Maricopa Agricultural Center Field Days, attended by 78 agricultural professionals. In November, 2016, master's student Juli Simons presented her results in a poster at the ASA-CSSA-SSSA International Annual Meetings in Phoenix, Arizona. During the poster presentation, Juli spoke to 225 attendees. Two (2) of these attendees contacted Juli after the poster session to ask additional questions about the project and the results.

Lessons Learned

The finding of lower efficacy of QACs in destroying contaminating bacteria (compared to traditional methods, e.g., bleach) was unexpected. We had hypothesized that newly developed methods would outdo traditional methods. This data, though not agreeing with our original hypothesis, has been valuable in designing follow-up experiments. As aforementioned, Arizona Department of Agriculture funding has been awarded for "Creation of Self-Sterilizing Irrigation Pipelines." Although QACs will also be examined as one treatment in the follow-up work, two additional sterilization agents have been added to that project to enhance the probability of success.

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Additional Information

Poster presentations resulting from this work. Arizona Department of Agriculture funding has been noted on all of these presentations.

- Isadora Garcia, Channah Rock, Kurt Nolte, and Jean E. McLain. 2015. QUAT are you working for? Testing quaternary ammonium compounds on agricultural tools. USDA-ARS, US Arid-Land Agricultural Research Center Annual Field Day, Maricopa, Arizona.
- Alexa Brown, Channah Rock, Kurt Nolte, and Jean E. McLain. 2015. The effectiveness of quaternary ammonium compounds on agricultural tools as an antimicrobial agent. USDA-ARS, US Arid-Land Agricultural Research Center Annual Field Day, Maricopa, Arizona.
- Juli Simons, Channah Rock, Kurt Nolte, and Jean E. McLain. 2016. Self-sterilizing harvesting tools and irrigation pipelines. American Society of Agronomy-Crop Science Society of America-Soil Science Society of America International Annual Meeting, Phoenix, Arizona.

Enhancing IPM Research in Arizona Vegetables

This project was completed on September 30, 2016

Project Summary

Translational IPM research is essential in providing specialty crop growers with new information on pest population dynamics and management technologies. The goal of this project was to enhance science-based IPM programs for watermelon, celery, and sweet corn crops by developing a knowledge base that identifies the seasonal insect spectrum, documents their impacts on crop yield and quality, and identifies effective control alternatives. The outcomes of this project will provide growers and PCAs with new, local-based information and tools to manage insects on these vegetable and melon crops that have traditionally received little scientific attention. Specifically, cucumber beetles on watermelons should be anticipated to occur on spring crops, and if not properly controlled can lead to cosmetic injury and yield losses. Sweet corn growers are now aware that fall armyworm and corn earworm occur on corn plants throughout the growing season, not just when ear production is occurring. Early suppression of these worm pests with insecticides during the whorl stage can lead to improved yields. Studies in celery showed that Lygus bug does not appear to be as significant a pest in Arizona as previously believed, however seasonal control of beet armyworm and aphids is required to avoid yield and quality losses. In addition, new insecticide products and application techniques/timing have been recommended for these key pests in watermelons, celery and sweet corn.

Project Purpose

Arizona growers are one of the leading producers of fresh-market vegetables in the U.S. They produce vegetables and melons on greater than 140,000 acres at an estimated value of over $1 billion annually. The primary vegetable crops grown in Arizona include head and leaf lettuce, cole crops and melons, but crops like celery, sweet corn and watermelons are increasingly becoming more important. Vegetable cropping systems in Arizona are pest-intensive and growers annually battle a multitude of insect pests. Furthermore, new pest problems periodically challenge the industry causing unwanted losses. Because of the high crop values and consumer

demands for aesthetically appealing and pesticide-free produce, Arizona vegetable growers are forced to use IPM tactics that are both effective and safe.

Arizona growers presently rely almost exclusively on insecticides for management of insects on vegetable and melons to satisfy regulatory and consumer requirements. This level of crop quality however, comes at a significant cost. Insect control alone annually costs head lettuce growers over $360/acre, and nearly $320/acre for melon growers. Insecticide costs continue to increase and IPM alternatives need to be developed. New invasive pests have recently put significant strains on vegetable producers due to lack of information on pest biology and management (i.e, CYSDV, Bagrada bugs). In addition, recent EPA regulatory decisions have placed limitations on important crop protection chemicals (i.e., flubendiamide and sulfoxaflor were recently removed from the market) that could make vegetable production more difficult and expensive. Furthermore, even though minor vegetables like celery and sweet corn are produced on fewer acres, their economic value is often equal to or even greater than lettuce and cole crops. Consequently, for growers of these crops to remain competitive, the need for translational IPM information is now greater than ever before.

Translational research is essential for sustaining economically and environmentally sound production of vegetable crops in Arizona. Cost-effective adoption of new reduced-risk control technologies by the industry will require a crop-specific, knowledge base of pest biology, ecology, impact and management. Because "All IPM is local", the research knowledge necessary for implementing new IPM approaches must be developed specifically for Arizona's unique desert growing conditions. Presently, information on vegetable IPM in Arizona has resulted almost exclusively through the research developed by University of Arizona scientists. In crops such as celery, sweet corn, and watermelons local information on IPM is lacking, and new research data should enable growers to improve yields and quality, use pesticides more cost-effectively and safely, and consequently stabilize, if not increase their profit margins.

Accordingly, the objective of this project was to enhance our science-based IPM research/ outreach program through the development of new information and technologies for managing pests in specialty vegetable and melon crops which are often considered secondary in terms of production value and harvested acreage in Arizona. Our goal was to develop a knowledge base for insect management on watermelon, celery, and sweet corn that produces new information for each crop information identifying the seasonal insect spectrum, documenting impacts of insect occurrence/abundance with crop yield and quality, and identifies cost-effective control alternative (chemical or non-chemical).

Project Activities

Watermelons

A series of studies were conducted in the spring/summer of 2015 and 2016 to develop a knowledge base for insect pests, their impact on yields, and management. Specifically, this consisted of studies to identify the pest spectrum affecting watermelons, and studies to measure insecticide alternatives effective against whiteflies and their impact on yields.

Insect Surveys: Studies were conducted to survey the abundance and diversity of insect pests found on transplanted watermelons grown in 0.5 acre plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. Beginning 6 weeks following transplanting (Mar 5, 2015), 40 plants were randomly sampled at 6-7 d intervals and the number of key pests present on a 5 plant sample were recorded. Damage to developing and mature fruit were also recorded.

	Mean / 5 plants				
Date	Damaged Fruit	Cucumber Bettle	Looper / Armyworm	Whitefly adults	Whitefly nymphs
17-Apr	0	0	0	0.6	0
23-Apr	0	0	0	2.4	0
30-Apr	0	0.2	0	2.6	0
7-Apr	0.5	2.1	0.5	4.1	0
14-May	3.3	4.0	0.5	6.4	0.2
20-May	1.7	4.5	0.0	7.5	1.5
26-May	3.2	4.5	0.0	11.8	5.5
3-Jun	1.6	3.0	0.0	11.1	6.1

Means followed by the same letter are not significantly different (Tukeys; *p>0.05*)

The results above show that sweetpotato whitefly (SWF) and striped cucumber beetles (SCB) were the most abundant pests present. SWF have been a major pest since 1993 and were abundant as expected in this survey, particularly later in the season. However, SCB is generally not considered a pest on desert melons, but they were clearly abundant, where they could be found feeding on blooms early in the study and subsequently caused significant damage to immature fruit. Beet armyworm and cabbage looper were observed occasionally on plants, but feeding on fruit was not observed. At harvest, SCB caused significant scarring on mature watermelons (1.6-3.2 damage melons /5 plants) rendering these fruit unmarketable. A similar survey was conducted in 2016, however insect pressure was very light. SCB and beet armyworm/cabbage loopers were considerably less abundant and their related feeding damage was not observed. SWF was present as expected, but again at lighter densities than 2015. Because the whitefly populations occurred very late in the season, no yield or quality losses were measured.

Soil Insecticide Studies: A study was conducted to evaluate the effectiveness of new soil-applied insecticides applied through drip irrigation against sweetpotato whiteflies (SWF) on transplanted watermelons grown in small plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. At 3 weeks following transplanting (Mar 5, 2015), insecticides were injected into the drip tape and plants were sampled for immature SWF at 7 day interval following application. Plots consisted of a single 84inch bed, 45 ft long with a 7 ft buffer between each plot. The study was designed as a RCB design with four replicates per treatment. All treatments, except the non-treated control, received a soil insecticide application through the drip tape. The tape was placed 6 inches below the seed line and the system was set up to deliver 0.67 gpm/100ft of tape at 8 psi. Distance between emitters was 8 inches. The duration of chemigation was as follows: the irrigation system was run for ½ h, then the treatments were delivered through the system for approximately 20 min followed by another 3 h of irrigation to flush the lines and irrigate the plots. No additional insecticides were applied to the plots. Immature densities were estimated periodically by sampling 10 plants / plot, where 3 leaves per plant were collected from

various node locations on the primary vine. Leaves were taken into the laboratory where densities of eggs, and nymphs were counted on two, 2-cm^2 leaf discs of each leaf using a dissecting microscope.

		SWF Eggs /cm^2					
	Rate amt product/acre	*7 DAA*	*14 DAA*	*21 DAA*	*28 DAA*	*35 DAA*	*42 DAA*
Verimak 1.67 SE	10.3 oz	57.6a	8.1a	16.5a	15.1ab	28.1a	38.5a
Venom 70WG	6 oz	13.6a	0.8b	3.6b	6.0d	7.5c	35.0a
Sivanto 240SL	21 oz	15.2a	4.0b	3.9b	11.4bc	22.4ab	30.8a
Sivanto 240SL	28 oz	13.6a	1.6b	4.2b	9.2cd	11.2bc	27.3a
UTC	-	64.0a	7.2a	15.5a	19.8a	28.9a	26.6a

The results showed that Sivanto significantly reduced whitefly eggs on watermelons leaves for more than 30 days and suggests that the compound has systemic activity on the adult life stage comparable to the industry standard - Venom. Furthermore, Sivanto provided significant reductions in nymph densities for 28 days comparable to Venom. In contrast, Verimark did not significantly reduce SWF egg or nymph densities comparable to either Venom or Sivanto. Yield measurements at harvest showed that only the Sivanto and Venom treatments adequately protected watermelon yields and quality from whitefly feeding. Verimark did not protect cantaloupes in this and resulted in a 15% quality reduction due to sticky melons at harvest. This study demonstrated that Sivanto is a viable alternative to controlling SWF on watermelons and are recommending that growers consider using Sivanto for future watermelon production.

		SWF Nymphs /cm^2					
	Rate amt product/acre	*7 DAA*	*14 DAA*	*21 DAA*	*28 DAA*	*35 DAA*	*42 DAA*
Verimak 1.67 SE	10.3 oz	1.0a	17.7b	10.4ab	15.4a	17.5a	36.4a
Venom 70WG	6 oz	0.5a	2.8c	1.6c	3.5b	7.2a	24.1a
Sivanto 240SL	21 oz	0.3a	3.1c	3.2bc	10.5ab	16.1a	25.0a
Sivanto 240SL	28 oz	0.5a	2.2c	1.6c	6.3b	9.5a	21.5a
UTC	-	1.2a	25.3a	16.5a	17.5a	24.4a	22.4a

<u>Foliar Insecticide Studies:</u> A study was conducted in spring of 2016 to evaluate the effectiveness of new foliar applied insecticides against sweetpotato whiteflies (SWF) on transplanted watermelons grown in small plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. Plots consisted of a single 84-inch bed, 45 ft long with a 7 ft buffer between each plot. The study was designed as a RCB design with 4 replicates / treatment. Two foliar spray treatments were applied on 5 and 16 June with a CO_2 backpack sprayer that delivered 20.5 gpa at 40 psi, using 4 – TX18 ConeJet nozzles per bed as a broadcast spray. All spray treatments

included an adjuvant, DyneAmic at 0.25% vol/vol. Populations of whitefly adults were evaluated at 1, 3 and 7 day intervals following each application (DAT). Adult populations were estimated using a modified vacuum method. On each sample date, 5 separate plants from each replicate were sampled by vacuuming the terminal area of the plants for 3 s. Containers with adults were taken into the laboratory, placed in a freezer for 24 h after which the number of adults/ plant was recorded. Immature densities were estimated at 14 DAA2 by sampling 10 plants / plot, where 3 leaves per plant were collected from various node locations on the primary vine. Leaves were taken into the laboratory where densities of eggs, and nymphs were counted on two, 2-cm^2 leaf discs of each leaf using a dissecting microscope.

Population of SWF adults during the study were light-moderate. Following each application, Sivanto and Exirel provided significant knockdown control of adults. However, residual control at 7-14 DAA was not significant. The industry standard, Assail, did not provide activity that was significantly different from the untreated check on any post-treatment sample dates. This is not surprising since anecdotally growers have complained about the poor effectiveness of Assail for the past year or so. Mitius, an acaricide, did not provide significant knockdown or residual control either. Perhaps more importantly, results show that Exirel and Sivanto provided significant control of immature SWF as measured 14 DAA2. This is useful information since SWF nymphs are the primary life stage that causes significant reduction in quality and causes sticky fruit due to honeydew and sooty mold contamination. Due to the moderate numbers in the trial we did not observe sticky fruit at harvest in any of the treatments including the untreated check. Because of the excellent performance of Sivanto and Exirel, growers are encouraged to use these products, rather than Assail, in their watermelon IPM program to control SWF.

		Adults / Sample									
		1 DAA-1	*3 DAA-1*	*7 DAA-1*	*11 DAA-1*	*14 DAA-1*	*1 DAA-2*	*3 DAA-2*	*7 DAA-2*	*14 DAA-2*	Trial
Treatment	Rate/ac	17-May	19-May	23-May	27-May	30-May	1-Jun	3-Jun	7-Jun	14-Jun	Avg.
Exirel	20.5	1.3ab	0.4c	1.9	3.6	2.8	0.3b	0.2cd	1.2	1.9	1.5c
Exirel	15	1.3ab	0.5bc	1.5	3.8	2.4	0.7ab	0.1d	1.1	2.4	1.5c
Sivanto	14	0.7b	0.2c	2.0	4.1	2.5	0.4b	0.4bcd	2.4	3.3	1.8bc
Sivanto	10.5	0.6b	0.3c	2.5	5.4	2.9	0.7ab	0.5bcd	1.6	3.3	1.9bc
Assail	8 oz	1.5ab	0.7abc	2.4	3.8	3.1	1.2ab	0.8abc	3.0	4.7	2.3ab
Mitius	2 pts	0.8ab	1.8ab	3.6	4.0	3.3	1.9ab	1.1ab	3.9	6.9	3.0ab
Untreated	-	2.3a	2.6a	3.1	6.4	4.0	2.5a	2.5a	3.5	4.9	3.5a
	F value	*4.01*	*7.62*	*1.51*	*1.08*	*0.91*	*4.26*	*7.43*	*1.91*	*1.35*	*11.4*
	P > F	*0.01*	*0.0004*	*0.23*	*0.41*	*0.52*	*0.008*	*0.0004*	*0.14*	*0.29*	*<.0001*

Means followed by the same letter are not significantly different (Tukeys; *p>0.05*)

		Avg. whitefly nymphs / cm^2			
		Terminal Leaf		Mid-vine Leaf	
Treatment	Rate/ac	Eggs	Nymphs	Eggs	Nymphs
Exirel	20.5	4.4b	1.3bc	2.1a	0.6bc
Exirel	15	1.2b	0.6c	0.7a	0.2c
Sivanto	14	3.3b	0.8bc	1.3a	1.1bc
Sivanto	10.5	3.7b	1.3abc	1.4a	1.1bc
Assail 30SG	8 oz	4.9b	2.9ab	1.4a	2.4ab
Mitius	2 pts	5.5b	3.0ab	1.5a	2.3ab
Untreated	-	14.1a	3.8a	2.9a	5.8a
	F value	*3.51*	*5.56*	*0.68*	*8.59*
	P > F	*0.04*	*0.002*	*0.67*	*0.0002*

Celery

A series of studies were conducted in the fall/winter of 2014-15 and 2015-16 to develop a knowledge base for pests of celery, their impact on quality, and new tools for management. Studies consisted of surveys to identify the key pest spectrum, and studies to measure insecticide alternatives effective in controlling beet armyworm and aphids.

Insect Surveys: Three field studies were conducted to survey the abundance and diversity of insect pests found on transplanted celery grown in 0.5 acre plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. Beginning about 2 weeks following transplanting (15 Oct and 31 Oct, 2014; 1 Nov 2015), 10 plants were randomly sampled from 5 locations at 7-14 d intervals and the number of key pests present on each plant sample were recorded. Damage to petioles, terminal growth and trifoliate leaves were also recorded. The results from surveys in 2014-2015 showed that damage to celery plants appeared soon after transplanting, and became progressively worse as the season progressed. The damage was primarily attributed to beet armyworm (BAW) that fed on the celery terminal growth and the inner midrib of the petioles. In addition, the presence of larvae, frass and damage in celery hearts at harvest would be considered contaminants and could possibly result in crop rejection. Not surprising, BAW was the most abundant pest found in both celery plantings in 2014-2015. This is not unusual given the warm winter growing conditions experienced during the trials. A number of plant bugs were also present including three-corned alfalfa hopper, Lygus bugs, and *Empoasca* leafhoppers. But these pests occurred at much lower abundance and their presence varied throughout the crop season in both trials. Presence of plant bugs contaminating celery hearts at harvest can also result in crop rejection. We had anticipated that Lygus bugs would be present at higher densities since it is considered one of the main pests by local growers. Although, they occurred at their peak abundance near harvest, we were not able to attribute any petiole damage to their feeding and they failed to have a negative impact on yield or quality during these studies. In contrast, aphids were abundant in the studies, particularly the last few weeks before harvest, and reached damaging levels at harvest by contaminating celery hearts. Early in the season, melon aphid showed up on plants, but green peach and foxglove aphids were the predominate species at harvest.

2014-15 Celery Pest Survey- I (Oct 15 transplant date)

		Avg. per 10 Plants					
Date	DATP	Damaged plants	Beet armyworm	Alfalfa hopper	Lygus bug	*Empoasca* leafhopper	Aphids
23-Oct	10	0.0	0.0	1.2	0.0	0.0	0.0
6-Nov	22	0.5	0.5	0.6	0.0	1.0	0.0
12-Nov	28	1.0	0.5	0.0	0.0	0.0	0.0
21-Nov	37	3.0	4.5	0.0	0.0	0.5	0.5
26-Nov	42	4.5	3.0	0.5	0.0	0.0	0.0
5-Dec	51	4.0	1.0	1.0	0.0	0.0	0.0
11-Dec	57	4.0	2.5	0.0	0.0	0.5	0.0
18-Dec	64	5.5	3.5	1.5	0.0	1.0	0.0
30-Dec	76	10.0	4.0	0.5	0.5	1.0	0.0
6-Jan	83	4.5	1.5	0.0	0.0	0.5	30.5
15-Jan	92	6.0	6.5	0.0	0.0	0.0	10.5
26-Jan	Harvest	5.0	5.0	0.0	2.0	1.0	25.3

2014-15 Celery Pest Survey- II (Oct 31 transplant date)

		Avg. per 10 Plants					
Date	DATP	Damaged plants	Beet armyworm	Alfalfa hopper	Lygus bug	*Empoasca* leafhopper	Aphids
12-Nov	11	1.2	1.0	0.0	0.2	0.0	0.0
21-Nov	20	4.5	3.7	0.0	0.0	0.0	0.0
28-Nov	27	4.0	2.2	0.2	0.0	0.0	0.0
5-Dec	34	3.7	4.5	0.2	0.0	0.0	0.0
11-Dec	40	2.5	1.0	0.0	0.0	0.3	0.0
17-Dec	47	1.3	1.2	0.2	0.0	0.8	0.3
30-Dec	60	4.5	1.3	0.0	0.0	0.0	0.0
9-Jan	70	3.8	2.3	0.0	0.0	0.3	0.3
15-Jan	76	2.5	1.5	0.0	0.0	0.0	0.5
22-Jan	83	4.5	5.0	0.0	1.0	0.0	2.5
5-Feb	97	4.0	1.5	0.0	0.0	0.0	3.5
22-Feb	Harvest	3.0	3.0	0.0	0.0	0.0	51.5

We observed similar trends in pest presence in our 2015-16 survey study, but overall pest abundance was lighter. BAW and green peach aphids (foxglove aphid was absent) were the predominant pests but were considerably lower than the previous season. Damage to plants was lower also, particularly at harvest. Furthermore, Lygus was only present near harvest, and did not cause observable damage to plants. Based on our experience, Lygus would be considered a minor pest. This is different from other celery growing regions where Lygus is considered a major pest. Results of these studies have for the first time documented that BAW and aphids (foxglove and green peach) are the major pests currently affecting celery production in Arizona.

2015-16 Celery Pest Survey (Nov 15 transplant date)

		Avg. per 10 Plants					
Date	DATP	Damaged plants	Beet armyworm	Alfalfa hopper	Lygus bug	*Empoasca* leafhopper	Aphids
12-Nov	12	0.0	0.0	0.0	0.0	0.0	0.3
20-Nov	20	0.3	0.3	0.0	0.0	0.0	0.0
28-Nov	28	0.5	1.0	0.0	0.0	0.0	0.0
5-Dec	35	0.8	0.3	0.0	0.0	0.0	1.0
13-Dec	42	1.8	2.0	0.0	0.0	0.0	0.8
21-Dec	50	2.0	1.5	0.0	0.0	0.0	0.0
6-Jan	67	1.8	1.0	0.5	0.0	0.0	0.3
12-Jan	73	1.0	0.5	0.0	0.0	0.0	0.4
19-Jan	80	4.2	2.5	0.0	0.0	0.0	1.0
29-Jan	90	1.7	1.3	0.4	0.0	0.0	1.3
5-Feb	97	3.0	1.5	0.5	0.0	0.0	6.5
12-Feb	104	1.7	1.2	0.4	2.0	0.0	9.6
20-Feb	112	0.8	1.3	0.4	1.0	0.0	3.8
27-Feb	Harvest	1.0	1.0	0.0	1.0	0.0	13.9

Soil Insecticide Study: A study was conducted to evaluate the effectiveness of new soil-applied insecticides applied as transplant tray drenches against BAW on celery grown in small plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. Plots were two beds wide by 50 ft long and bordered by two untreated beds. Four replications of each treatment were arranged in a RCB design. Formulations and rates for each treatment compound are provided in the table. The transplant tray treatments were applied to three transplant trays (n=224 cells) for each treatment 24 hrs prior to transplanting. The products were applied by spraying the transplants with a CO_2 operated, back-pack sprayer that delivered a band that was the width of the tray through a single TX8008 flat-fan nozzle at 30 psi. A total volume of 500 ml was used to deliver each treatment. Following application of the insecticides, each treatment (3 trays) was sprayed with water to incorporate the materials into the transplant plugs. At various intervals after transplanting (10-45 DAA), 10 plants were randomly selected from each replicate and sampled for the presence of each BAW larvae. Efficacy was based on the examination of whole plants for presence of small (newly hatched and 1st instar) and large (2nd instar or >) larvae.

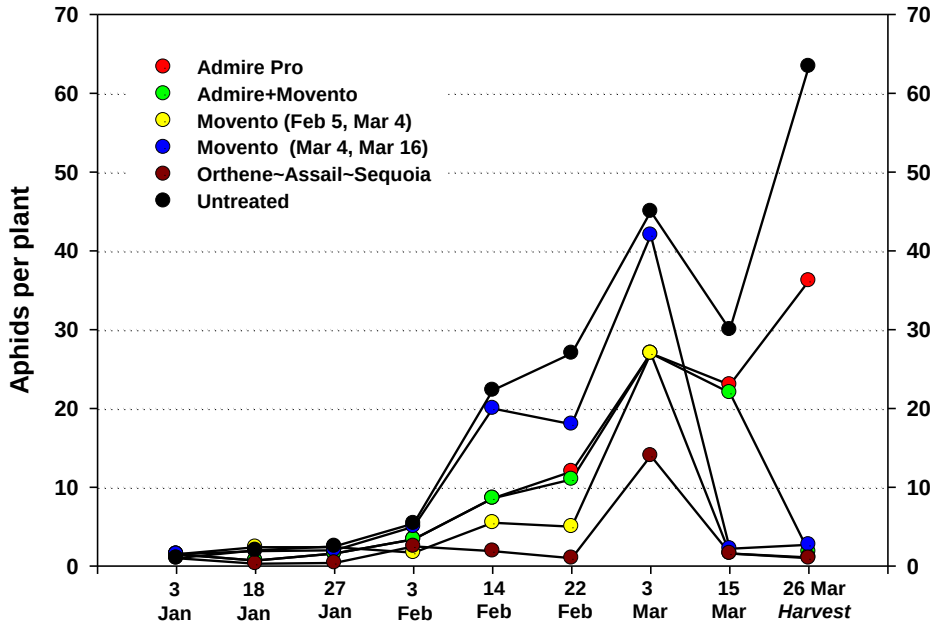
		Avg. BAW larvae / 10 plants					
		10 DAA	*15 DAA*	*21 DAA*	*28 DAA*	*35 DAA*	*45 DAA*
Treatment	**Rate/ac**	**25-Oct**	**30-Oct**	**6-Nov**	**13-Nov**	**20-Nov**	**30-Nov**
Exirel	13.5 oz	0.0a	0.0b	0.0b	0.0b	3.0a	2.5a
Coragen + Admire Pro	7 + 10.5 oz	0.0a	0.0b	0.0b	0.5b	1.5a	4.0a
Durivo	13 oz	0.0a	0.0b	0.0b	0.5b	2.5a	3.0a
UTC		0.5a	1.5a	2.0a	2.5	3.5a	4.0a

Means followed by the same letter are not significantly different (Tukeys; *p>0.05*)

Results from the study showed that all three insecticides including Coragen, Durivo and the new diamide, Exirel provided comparable control of BAW when used in a tray drench application. Similar to results seen in other leafy vegetable, these systemic products provided significant control for 28 DAA compared to the untreated check. By 35 DAA, control of BAW had

diminished and larvae readily began to infest and damage plants. We currently recommend growers use these soil alternatives applied to transplant trays in areas where they consider BAW to be a threat at stand establishment.

Foliar Insecticide Study: A study was conducted in spring of 2016 to compare the effectiveness of Movento with other industry standards against sweetpotato whiteflies (SWF) on transplanted celery grown in small plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. Plots consisted of a single 84-inch bed, 45 ft long with a 7 ft buffer between each plot. The study was designed as a RCB design with 4 replicates / treatment. Foliar spray treatments were applied with a CO_2 backpack sprayer that delivered 20.5 gpa at 40 psi, using 4 – TX18 ConeJet nozzles per bed as a broadcast spray. All spray treatments included an adjuvant, DyneAmic at 0.25% vol/vol. Aphid populations were assessed weekly by estimating the number of aphids / plant in whole plant, destructive samples. On each sampling date, 5-10 plants were randomly selected from each plot and placed individually into large 5-gal tubs. At harvest, aphid contamination of celery hearts was estimated by sampling 10 plants per plot by removing older foliage and petioles from the plants and counting the numbers of aphids within celery hearts.
Aphid densities for both foxglove aphid (FGA) and green peach species (GPA) were low early in the crop season but reached significantly high levels in early March. At harvest (28 March), GPA was more abundant in the UTC and all treatments had significantly fewer aphids than the UTC with the exception of the Admire Pro treatment that had been soil applied at planting. FGA numbers in celery hearts at harvest differed among treatments. The Admire Pro treatment was not different than the UTC, both of which were heavily contaminated with aphids and would have been considered unmarketable. In contrast, Admire Pro followed by an application of Movento before harvest had significantly lower numbers in celery hearts. All of the Movento and Industry Standard treatments, applied without Admire Pro, significantly reduced FGA numbers compared to the UTC at harvest.



			Mean Aphids / Plant		
Treatment	N sprays	Spray Dates	Foxglove aphid	Green Peach aphid	Total aphids
Admire Pro	0	-	25.3a	10.9 b	36.2b
Admire Pro+Movento	1	Mar 4.	1.2c	0.5c	1.8c
Movento	2	Feb 5, Mar 4	0.9c	0.2c	1.1c
Movento	2	Mar 4, Mar 16	2.2c	0.5c	2.7c
Orthene~Sequioa~Assail	3	Feb 5, Mar 4 & 16	1.0c	0.0c	1.0c
Untreated	0	-	28.5a	34.9a	63.4a

Sweet Corn

A series of studies were conducted in the spring of 2015 and 2016 to develop a knowledge base for pests of sweet corn, their impact on yield/quality, and new approaches for management. Studies consisted of surveys to identify the key pest spectrum and their distribution on corn plants, studies to examine spray schedules and rotations, and studies to evaluate insect alternatives effective in controlling corn earworms and fall armyworms in sweet corn.

Insect Survey: Two separate field studies were conducted in 2015 to survey the abundance and distribution of insect pests found in 0.5 acre plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. Plots were established on March 24 and April 12. Beginning at about the 2 leaf stage, 10 plants were randomly sampled from 5 locations at 7-10 d intervals. The only pests found in experimental plots were corn earworm (CEW) and fall armyworm (FAW). On each sample, the number CEW and FAW present on each plant sample were recorded. Furthermore, the locations within the plants that the larvae were observed (i.e., whorl, silk tassel, ear) were also recorded.

The results below of the temporal and spatial distribution of CEW and FAW in sweet corn were consistent in both plantings and show some very interesting trends. During the whorl stage, FAW was significantly more abundant on plants than were CEW. However, once plants began to tassel and produce silk (either internal within developing ears, or external above larger ears), the proportion of CEW was comparable and often greater than FAW. During early stages of ear development FAW were found to be more abundant on small ears, but as ears matured and especially at harvest maturity, the proportion of CEW in/on the silk and within ears was significantly higher than FAW. Finally, worm pressure appeared to heavier in the early planted sweet corn, particularly at harvest (28 May, 19 Jun), although peak densities varied through the season in both planting and plant phenological locations. These results suggest that management of CEW and FAW should begin during the whorl stage to minimize numbers in the field before the plants begin to tassel and push silk. A study was designed in 2016 to examine this idea.

Sweet Corn Larval Distribution Survey I (Mar 24 planting date)

	Avg. no. Larvae / 10 Plants							
	Whorl		Tassle		Silk		Ear	
Date	FAW	CEW	FAW	CEW	FAW	CEW	FAW	CEW
14-Apr	1.5	0.5	-	-	-	-	-	-
21-Apr	12.8	7.0	-	-	-	-	-	-
28-Apr	30.8	3.0	-	-	-	-	-	-
5-May	-	-	2.3	5.8	6.5	9.5	2.3	1.0
13-May	-	-	0.0	2.5	3.8	30.4	2.1	0.8
21-May	-	-	0.0	0.0	35.0	56.0	1.0	1.0
28-May	-	-	0.0	0.0	0.0	0.3	0.4	7.8

Sweet Corn Larval Distribution Survey II (Apr 12 planting date)

	Avg. no. Larvae / 10 Plants							
	Whorl		Tassle		Silk		Ear	
Date	FAW	CEW	FAW	CEW	FAW	CEW	FAW	CEW
1-May	0.0	0.3	-	-	-	-	-	-
6-May	0.5	0.8	-	-	-	-	-	-
12-May	13.8	0.5	-	-	-	-	-	-
19-May	33.8	0.0	-	-	-	-	-	-
29-May	-	-	8.0	1.5	2.5	0.5	11.0	3.5
4-Jun	-	-	3.5	1.0	3.5	1.5	12.0	0.0
10-Jun	-	-	1.5	1.0	5.5	32.0	13.0	15.5
19-Jun	-	-	0.0	0.0	0.0	0.0	0.2	1.3

Spray Schedules: Field studies were conducted in 2015 and 2016 to examine the intensity of insecticide spraying on insect control and yields of sweet corn in large plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. Our goal was to determine whether the conventional approach of spraying on a 3-day schedule was optimal for protecting ears from SEW and FAW, as opposed to a 2-d or 4-d spray schedule. We also compared different insecticide rotations with each spray schedule. Plots of 4 beds wide by 75 ft long were established on March 24, 2015 and Mar 31, 2016. In the 2015 study, sprays were initiated at first sign of silk on ears, and continued until ears were at harvest maturity. In the 2016 study, sprays were initiated at 20% silk. In 2015, the Tank mix-rotations consisted of making consecutive Nudrin+Asana sprays followed by a Belt+Baythroid spray. The Solo rotation, consisted of consecutive sprays of single products: Nudrin, Asana, Nudrin and Voliam Xpress. The 2-d schedule received 11 sprays, the 3-d received 8 sprays and the 4-d schedule was sprayed 6 times. At harvest, assessment of damaged ears (unmarketable), live larvae and tip damage were conducted by randomly sampling 25 ears per replicate (100/tmt) and counting damaged ears, live

larvae by species, and measuring damage on ear tips. The table below shows that the spray schedules using tank-mixtures resulted in significantly fewer damaged ears than any other treatment. The 2-d spray scheduled provided the cleanest ears (6.6% damage), and the 3- and 4-d schedules using tank-mixtures provided better control than any of the Solo product rotations, regardless of spray schedule. Among the Solo rotations, the 2-d schedule had significant fewer damaged ears than the 3-and 4-d schedules. All spray schedule/rotation combinations had significantly less damage and fewer larvae in ears than the untreated check.

2015 Spray Schedule Trial

Spray Schedule	Rotations	% Damaged ears	Live Larvae / 25 ears: 1st-3rd instars	Live Larvae / 25 ears: 4th-5th instars	Live Larvae / 25 ears: Total larvae	Avg tip damage (cm)
2 day	Tank-mixture	6.6 e	0.8 b	0.0 c	0.8 c	2.6 b
3 day	Tank-mixture	17.4 de	0.5 b	1.0 bc	1.5 bc	3.7 ab
4 day	Tank-mixture	22.1 d	0.5 b	1.0 bc	1.5 bc	4.6 a
2 day	Solo	32.7 c	1.5 b	2.8 bc	4.3 bc	4.1 ab
3 day	Solo	45.2 b	1.3 b	1.3 bc	2.6 bc	4.5 a
4 day	Solo	51.0 b	2.0 ab	3.3 ab	5.3 b	4.1 ab
UTC	UTC	93.6 a	8.0 a	12.0 a	20.0 a	5.4 a
	F value	*85.88*	*7.08*	*9.81*	*12.99*	*4.68*
	P>F	*<.0001*	*0.0005*	*<.0001*	*<.0001*	*0.005*

Means followed by the same letter are not significantly different (Tukeys; *p>0.05*)

The 2016 study was modified to include a Conventional rotation which consisted of making consecutive Nudrin+Asana sprays followed by a Belt+Baythroid spray. The Hybrid rotation consisted of consecutive sprays of Voliam Xpress, Radiant+Brigade, and Belt+Brigade. The 2-d schedule received 12 sprays, the 3-d received 8 sprays and the 4-d schedule was sprayed 6 times. At harvest, assessment of damaged ears (unmarketable), and ears infested with larvae were conducted by randomly sampling 25 ears per replicate (100/tmt) and counting damaged ears. Results in the table below show that in the 2016 study that the 2-d spray schedule provided the best protection from CEW, regardless of whether the Conventional or Hybrid spray program approach was used. The 3-d spray schedule was significantly better than 4-d schedule and did not differ between spray programs. Essentially, these results suggest more strongly that the 2-d schedule resulted in fewer damaged ears and that the insecticide mixtures used in both spray programs were comparable. It is important to note that the level of ear damage in the 2-d schedule in 2016 was higher than what we saw in 2015. This was in part due the fact that we instituted spray schedules at 20% silk in ears. This was not by design, but a different sweet corn variety was planted in 2016, and silking progressed at a much more rapid rate than the variety we planted in 2015. Consequently, at pollen shed we anticipated a 5-day or so delay in silk in 2016, when in fact it occurred almost simultaneously with pollen shed. Thus we were late in initiating our spray, and the results show what happens when sprays schedules initiated for CEW control are delayed. In conclusion, under heavy CEW pressure experienced in spring sweet corn in Arizona, a 2-d spray schedule will ultimately provide better protection of ears. Similarly, using a

4-d schedule, as suggested by some entomologists, would not allow for marketable production of sweet corn. Also, tank mixtures of products appear to provide more consistent control of CEW than individual products applied alone.

2016 Spray Schedule Trial

Spray Program	Spray Schedule	Avg. Damage / 25 ears	Damaged ears (%)
Conventional	2 d	4.8d	19.0d
Conventional	3 d	10.3b	41.0c
Conventional	4 d	13.8c	55.0b
Hybrid	2 d	5.8d	23.0d
Hybrid	3 d	10.0c	40.0b
Hybrid	4 d	13.9b	55.0c
Untreated	-	21.8a	87.0a
	F value	*59.81*	*56.89*
	P>F	*<.0001*	*<.0001*

Means followed by the same letter are not significantly different (Tukeys; *p>0.05*)

Spray Alternatives: Field studies were conducted in 2015 and 2016 to examine different insecticide mixtures and spray timings on insect control and yields of sweet corn in large plots at the University of Arizona, Yuma Ag Center in Yuma, Arizona. Our goal was to compare different mixtures, as well as compare the use of a soil insecticide at-planting to bi-weekly sprays applied pre-tassel for their utility in preventing significant ear damage. Plots of 4 beds wide by 75 ft long were established on March 24, 2015 and Mar 31, 2016. In 2015, the Conventional program consisted of alternations of Asana, Lannate and Lannate+Asana; the Reduced -risk program consisted of alternations of Coragen, Radiant and Belt; the Hybrid program consisted of alternations of Voliam Xpress, Radiant+Brigade and Belt+Baythroid. The sprays were applied on a 3-d schedule and received a total of 9 applications. At harvest, assessment of damaged ears (unmarketable), live larvae and tip damage were conducted by randomly sampling 25 ears per replicate (100/tmt) and counting damaged ears, live larvae by species, and measuring damage on ear tips.

		Live Larvae / 25 ears			
Spray Program	% Damaged ears	2nd-3rd instars	4th-5th instars	Total larvae	% Infested ears
Conventional	17.3 c	0.0 a	0.0 b	0.0 c	0.0 c
Reduced-risk	37.5 b	0.5 a	1.5 ab	2.0 ab	8.5 b
Hybrid	23.0 c	0.5 a	0.5 b	1.0 bc	4.0 c
UTC	87.0 a	0.3 a	3.5 a	3.8 a	16.8 a
F value	*128.71*	*0.74*	*17.25*	*10.09*	*128.71*
P>F	*<.0001*	*0.55*	*0.0004*	*0.003*	*<.0001*

Means followed by the same letter are not significantly different (Tukeys; *p>0.05*)

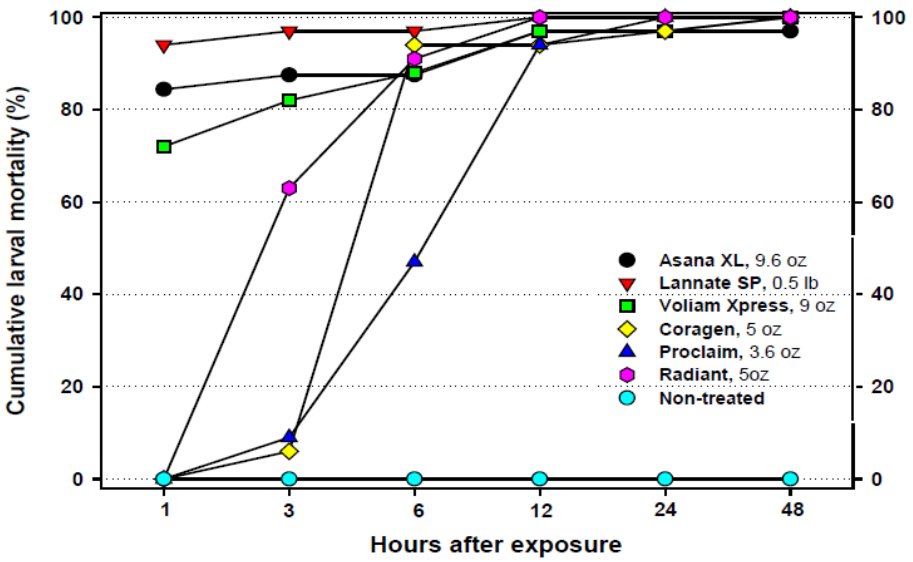
The table above shows that when applied on a 3-day schedule the Conventional and Hybrid Spray programs provided significantly comparable levels of ear protection. The Reduced-risk spray program did not; it had significantly higher percentage of damaged and infested ears. All spray programs had significantly lower ear damage than the untreated check. The results are not surprising since the Reduced-risk products have minimal contact toxicity against CEW larvae and must be consumed by larvae for optimal insecticidal activity. In contrast every application with the Conventional and Hybrid program contained a contact insecticide which is necessary for optimal control in Arizona sweet corn protection. Also, using the 3-d scheduled resulted in about 20% damage in ears at harvest, but may in part be due to our late start in initiating sprays.
The 2016 study was quite different from any of the other studies. One treatment received an at planting application of Coragen where we presumed that that the Coragen would be taken up through the roots and protect plants from FAW and CEW during the whorl stage. As a comparison, Bi-weekly sprays were applied to plots beginning at the 4-leaf stage. A total of 3 sprays were made prior to silking with Coragen, Intrepid and Radiant. At silking, sprays were initiated on a 3-d schedule using alternations of Lannat+Asana, and Voliam Xpress. All treatments received 8 sprays. At harvest, assessment of damaged ears (unmarketable), and ears infested with larvae were conducted by randomly sampling 25 ears per replicate (100/tmt) and counting damaged ears. Although all treatments provided better protection of ears compared with the untreated check, results in the table below clearly showed that the use of the soil, systemic insecticide Coragen applied at planting did not provide additional protection of plants, nor did it result in better protection of ears. However, application of bi-weekly sprays during the whorl stage did result in significantly fewer damaged ears at harvest. This is a common practice with many local sweet corn growers as they feel that minimizing FAW and CEW from building up prior to silking improves overall control during ear formation. Results from this study support this management approach.

Pre-silk Treatment	Avg. Damage / 25 ears	Infested Ears (%)
Coragen, at-plant	12.3b	49.0b
Bi-weekly sprays	4.5c	18.0c
None	13.8b	55.0b
Untreated	22.0a	88.0a
F value	*47.18*	*44.59*
P>F	*<.0001*	*<.0001*

Laboratory Bioassay of CEW: A laboratory bioassay was conducted in 2016 to compare toxicity of many of the common products used in sweet corn CEW management programs. The laboratory bioassay was conducted at the University of Arizona, Yuma Agricultural Center (YAC), Yuma, Arizona in April, 2016. The assay consisted of spraying corn plants with several different insecticides and then removing leaves 2-hr after the spray had dried. Sections of leaf tissue (2x2") were cut from sprayed leaves and then placed into plastic Petri dishes (9 cm). In each dish containing treated leaf discs, 5 second-instar CEW larvae were placed; larvae in the

control dishes were placed on leaf discs treated with water. Petri dishes e were then placed in an environmental chamber at 30°C with a photoperiod of 12:12 h (light:dark) in a RCBD arrangement. Eight replicates of each treatment with 5 larvae were treated (n=40). Larval mortality was assessed by counting the number of dead larvae (unresponsive to touch) in each dish at 1, 3, 6, 12, 24, and 48 h following exposure.

Results of the bioassay in the graph below are consistent with observations made from our field studies. In essence, the contact insecticides (Asana, Lannate and Voliam Xpress) provided the most rapid mortality of larvae. This is important of management of CEW in sweet corn where eggs are laid on developing silk. Upon hatching, the neonate larvae immediately move into the ear. Thus contact toxins on silk should be more effective than products which have little to no contact toxicity against larvae. Radiant, known to have some contact activity, was comparatively slower initially, but by 6 hrs. provided 95% mortality. Similarly, Coragen required 6 hrs before high mortality was observed. Proclaim appeared to have the slowest activity and required about 12 hrs to provide control comparable to the other treatments. No mortality was observed in the untreated check.



Goals and Outcomes Achieved

The goal of this project was to develop a knowledge base for insect management on watermelon, celery, and sweet corn that produced new information for each crop identifying the seasonal insect spectrum, documenting impacts of insect occurrence/abundance with crop yield and quality, and examining effective control alternatives. Prior to this project, no such information existed for these specialty crops grown in Arizona. Because our desert growing conditions are unique, it was necessary to conduct research in Yuma to develop new information for new IPM recommendations. This project certainly generated important scientific information relevant to production of these specialty crops in Arizona. The outcome of this research should in the long term improve management of key insect pests important in watermelons, celery and sweet corn.

In watermelons, we documented for the first time that stripped cucumber beetles are present during spring production in Arizona and can cause significant cosmetic damage to fruit if left

uncontrolled. This pest tended to feed on blooms initially, but quickly fed on small immature melons later resulting in large gray scars on the fruit. This cosmetic injury is generally not acceptable in commercial watermelon markets. Beet armyworm and cabbage loopers were also present and caused similar damage to fruit. However, growers are aware of the damage potential of BAW, but this project documents it for modern seedless varieties. Evaluation of new insecticides showed that Sivanto, a new foliar and soil systemic mode of action, provided excellent activity when applied to the soil or as a foliar spray, and provides growers with a viable alternative to the standard neonicotinoid, Venom. Similarly, Exirel, a new foliar chemistry, provided excellent control of whitefly adults and nymphs and provides growers with a cost-effective alternative to the standards. We have formulated recommendations for both of these products in local Watermelon IPM programs. Another significant result from the trial was the determination that Assail appears to be losing its effectiveness for whitefly control. Similarly, we are recommending the growers use alternatives to this product.

This project documented for the first time in Arizona the key pests associated with Arizona celery production. We had anticipated that Lygus bug and other plant bugs would have a major presence on celery, but it occurred in low numbers in three season-long studies. This is very important information as many local growers often associate cosmetic damage on petioles with these pests based on what they perceive Lygus damage looks like on celery in coastal California. In contrast, this project clearly documented the that beet armyworm and aphids (green peach and foxglove) are the major pest of celery produced in Arizona. We further demonstrated how important their management is for preventing yield and quality losses. Insecticide efficacy studies showed that viable alternatives exist for management of both pests, either soil applied products (Exirel, Coragen, Durivo) or foliar products like Movento. Both of these products are currently recommended for worm and aphid control in Arizona celery.

Because sweet corn is a minor commercial crop in Arizona, little to no information on pests found in the crop existed prior to this project. Our studies showed that the only yield limiting pests that occurred in spring sweet corn were corn earworm and fall armyworm. Of these, corn earworm was by far the most damaging to ears, prior to and at, market maturity. We also discovered that suppression of these pests with insecticides prior to tassel push and silking improved earworm/armyworm control and yields. Anecdotally, growers in California are already doing this, but this approach had not been previously empirically demonstrated. We are now formulating recommendation that sweet corn growers apply sprays prior to tassel push. Our initial studies suggest that this is best achieved using bi-weekly sprays of Coragen or Radiant. Soil systemic insecticides applied at-planting will not provide similar results. Under Arizona pest pressures, 2-d spray schedules proved to be superior in protecting marketable ears compared with the standard 3-d schedule; and the 4d schedule was unacceptable for producing marketable ears. We also verified that tank-mixtures containing at least on contact product, provide better control of corn earworm than contact and reduced-risk, selective products applied alone. A lab bioassay confirmed this.

Beneficiaries

The stakeholders who will directly benefit from this project include Arizona watermelon, sweet corn and celery growers, PCAs, and local Agro-business representatives. Much of the information discussed in this report has been presented to stakeholders via email updates (6) and presentations at local and statewide educational meetings (12 CEUs). Based on the recipients of our email updates and attendees at meetings, it is estimated that at more than 100 Arizona PCAs and specialty crop growers benefited from the information generated in this project. In the next two years, we anticipate that new educational materials on this new information will be published in the form of Extension Factsheets and scientific publications

Overall, growers have benefitted from this project from new information detailing key pests found on these crops, their associated damage potential under Arizona growing conditions, and new management approaches. Specifically, cucumber beetles on watermelons should be anticipated occurring on spring crops, and if not properly controlled can lead to cosmetic injury and yield losses. Sweet corn growers are now aware that fall armyworm and corn earworm occur on corn plants throughout the growing season, not just when ear production is occurring. Early suppression of these worm pests during the whorl stage can lead to improved yields. Finally, Lygus bug does not appear to be as significant a pest in Arizona celery as previously believed, but armyworms and aphids require control to previous yield/quality losses. In addition, new insecticide products and application techniques/timing have been recommended for these key pests in watermelons, celery and sweet corn.

Lessons Learned

Perhaps the most important lesson learned from this project was the importance of collecting empirical data for making IPM recommendations. Prior to this project very limited scientific information specific for these crops existed in Arizona. Most growers had anecdotal perceptions and expectations of the pest problems, and made management decisions based on these perceptions. However, as identified in this project, in some cases grower's perceptions of major issues faced in these crops were not correct. For example, we had anticipated certain pests (i.e., Lygus) to be present and were somewhat biased in surveying them in celery based on anecdotal perceptions from growers. As we discovered, Lygus does not appear to be an important pest of celery in Arizona. In contrast, stripped cucumber beetle was not known to be an economic pest in Arizona, but occurred during both years of the project.

Perhaps more importantly, we should have planned the specifics of this project better before we submitted this project for approval. In hindsight, we should have scaled this project down to focus solely on survey studies to more closely identify the key pests and their associated damage on these crops. We should have included more planting dates for each crop to extend throughout the growing season to temporally identify seasonal occurrences. In addition, it would have been ideal to conduct surveys in commercial fields, although this can be challenging because of intensive insect management. After the completion of that project, a subsequent proposal based on the robust survey database could have been more specifically focused to investigate key insect management approaches

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Additional Information

As described above, the information generated from this project has been beneficial to the industry and the results of this research have been presented in various forms at Extension meeting and included the 2015 and 2016 Southwest Ag Summit in Yuma; the 2015 and 2016 Desert Ag Conference in Phoenix; the 2015 and 2016 Fall Preseason Vegetable Workshop in Yuma; and various local Agricultural industry sponsored meeting in 2015 and 2016.

Herbicide Tolerance of Chile Peppers

This project was completed on March 31, 2017

Project Summary

Chile peppers exhibited tolerance to pendimethalin (Prowl H_2O) applied broadcast topically at 1, 2, 3, and 4 pints/A at the 4 to 6 leaf growth stage prior to thinning early in the season in 2015. Plants did not exhibit significant foliar symptoms following application but a few plants later developed brittle stems that were prone to breaking off at the soil surface. The number of brittle stems breaking increased with increasing Prowl rate but there were no differences between treatments in fresh weight of chile peppers at harvest. Chile peppers tolerated post-directed applications of flumioxazin (Chateau SW) in a 22-inch band directed on the soil between rows of plants canopies when the chile plants were 9 to 12 inches tall. The spray also contacted the lower leaves and caused some necrotic spotting but the necrotic spotting did not increase with increasing rate (0, 1.5, 3.0 and 6 oz/A). It appeared that the leaves protected or shielded the stems from the herbicide spray limiting injury. There were no differences between treatments in the yield of fresh chile peppers as a function of Chateau rate. A severe thunderstorm with hail and 4 inches of rain destroyed the 2016 experiments.

Project Purpose

Arizona chile pepper producers currently use a combination of cultivation, hand labor and herbicides to control weeds. Hand labor is expensive and scarce and there are few herbicides registered for use in Arizona chile peppers. Growers need additional herbicide registrations, especially soil active, residual herbicides that ideally a) can be applied after thinning, b) do not injure chile pepper plants, c) have postemergence activity that will control emerged weeds, and d) that provide broad spectrum, long-term residual control of germinating broadleaf and grass weed seeds. The primary objective of this project was to applying flumioxazin to row middles using spray hoods and/or shields in several varieties of direct seeded chile peppers. A secondary objective was to evaluate the tolerance of chile peppers to topical broadcast applications of Prowl H_2O. Crop tolerance data was collected to support "Special Local Need" (SLN) labels or

registrations for flumioxazin and the Prowl H_2O formulation of pendimethalin as specified in Section 24(c) of FIFRA.

This project is timely due to the increasing hand weeding costs growers face and the difficulty they have finding enough labor to thin, hand weed fields and harvest chile peppers. Arizona and U.S. regional chile pepper producers face foreign competition with cheaper labor costs and increasing production costs generally. Thus, any project that develops technology that reduces production costs is timely.

This project was a new project and did not complement or enhance previously completed work.

Project Activities

The activities proposed as part of this project (see below) were accomplished for the most part except that we were unable to collect yield data in year 2 of the project. The field experiments were established in spring of 2015 and 2016, plant populations were counted and injury was visually estimated following the herbicide applications. In spring 2015, four rates of Prowl H2O (0.0475, 0.95, 1.43 and 1.9 lb ai/A) were applied topically using a broadcast boom with 4 nozzles on 20 inch spacing. This meant that the nozzles were not over the crop rows which were on 30 inch centers but rather were offset from the row. The chile pepper plants were also fairly small with a height of 5 inches and range of 3 to 8 inches. These two factors may have contributed to a small number of plants developing “brittle stem” injury observed later in the season.

Project Activity	Timeline
Establish field plots in year 1	February 2015
Spray Prowl H2O and Chateau treatments in year 1	End of March 2015
Collect chile pepper tolerance and yield data in year 1	April to October 2015
Analyze and write interim year 1 reports	November 2015 to January 2016
Establish field plots in year 2	February 2016
Spray Prowl H2O and Chateau treatments in year 2	End of March 2016
Collect chile pepper tolerance and yield data in year 2	April to October 2016
Analyze and write final reports	November to December 2016

The Prowl-chile pepper experiment was monitored and periodically evaluated for injury. Stand counts were collected on 5/26, 6/29, 8/5 and 9/25 in 2015; no differences in plant populations were noted. There were also no differences between treatments in the yield of chile peppers; the LSD was about 20% of the mean yield (18, 295 lb/A) at P=0.05 and the coefficient of variation was about 15%. A rare response of chili peppers exposed to Prowl H_2O was the development of brittle stems that resulted in the stems breaking off at ground level. The number of broken stems and dead plants were recorded on 6/29. The mean number of plants exhibiting brittle stem increased with rate from 0 in the control plots to 0.8, 1.4, 2.8 and 4.4 plants/100 row-ft. at 0.0475, 0.95, 1.43 and 1.9 lb ai/A of Prowl H_2O, respectively. Overall, chile pepper tolerance to Prowl H_2O was good and the results indicated the need to study nozzle spacing relative to crop rows and the optimum size of plants to spray.

The Chateau treatments (0. 1.5, 3 and 6 oz. /A) were applied later in the season than the Prowl H_2O treatments because there were intended to be layby treatments. The treatments were applied on 6/30/2015 and no adjuvants (i.e., crop oil concentrates or surfactants) were added to the herbicide mixture. The plants were about 12 inches tall with a size range of 8 to 14 inches with numerous leaves. Plant populations were counted on 8/5/2015 and 9/25/2015 and there were no differences between treatments. There was some minor foliar injury, 1 to 2% up to 9-10%, with the symptoms being necrotic spots on the lower, sprayed leaves. There were no or very few peppers on the plants at the time of application. The injury symptoms dissipated over time and there did not appear to any long-term injury. The chile peppers were harvested 10/07/2015 and there were no significant yield differences between treatments. The LSD was 3336 lb/A (18% mean difference at P=0.05) with a mean yield of 18,783 lb/A of chiles and a coefficient of variation of 12%. Thus, it did not appear that the Chateau caused lasting injury symptoms or affected yield.

The Prowl experiment in 2016 was changed to include more treatments designed to compare boom nozzle configurations in order to gain a better understanding of Prowl injury on chile peppers. As shown in the table below, three rates of Prowl were applied using three different nozzle configurations or geometries. In one configuration, the nozzles were on 30 inch centers so the nozzles were over the crop row. In this nozzle arrangement my hypothesis is that the chile pepper foliage will protect the stem from damage that causes the “brittle stem” injury noted in the 2015 experiments. The second configuration had nozzles on 20 inch centers the way treatments were sprayed in 2015. In the third configuration, a single nozzle boom was placed in the center of the furrow and the nozzle sprayed across the furrow to base of the pepper stems in the crop rows on either side of the furrow (a 22” band application). This nozzle arrangement was expected to cause more “brittle stem” injury than was seen in 2015 because more Prowl was sprayed at the base of and potentially on the stem of the chile pepper plants.

Trt No.	Treatment Name	Rate Unit	Other Rate Unit
1	Prowl H_20 – nozzle spacing - 30", over crop row	0.95 lb ai/a	32 fl oz/a
2	Prowl H_20 – nozzle spacing – 20” on boom	0.95 lb ai/a	32 fl oz/a
3	Prowl H_20 – one nozzle boom between rows	0.95 lb ai/a	32 fl oz/a
4	Prowl H_20 – nozzle spacing - 30", over crop row	1.43 lb ai/a	48 fl oz/a
5	Prowl H_20 – nozzle spacing – 20” on boom	1.43 lb ai/a	48 fl oz/a
6	Prowl H_20 – one nozzle boom between rows	1.43 lb ai/a	48 fl oz/a
7	Prowl H_20 – nozzle spacing - 30", over crop row	2.87 lb ai/a	96 fl oz/a
8	Prowl H20 – nozzle spacing – 20” on boom	2.87 lb ai/a	96 fl oz/a
9	Prowl H20 – one nozzle boom between rows	2.87 lb ai/a	96 fl oz/a
10	untreated with Prowl		

The chile peppers were at a larger growth stage when sprayed with Prowl H_2O in 2016 than in 2015; plants had an average height of 9 inches and a range of 4 to 11.5 inches at application. The plants also had more leaves in 2016 (13/plant) that protected the stem compared to plants in 2015 (7-8 leaves/plant). The center pivot field where this experiment was conducted was very weedy and also contained a lot of disease that was exacerbated by the frequent irrigation and summer monsoon rainfall. The finer soil textures, constant moisture and wet soil made it impossible to evaluate brittle stem injury in 2016 without pulling plants out of the ground.

Curry Farms unfortunately experienced a massive thunderstorm on September 7, 2016 with hail and 4 inches of rain in an hour on the center-pivot field with the herbicide experiments. The Prowl H_2O experiment was on the south side of the center pivot and the Chateau experiment was on the north side of the center pivot. Ed Curry had crop insurance on this field and the crop insurance adjuster estimated the loss in the area with the Prowl experiment at 50%. In addition to hail and rain, runoff from Highway 191 and fields upslope from the center pivot field drained onto the north side of the center pivot flooding the Chateau experiment and moved phytophthora through field. Most of the Chateau area of the field was impacted by the phytophthora resulting in dead or dying plants with desiccated fruit at harvest. The crop insurance adjuster estimated the loss in the area of the center pivot with the Chateau experiment at 85%.

The Prowl H_2O experiment was harvested on October 19th. Only replications 2 (two missing plots) to 5 were harvested as the cooperator's field laborers had mistakenly harvested the edges of the trial where replications 1 and 6 were located. As in 2015, there were no significant differences in chile pepper yields but the LSD was 5,636 lb/A out of 20,785 lb/A (the % mean difference was 32% at P= 0.05). Thus, the data were highly variable and it was not possible to detect meaningful treatments differences. The harvest data collected from the Chateau experiment was of limited value.

The results and researcher's experiences in 2015 and 2016 indicated that chile peppers have sufficient tolerance to topical Prowl H_2O and post-directed Chateau applications to develop 24 c herbicide labels. Further research is needed to collect additional tolerance data and to develop application parameters for these two herbicides. This project was focused on chile peppers and did not benefit non-specialty crop commodities.

Goals and Outcomes Achieved

The goal of providing technical reports on the experiments for BASF (Prowl H_2O) and Valent (Chateau) was achieved. Acceptable herbicide tolerance was demonstrated indicating the feasibility of obtaining 24c Special Local Needs labels for Prowl H_2O and Chateau on Arizona chile peppers. Unfortunately, we did not collect enough data to support the desired requests for 24c labels in part due to our weather related difficulties in 2016 and in part due to the high level of soil fungal diseases in Cochise County chile pepper fields. More research and data collection is need to convince BASF and Valent to support these registrations. I hosted a field site visit in 2015 and sent a technical report and data files to the BASF field scientist who had Arizona in her territory in 2016 and 2017. Her response was that more trials and data are needed to support a change in the label for Prowl H_2O use on chile peppers. Since that time, BASF realigned its territories and assigned a new field scientist to cover Arizona. Thus, I will be hosting a site visit

with new personnel in the future in addition to discussing past results and future data needs with the new BASF representatives to inform 2018 studies. Similarly, I sent a technical report and data to Valent scientists but I did not receive much feedback from them. I will pursue continued collaboration with them in hopes of making progress towards obtaining a Chateau layby 24c SLN. Unfortunately, I recently learned that Chateau layby applications in a New Mexico research project lead to crop injury. I will also be discussing this result with the researcher in question (Brian Schutte at New Mexico State University) to inform 2018 experiments.

Recommendations for future work with Prowl H_2O include comparing nozzle/boom configurations and applying the treatments a little later in the season when plants are larger with more leaves. The Chateau applications should be made at a point in the season when no future tillage will occur in the field. This will involve convincing grower cooperators to allow us to hand-weed the experiments for the remainder of the season if needed. Lastly, the Chateau and Prowl experiments should be conducted in different fields minimize the probability that all experiments could be lost due to extreme weather events or human error. It would also be beneficial to conduct the same experiments with two different growers to maximize data collection and minimize the risk of losing experiments.

Beneficiaries

The specialty crop beneficiaries of this proposed project are the chile pepper producers in Arizona and possibly other fruiting vegetable producers in the state. The chile industry is severely impacted by foreign competition that enjoys significant labor advantages in a labor-intensive crop. New herbicide registrations in chile pepper could reduce hand-weeding costs by $500 to $600/acre or more and increase the economic competitiveness of the industry. Although the industry is relatively small with about dozen producers who will benefit from this project and a few thousand acres of production, it is estimated to be a $10 million industry in Cochise County (personal communication, Ed Curry) which is significant in a relatively poor, rural county. Increasing the economic efficiency of production and reducing labor inputs could also result in an increase in production acreage which would increase the impact of this project.

Lessons Learned

Recommendations for future work with Prowl H_2O should compare nozzle/boom configurations and apply the treatments a little later in the season when plants are larger with more leaves.
The Chateau applications should be made at a point in the season when no future tillage will occur in the field. This will involve convincing growers to allow us to hand weed the experiments for the remainder of the season if needed.

Lastly, the Chateau and Prowl experiments should be conducted in different fields minimize the probability that all experiments could be lost due to extreme weather events or human error. It would also be beneficial to conduct the same experiments with two different growers to maximize data collection and minimize the risk of losing experiments.

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Irrigation Sediments as Reservoir for Pathogens

This project was completed on December 31, 2015

Project Summary

Increasing evidence suggests that waters used in the irrigation of produce are a significant source of the pathogens involved in foodborne disease outbreaks. *Escherichia coli* is known to occur in levels ten times greater in the sediments than the overlaying water in irrigation channels in Yuma. The overall goal was to determine how sediment and flow properties of water in the channels impact the microbial quality of irrigation water. This was done in a series of experiments in which *E. coli* and bacterial virus MS-2 were added to sediments in an experimental channel and identifying flow and sediment conditions which would result in their resuspension. This data was used to develop a model to determine under what conditions sediment-bound bacteria and viruses present a risk of crop contamination during the irrigation of produce. This study determined that although *E. coli* and *Salmonella* are present in irrigation channel sediments in Yuma their influence on overall water quality is minimal given the types of sediment present in the canals and water flow conditions. Thus, additional guidelines for irrigation water used for produce production are not necessary to minimize the risk of contamination from pathogenic bacteria or viruses to produce crops.

Project Purpose

Previous studies have indicated that sediments in irrigation channels may play an important role as a reservoir of indictor bacteria and the pathogens involved in foodborne disease outbreaks. It was found in these studies that the occurrence of the pathogen *Salmonella* was 10 times greater in the sediments than the overlaying water. It was also found in laboratory experiments that the survival of *E. coli* and *Salmonella* was much greater in sediments than in the overlaying water.

Events which cause resuspension of the sediments (e.g., rainfall, storm water runoff, flow rate changes, lined vs. earthen channel) may cause deterioration in the water quality which may lead to an increased risk of food crop contamination during irrigation events. Kayed (2004) observed that there was a correlation with a significant increase in *E. coli* in irrigation channels in the Yuma and Maricopa regions for up to a week following rainfall events. This was likely due to the flow increase from storm water runoff that re-suspended sediments from the channel bottom. An outbreak of *E. coli* O145 associated with romaine lettuce harvested from the Yuma area was attributed to a preceding period of heavy rainfall (Taylor *et al.*, 2013). Viruses also accumulate

to greater concentrations in sediments and also represent a potential risk when re-suspended (Gerba and McLeod, 1976). However, few studies regarding the association of *E. coli* with sediment are available.

The overall goal is to determine the impact of sediment associated indicators (e.g., sediment size, flow velocity) and pathogens on the quality of irrigation water, and consequently the safety of irrigated produce. Specific objectives of this study are to: 1) identify factors which would result in resuspension of sediment-bound bacteria in irrigation channels (e.g., flows, channel design); 2) quantify the impact of resuspension of different levels of bacteria on the quality of overlaying water; 3) suggest guidelines to minimize the occurrence of sediment-bound bacteria in the irrigation water (e.g., flows, channel design).

Project Activities

Field Study

Along with modeling the irrigation canal system in a flume, field measurements were taken from five canals in the Yuma Valley, Arixona. Data collected included: water depth, flow rate, velocity and sediment characteristics (Table 1). This information was used in the design of the laboratory experiments and assessment of the potential for resuspension of sediment containing bacteria and virus.

Table 1. Field measurements from Yuma Valley canal characteristics of canals and sediment from irrigation canals in Yuma, Arizona

	Canal Characteristics				***Sediment Grain Sizes***	
Canal	***Water Depth (m)***	***Width (m)***	***Velocity (cm/s)***	***Flow Rate (L/s)***	***(mm)***	***(mm)***
1	*0.76*	*9.33*	*0.61*	*39.79*	*0.36*	*1.87*
2	*0.09*	*3.35*	*N/A*	*N/A*	*15.9*	*N/A*
3	*0.88*	*9.33*	*60.7*	*4500*	*11.2*	*24.5*
4	*0.91*	*2.74*	*21*	*349.9*	*0.17*	*1.44*
5	*0.41*	*N/A*	*0.02*	*N/A*	*1.45*	*15.9*

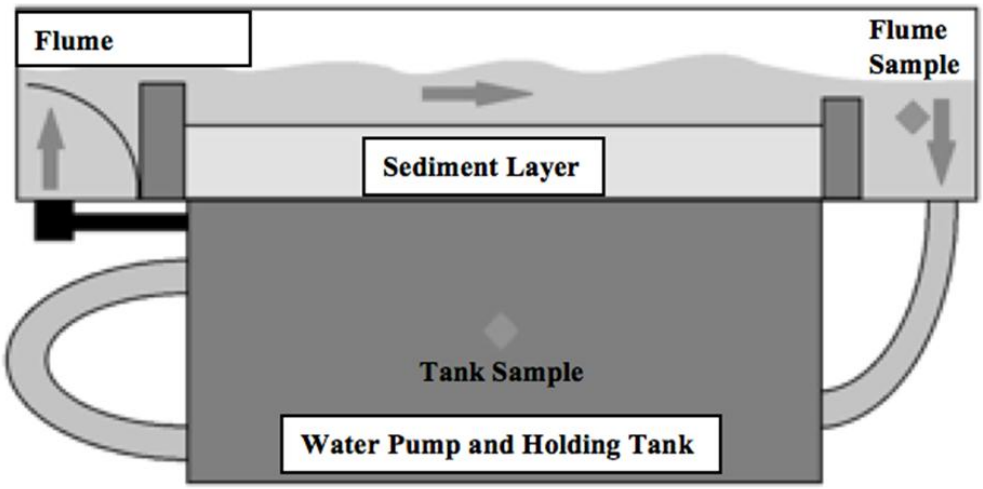
N/A= an accurate measurement was not observed or observable due to canal conditions

Laboratory flume studies

To assess the potential for resuspension of bacteria and viruses an irrigation canal was simulated using a closed-system flume constructed at the University of Arizona (Figure 1) (Hydraulic Design and Product Co.) lined with either sand or clay. The flume was filled with tap water (Sigma-Aldrich, St. Louis, MO, USA) and the set-up adjusted to different flow rates (Q) and velocities (v). The flow rate was measured in liters per second (L/s) and centimeters per second (cm/s), respectively. The flume was packed with 8-10 cm of sediment for a base layer. The sediment was then transferred to sterile stomacher bags (Seward Laboratory Systems Inc., Davie, FL, USA) and saturated using 1 L of sterile deionized water, inoculated with 2 mL of either *E. coli* (ATCC 25922) or MS2 bacteria virus (Host ATCC 15597). The average concentration of the

E. coli inoculum was 1E+08. The inoculum and water were hand massaged into sediment in the bags until all sediment was fully saturated. After inoculation, the soil sediment was given a allowed to drying time of for 1-2 h to allow excess liquid to be absorbed, depending on the particle size , and added onto the base layer of sediment in the flume. The top layer was evenly distributed along the flume and packed down.

Figure 1. Sketch of the flume used in laboratory studies



After addition of the sediment, was added, the flume holding tank was then filled with 65-gallons (246 L) of water. The flow rate and velocity were set accordingly by adjusting the lift gate, which controls the rate at which the water discharge back into the holding tank. Each velocity was run for a period of 0.5 h and then water was sampled from the flume stream and from the holding tank. Samples were collected using sterile 250 mL plastic bottles (Thermo Scientific Nalgene, Waltham, MA, USA). In the case of *E. coli* experiments, 1 mL of sample was spread plated across 3 plates in volumes of 0.333 mL/plate. In addition, serial 10-fold dilutions were made using sterile phosphate buffered saline (PBS) (pH 7.4) (Fisher Scientific, Waltham, MA, USA). The dilutions were plated in volumes of 100 mL in duplicates. *E. coli* was plated on sterile MacConkey agar (Difco, Becton, Dickinson and Company, Franklin Lakes, NJ, USA). The plates were then incubated at 37 ºC for 24 hours and *E. coli* colonies (pink) were enumerated.

MS2 virus samples were plated assayed using the double agar overlay method. Briefly, 5 mL of sterile top agar was melted and held at 50 ºC in a water bath. A host of *Escherichia coli* ATCC 15597 was propagated in 125 mL of sterile tryptic soy broth (TSB) (Difco, Becton, Dickinson and Company, Franklin Lakes, NJ, USA) for approximately 4 hours at 37 ºC with agitation. After exponential phase was achieved, 0.5 mL of host organism was combined with 1 mL of sample water in the sterile top agar. Serial 10-fold dilutions were also made for MS2 experiments using sterile PBS (pH 7.4); for dilutions, a volume of 0.1 mL was used. The tube was gently swirled and then poured onto a sterile tryptic soy agar plate (TSA) (Difco, Becton, Dickinson and Company, Franklin Lakes, NJ, USA). The plates were allowed to solidify, then flipped and incubated for 24 h at 37 ºC. The plaques were enumerated after incubation.

To obtain the *E.coli*/MS2 counts in water, the number of *E. coli*/MS2 in the water is calculated as:

$$N_w = C_f V_f + C_t (247000 - V_f)$$

where N_w is the number of *E. coli*/MS2 in the water, CFU (or PFU); C_f is *E. coli*/MS2 concentration in the flume, CFU (PFU)/mL; V_f is the volume of water in the flume, mL; C_t is the *E. coli*/MS2 concentration in the tank, CFU(PFU)/mL. The total volume of the water was 247,000 mL (246,000 mL in the tank and 1,000 mL of the innocula). To determine the correlation between *E. coli*/MS2 and bed shear stress, the non-dimensional shear stress is calculated as:

$$\tau_* = \frac{\rho_w u_*^2}{(\rho_s - \rho_w) g D_{50}}$$

where τ* is non-dimensional shear stress; u* is shear velocity, calculated from $\frac{u}{u_*} = \frac{1}{\kappa} \ln \frac{z}{k} + A_r$, m/s; ρw is water density, kg/m^3; ρs is sediment density, kg/m^3; g is the gravitational acceleration, m/s^2; D_{50} is the medium diameter of the sediment, m.

To cover the range of sediments that might occur in irrigation canals both clay and sandy sediments were compared as with varying flow rates. The result of flow rate vs resuspension of *E. coli* in sandy sediments and clay are shown in Figures 2 and 3.

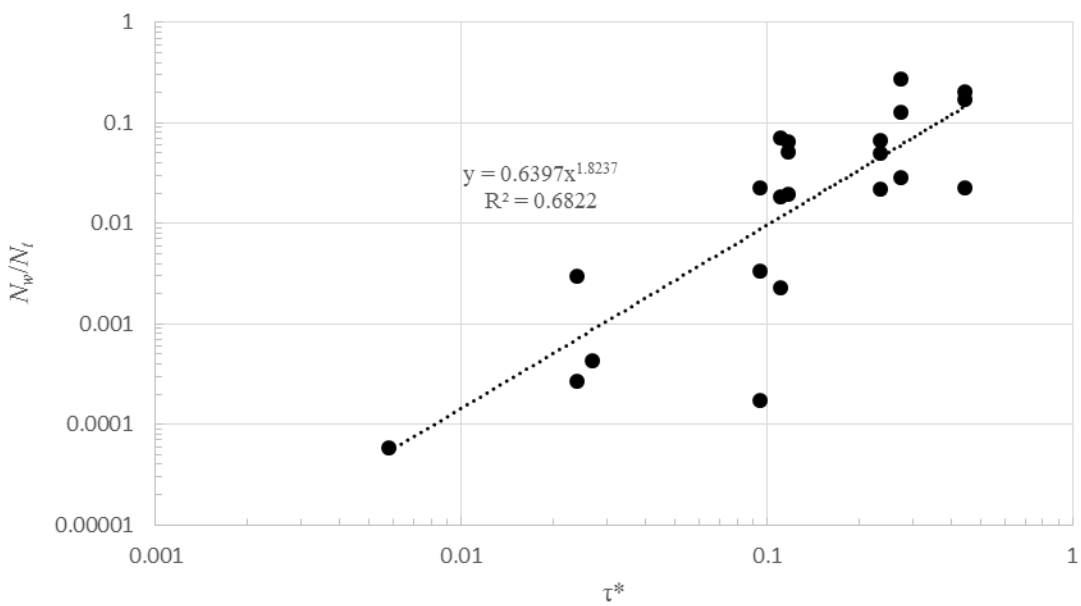


Figure 2. Fraction of *E.coli* in the water with clay bed (N_w/N_t) with increasing shear stress (*t*) (flow rate)

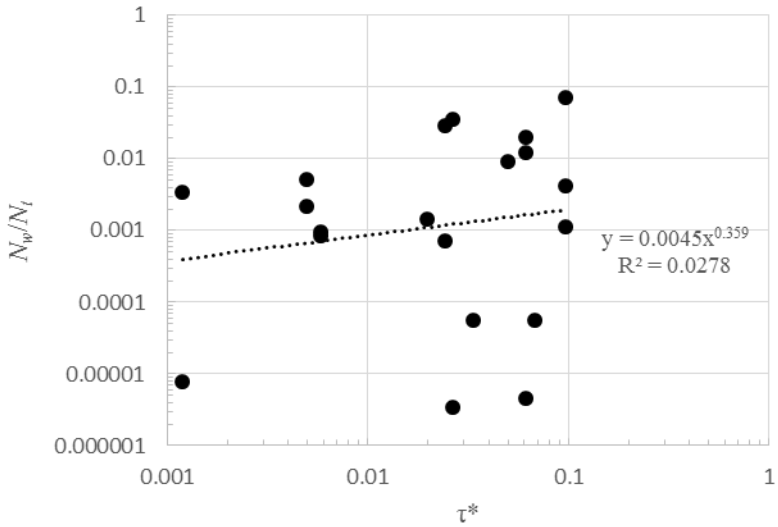


Figure 3. Fraction of *E. coli* in the water with sandy sediment (N_w/N_t) with increasing shear stress (t) (flow rate)

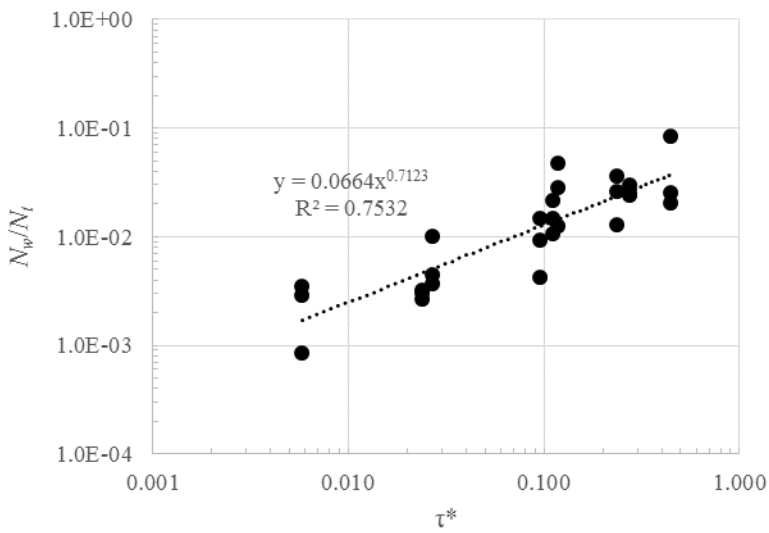


Figure 4. Fraction of MS-2 virus in the water with clay bed (N_w/N_t) with increasing shear stress (t) (flow rate)

The results from this study show that bacterial and viral pathogens in sediments in irrigation canals do have the possibility of becoming re-suspended in water depending on changes in flow rates. Based on the results from the statistical analyses, the likelihood of transfer into water can significantly increase as velocity and flow rate increase. After a certain point, however, the difference is no longer statistically significant. In the case of *E. coli*, the size of the sediment particles used in this study did not impact the transfer into water significantly.

The sediment in the found in the canals in Yuma, Arizona likely originate from surrounding, earth embankments, fields, roads, alleys and recreational areas (parks and golf courses observed nearby to some canals). The characterization data from the five field samples of sediments collected from the canals show much of the bottom sediment in open canals consists of sand (0.06-2.0 mm) to gravel (2.0 mm and greater) sized grains. This could be a positive finding for produce growers in the area. Larger particle sizes have a lower overall surface area and increased space between particles, making it more difficult for microorganisms to strongly attach to individual particles. This forces the organisms to remain suspended in water, where the survival time may be reduced compared to the sediment (Burton et al, 1987).

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Goals and Outcomes Achieved

This study determined that although bacterial indicators (*E. coli*) and pathogens (*Salmonella*) are present in irrigation channel sediments (BENCHMARK) in Yuma, Arizona their influence on overall water quality is minimal given the types of sediment present in the canals and water flow conditions. Thus, additional guidelines (TARGET) for irrigation water used for produce production (GOAL) do not seem necessary to minimize the risk of contamination from pathogenic bacteria or viruses to produce crops (PERFOMACE MEASURE).

Beneficiaries

The microbial quality of irrigation water is a potential source of contamination of bacterial and viral pathogens to produce crops traditionally consumed raw or with minimal processing (lettuce, broccoli, Swiss chard, leafy greens). It is important to understand factors which control the microbial quality of irrigation water used to produce these crops. Our results show that although greater concentrations of *E. coli* and *Salmonella* can be found in the sediments of irrigation canals in the Yuma area, they do not present a significant risk to the irrigation waters used for produce production. In addition, there appears no need for guidelines or changes in practices for the delivery of irrigation waters by irrigation district managers. We estimate at least 500 growers in Arizona will benefit from this project. All the irrigation districts and farms involved in produce production in the Yuma area should benefit from the results of this study.

Lessons Learned

The usefulness of the project was enhanced by the multidisciplinary approach of the project in which hydraulic engineers and water quality microbiologists where involved. This allowed for the results to be based on sounder science resulting in better understanding of the potential of sediments to influence microbial water quality in irrigation canals.

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Additional Information

Presentations:

Characterizing the influence of water velocity and flow rate on the transfer of pathogens from sediment into irrigation waters. C. Morrison, S. P. Sassi, K. Zhao, J. G. Duan and C. P. Gerba. Arizona Water 2016 Workshop on working together on water research. January 16, 2016. Tempe, AZ.

Impact of irrigation canal sediments on microbial water quality. C. Morrison, S. P. Sassi, K. Zhao, J. G. Duan and C. P. Gerba. Annual Undergraduate Biology Research Conference. January 23, 2016. Tucson, AZ.

Impact of irrigation channel sediments on microbial water quality. C. Morrison, S. P. Sassi, K. Zhao, J. G. Duan and C. P. Gerba. Annual Conference of the Arizona Water Association. May 13, 2016. Glendale, AZ

Publications:

Entrainment of *Escherichia coli* and MS2 Bacteriophage in Bed Sediment in Irrigation Canals. K. Zhou, H. P. Sassi, C. M. Morrison, J. G. Duan and C. P. Gerba. Submitted for publication to Journal of Irrigation and Drainage.

Potential for Transfer of *Escherichia coli* and Coliphage from Sediments into Overlying Water in Irrigation Canals. H. P. Sassi, Kang Zhou, C. M. Morrison, J.G. Duan and Charles P. Gerba. In preparation.

Low Maintenance Grasses for Reduced Irrigation

This project was completed on September 30, 2016

Project Summary

Seven commercially available warm season turfgrass cultivars were irrigated at 75, 65, 55, 45, 35 and 25% of on-site Penman- Monteith Reference evapotranspiration from August 3rd to October 20th, 2016. At the trials end on October 20th, the cumulative reference ET (0) was 16.6 inches. The minimum ET irrigation replacement level required for maintaining a minimal quality condition of 5.0, or greater occurred at the 45% ET level for all 3 buffalo grasses. For bermudagrasses, both Cheyenne II and Nu-Mex had quality scores of 5.0, while Jackpot was

slightly higher at 5.5, again at 45% ET (0) on October 20th. Wrangler bermudagrass was the only grass to have a mean quality value of 5.0 or greater at 35% at the close of the test (5.3), with yet a higher quality realized (5.8) at 45% ET replacement. At the 65% and 75% ET (0) replacement levels, all seven grasses produced fully acceptable quality turfs (6.0 or greater) with the one exception of Nu-Mex bermudagrass (5.8 at the close of the test) at 65% replacement of Reference ET (0). Digital Chlorophyll Index values were positively correlated with visual turfgrass performance data. Digital estimates for percent plots were not.

Project Purpose

In the ongoing industry effort to reduce water applications to turfgrass, a large field scale experiment was established and conducted to evaluate the response of commercially available seeded bermudagrasses and buffalograsses to differential amounts of applied water, as a function of evaporative demand as determined by reference ET using the standardized Penman-Monteith equation. The intended use of these grasses would include low maintenance turf areas (golf course secondary roughs) which when under separate irrigation would lead to potential water savings by maintaining normally out of play areas with a low water use / low maintenance turf.

Original grasses selected and planted included three cultivars of bermudagrass, one buffalograss, Viva Galleta, Sand drop seed and purple-three awn, with the latter three representing native grasses used for roadside covers and rangeland in the southwest. High salt and sodium conditions forced four of the seven grasses to be replaced even after re-establishment attempts were completed, followed by soil reclamation with gypsum and leaching. Therefore, grasses which were successfully established in the summer of 2015 included three buffalograss and four bermudagrass seeded cultivars. Differential applications of water were applied to all seven grasses in replicated fashion from August 1st to October 20th 2016, at 75, 65, 55, 45, 35, and 25% of on-site reference evapotranspiration.

Golf courses in the southwest have been intensively practicing water conservation for the last 30 years, with significant reductions in applied irrigation realized through the use of ET based irrigation, soil moisture sensors linked to irrigation controllers and improved nozzle technology. Since water use is highly visible and remains a point of public discussion regarding urban water use, increased and ongoing demands still challenge superintendents and property owners to further reduce overall water use on turfs. There are areas on both large acreage golf courses and even on target courses which could benefit from using low maintenance grasses that could be irrigated with less water than commonly used bermudgrasses in the following locations; (1) landing zones on large acreage golf courses, and (2) “off rough” areas on smaller sized target courses. The former case would allow for play to occur at normal pace of play even when turf acreages are reduced throughout the entire course, since the location of said grasses are strategically located within major landing zones. In the second case, target golf courses which have areas that are often “out of play” due to desert, xeriscape or gravel surfaces, could now use a low maintenance grass(es) which are irrigated at less than standard irrigation amounts used for higher maintenance turf-type bermudagrasses (standard case). These grasses could be used on the course in areas which have been documented as high ball loss areas, or frequent penalty areas which slow down total play and reduce play revenue overall.

This project investigates the performance of select commercially available buffalograss and bermudagrass cultivars in a true low maintenance management situation when irrigated at chronic fractional levels of Reference ET. The goals are to determine (1) what is the response of each grass to lower levels of applied irrigation (allows the end user to know the limits of that cultivar at various applied irrigation levels (2) determine the minimal amount of water required to produce either a (i) nominal turf, (ii) and a fully acceptable quality turf, and (3) when given a specific amount of water for irrigation (converted to, or as provided as an applied amount of Reference ET) , which grass or grasses can be used at some expected level of performance.

Grass species and cultivars evaluated in this trial were selected based on classification of grass water use and turf-type development advancements (buffalograss), and for growth habit of low maintenance bermudagrasses which produce large stout rhizomes, which by empirical observations over the last 25 years, have been noted to tolerate/persist under prolonged drought conditions.

Project Activities

Work accomplished:

This project accomplished the establishment and testing of low maintenance warm season grasses for their response to differential amounts of applied irrigation using a Linear Irrigation Design. Irrigation delivery amounts were defined as 75, 65, 55, 45, 35 and 25% of Reference ET, using the standard Penman-Monteith equation from an on-site weather station. From this project, the major objectives of determining (1) what is the response of each grass to lower levels of applied irrigation (allows the end user to know the limits of that cultivar at various applied irrigation levels), (2) determine the minimal amount of water required to produce either a (i) nominal turf, (ii) a fully acceptable quality turf, and (3) when given a specific amount of water for irrigation (converted to, or as provided as an applied amount of Reference ET) , which grass or grasses could be used at some expected level of performance.

Tasks:

(1) Establishment of seven commercially available warm season grasses (3 buffloagrass and 4 bermudagrass),
(2) Establishment of a linear irrigation gradient through in-depth calibration and nozzle modifications
(3) Execution of differential amounts of irrigation based on Reference ET values of 75, 65, 55, 45, 35 and 25% of Reference ET (resulting in 168 irrigated turfgrass plots).
(4) Recorded and evaluated turfgrass response to industry accepted turfgrass parameter standards (National Turfgrass Evaluation Program values for turfgrass color, quality and density) and investigated the use of digital measurements of Chlorophyll Index and a percent plot cover 'app'.
(5) Determined the effectiveness and potential application of these two digital measurements.

Quantitative data:

Percent ET replacement values were identified which would support these turfs at marginal/nominal quality (5.0 on a 1-9 scale), and also at a fully acceptable (6.0 or more) quality turfgrass condition. This was accomplished by assigning visual turfgrass parameter scores

during the final irrigation phase (August 3rd to October 20th 2016) and noting performance of the grasses to the chronic ET application levels at the prescribed ET replacement levels.

Likewise, quantitative data for Chlorophyll Index (C.I) values (Spectrum Technologies) were assigned to plots on six field dates and percent plot cover (0-100%) was recorded (on two field dates) from a smart phone application ("Canopeo", Oklahoma State University) which generates a cover value from a digital phone picture. These measurements were included in order to assess the feasibility of such measurements to be used as either companion data or serve directly as quantitative data for turfgrass performance parameters.

Significant Results:

Turfgrass Response to differentially applied water as the % ET replacement.

Based on the results, it was possible to determine the (lowest) base level of ET replacement percentage for each grass that would provide a nominal turfgrass cover (quality = 5.0 minimum) as well as a fully acceptable turfgrass surface (quality = 6.0, minimum) when using the 1-9 visual scale as set forth by the National Turfgrass Evaluation Program (NTEP).

In this report, data is presented for (1) the quality achieved for each grass at all the irrigation replacement levels, and (2) quality achieved by all grasses at each specific irrigation level. This answers the objectives of (a) which grass does best at some low irrigation replacement level and (b) at a specific irrigation replacement level, what is the overall quality of the different grasses themselves. These results assist consumers who want information about what grasses perform best at what (lower) levels of irrigation, and at any of the level of irrigation, what grass or grasses provide an acceptable low maintenance turf.

Table 1.8 in **Appendix B** shows turfgrass quality on six events from August 8th to October 20th 2016, for each of the seven turfgrass cultivars at each ET replacement irrigation level (25, 35,45,55,65 and 75%). From August 3th to August 31st, all seven grasses had fully acceptable quality at all levels of ET replacement with the one exception of Bison Buffalograss at 25% ET (0), which had a marginal quality of 5.3. By August 31st, the cumulative reference ET (0) was 7.3 inches of evaporation.

On September 20th, a few of the seven grass entries had then showed reduced turf quality from irrigation treatments. These included Cheyenne II bermudagrass at 25% replacement (4.3), and Jackpot bermudagrass (4.8). Nu-Mex Sahara maintained quality of 6.0 or greater at 45% ET replacement (6.3), while Wrangler bermudagrass also had fully acceptable quality at 45% ET replacement (6.0), on September 20th.

On October 5th, the cumulative reference ET (0) from August 3rd was now 14.08 inches, and all grasses had poor turf quality at the 25% ET replacement irrigation level, ranging from 3.0 to 4.5 for quality. A rating of "5.0"for quality represents a "marginal" but not poor turf condition. At 35% ET replacement, Bison buffalograss had the greatest numerical quality score in October 5th, with a value of 5.0. Among the bermudagrass cultivars, only Wrangler had a turf quality of 5.0 or greater (5.5)

On October 15th, all three buffalograss cultivars could not maintain a quality of 5.0 or greater at either 25 or 35% ET replacement, as those grasses had mean quality scores of 3.8 to 4.8 at the 35% replacement level. Wrangler was the only grass to have a marginal quality score of 5.3 at the 35% ET(0) irrigation replacement level on October 15th.

At the close of the test on October 20th, the cumulative reference ET(0) (from August 3rd) was 16.6 inches. At closure, the minimum ET irrigation level required to maintain a minimal quality condition of 5.0 or greater occurred at the 45% ET level for all 3 buffalograss cultivars. In this case, Bison, Topgun and Sundancer all had mean quality scores of 5.5 each. Again this was achieved at 45% ET(0). For bermudagrasses, both Cheyenne II and Nu-Mex had quality scores of 5.0, while Jackpot was slightly higher at 5.5, all at 45% ET(0) on October 20th.

Wrangler bermudagrass was the only grass to have a mean quality value of 5.0 or greater at 35% at the close of the test (5.3), with still yet higher quality (5.8) at 45% ET(0) replacement.

For turfs to achieve a quality of 6.0 or greater (fully acceptable - high quality turf) the minimal ET replacement applied Kc values would be obtained as follows.

For buffalograss, Bison 55% (6.3), Topgun 55% (6.3) and Sun Dancer 55% (6.3). For bermudagrass, Cheyenne II 55% (6.3), Nu-Mex Sahara 75% (6.5), Jackpot bermudagrass 65% (6.5), and Wrangler bermudagrass 55% (6.3).

Both Cheyenne II and Wrangler bermudagrass cultivars maintained a high quality turf condition (6.0 or greater) at the 55% ET irrigation replacement level at the end of the trial (6.3, 6.3, respectively). Again note that Wrangler bermudagrass essentially produced a low maintenance marginal quality turfgrass of a 5.0 minimum (5.3) at 35% ET(0), while all other grasses could not at that this same ET replacement level.

Alternatively, if clientele wanted to select a grass at a specific ET replacement level to irrigate by, information here can provide turfgrass quality performance at specific ET replacement levels. In all cases, no grasses would perform long term at 25% or 35% ET(0) replacements.

At 45% ET(0) replacement, Wrangler ranked first at 5.8 for quality, with all 3 buffalograsses following next with "end of season" quality scores of 5.5. Although the grasses did not differ significantly for quality at 45% ET replacement, Jackpot and Wrangler were the most different in general appearance from each other.

At 55% ET(0) replacement (*generally considered the lowest irrigation amount to provide warm season grasses with nominal quality)* all the buffalograss entries would qualify (6.0-6.3 mean quality), while Cheyenne II and Wrangler also produced fully acceptable quality turfs (6.3, 6.3, respectively) at 55%.

At the 65% and 75% ET(0) replacement levels, all seven grasses produced fully acceptable quality turfs (6.0 or greater) with the one exception of Nu-Mex bermudagrass (5.8 at the close of the test) at 65% of ET(0).

Digital Data:

In an effort to quantify turfgrass performance using digital imagery, two devices were used as follows. A **chlorophyll index (C.I.)** meter (Spectrum technologies, Spectrum 1000 C.I. meter) was used on five occasions from August 3rd to October 15th. This hand held unit measures wavelengths appropriate for use in the normalized difference vegetation index (NDVI), as well as for a greenness index. A proprietary algorithm incorporates these two parameters into a unit less scale which generates real time values that range from 0-999. Values increase as 1) turfgrass color or hue intensifies, 2) canopy becomes more dense, 3) canopy height increases, or any combination of the above. In this trial, the turfs were mowed weekly, so items 1) and 3) would have the greatest effect on generated values. The unit auto-corrects for light intensity, and all measurements were made without cloud cover. Nine (9) measurements per plot were averaged and the average C.I. value was recorded for analysis.

A digital phone application named **"Canopeo"** developed by Oklahoma State University was used on two occasions. A standard smart phone digital picture is processed to generate a percent plot cover value, from 0-100% of the surface captured within the lens. In this case images were taken 32 inches above the center of each plot, which covered a rectangular area of 32 x 24 inches (5.3 ft^2) over the center of the plot. Based on pictorial shadowing and hue sensitivity, the application generates a percent ground cover value within three seconds after pixilation excitation is requested. This instrument was selected to determine if generated values were close to visual surface values for cover, hoping that greater measurement precision may be realized for turfs which undergo green canopy loss from chronic drought (especially when turf loss is low, from 1-10% cover).

Values from both instruments were compared to each other, as well as to visual estimates of percent plot green cover (0-100%) which was calculated from the simple equation 100-(% bare soil exposure + %straw). In addition, the individual NTEP visual assignments of turfgrass color, overall quality, and shoot density were assigned on four occasions as well. These NTEP values were then "summed" in order to create a larger numerical value (CQD Index) encompassing the visual turf performance components together, which may be more related to the C.I. or digital % plot cover values, since a larger range of numerical possibilities to correlate among measurement techniques should be realized.

Correlation of Digital Responses:

"Canopeo" plot covers and C.I. values were compared on a per plot basis for joint measurements made on October 1st and October 14th. The simple correlations for values from both measurement devices were identical at r= 0.71 to 0.81 on both dates, for bermudagrass and buffalograss, respectively. A correlation "r" value of 0.70 indicates a "moderate" relationship, while a value of 0.80 is a "moderately strong" relationship. A perfect relationship occurs if the correlation coefficient is 0.99 or 1.0.

Table 3. Simple Pearson Product correlations between Chlorophyll Index (C.I.) values from the Spectrum 1000 canopy reflectance meter and percent living percent ground cover from the 'Canopeo 'smart phone application software, developed by Oklahoma State University. Concomitant measurements taken on 168 individual turfgrass plots, per calendar date. Uni. Arizona, 2016.

	Chlorophyll Index Oct 1.	Chlorophyll Index Oct 14	*Turfgrass*
Canopeo Oct 1st	*0.71*	- -	Bermudagrass
	0.81	- -	Buffalograss
	- -	*0.78*	Bermudagrass
Canopeo Oct 14th	- -	*0.81*	Buffalograss

1 Chlorophyll Index = (0-999) Increasing values indicate darker turfgrass color, higher density, taller canopy, or any combination therof.
2 Canopeo = (0-100%) = percent living ground cover using phone application software, Oklahoma State University
3 Turf = Bermudagrass (4 cultivars N= 96 observations). Buffalograss (3 cultivars, 72 observations). Paired comparisons across all ET replacement levels within each grass species.

When compared to visual assignment estimates of % plot green cover, the 'Canapeo' application of % plot cover values were only moderately correlated. These values ranged from 0.57 to 0.67 across both buffalogarss and bermudagrass entries on both the dates of October 4th and October 16th . Based on the existing version, the "Canopeo" percent cover application is only a slight-moderate predictor of turfgrass cover, and would not substitute for replacing visual assessments from a trained and experienced turfgrass researcher.

Table 4. Simple Pearson Product correlations between visual estimates of % plot green turfgrass cover and percent living ground coverestimates from 'Canopeo' smart phone application software, Oklahoma State University. Concomitant measurements taken on 168 individual turfgrass plots per calendar date. Univ. Arizona, 2016.

	Chlorophyll Index Oct 1.	Chlorophyll Index Oct 14	*Turfgrass*
Canopeo Oct 1st	*0.6*	- -	Bermudagrass
	0.6	- -	Buffalograss
	- -	*0.67*	Bermudagrass
Canopeo Oct 14th	- -	*0.58*	Buffalograss

1 % Plot green cover (0-100 %). Calculated as 100 -(% bare soil + % canopy straw). All estimates are visual assignments.
2 Chlorophyll Index = (0-999) Increasing values indicate darker turfgrass color, higher density, taller canopy, or any combination therof.
3 Turf = Bermudagrass (4 cultivars N= 96 observations). Buffalograss (3 cultivars, 72 observations). Paired comparisons across all ET replacement levels within each grass species.

The same visual assessment data for % plot green cover was also compared to the chlorophyll index values. C.I. values on October 8th were correlated with % plot green visual values assigned on October 4th and October 16th. The simple correlation was r = 0.76-0.74 for both grasses on October 4th, and 0.77 for bermudagrass and 0.93 for buffalograss on October 16th.

Table 5. Simple Pearson Product correlations between Chlorophyll Index (C.I.) values from the Spectrum 1000 canopy reflectance meter and visual estimates of % percent plot green turfgrass canopy cover.
Concomitant measurements taken on 168 individual turfgrass plots per calendar date. Uni. Arizona, 2016.

	% plot green Oct 4th	% plot green Oct 16th	*Turfgrass*
Chlorophyll Index	*0.76*	- -	Bermudagrass
Oct. 8th	*0.74*	- -	Buffalograss
Chlorophyll Index	- -	*0.77*	Bermudagrass
Oct 8th	- -	*0.93*	Buffalograss

1 Chlorophyll Index = (0-999) Increasing values indicate darker turfgrass color, higher density, taller canopy, or any combination therof.
2 % Plot green cover (0-100 %). Calculated as 100 -(% bare soil + % canopy straw). All estimates are visual assignments.
3 Turf = Bermudagrass (4 cultivars N= 96 observations). Buffalograss (3 cultivars, 72 observations). Paired comparisons across all ET replacement levels within each grass species.

Longer term studies across the full spring, summer and early fall seasons in multiple years would need to be conducted to determine if the C.I. devise could indeed be used to quantify canopy cover in response to drought aspects.

The summed turfgrass "CQD Index also was correlated with the Canopeo percent plot cover application, and also with the C.I. meter. Simple correlations on October 1st yielded correlations of r = 0.70-0.72 for both grasses, and 0.73-0.75 again for both grasses on October 14th for the CQD Index vs. Canopeo % plot cover.

These latter correlations of 0.70-0.72 could not be used for true quantitative analysis of grass performance, as perturbations in turfgrass plots (uniformity of color, density, leaf angle, necrotic tissue etc.) which are apparent to the trained turfgrass researcher, are not necessarily identified or quantified or integrated in the Canopeo software. In this trial, plots which received 0.25 ET had visual estimates of 15-20% green cover, while the Canopeo software produced values of 5% or less cover for those same plots. Likewise, high ET replacement turfs which had 98% or more visible plot cover had Canopeo values of only 80-85% plot cover maximum. Other software applications for turf performance and canopy status could be investigated in the future.

Table 6. Simple Pearson Product correlations between "Canopeo' living ground cover smart phone application software values and the Turfgrass CQD Summation Index.
Concomitant measurements taken on 168 individual turfgrass plots per calendar date. Uni. Arizona, 2016.

	Canopeo Oct 1st	Canopeo Oct 14th	*Turfgrass*
CQD Turf Index	*0.72*	- -	Bermudagrass
Oct. 1st	*0.7*	- -	Buffalograss
CQD Turf Index	- -	*0.75*	Bermudagrass
Oct 15th	- -	*0.73*	Buffalograss

1 Canopeo = (0-100%) = percent living ground cover using phone application software, Oklahoma State University
2 CQD Index = sum of (1-9) values each, of turfgrass color, quality, density using NTEP visual rating scale.
3 Turf = Bermudagrass (4 cultivars N= 96 observations). Buffalograss (3 cultivars, 72 observations). Paired comparisons across all ET replacement levels within each grass species.

Finally, the comparison of visual turf index (CQD) values taken on Oct 1st, 10th and 15th versus chlorophyll index (C.I.) values taken October 1st and 14th, resulted in slightly higher correlations which were now similar for both bermudagrass and buffalograss. Simple correlations between C.I. and the turf CQD index values were r = 0.79-0.80 on October 1st, and r = 0.87 for both grasses on October 10th, and 0.86 for both grasses on October 15th.

Table 7. Simple Pearson Product correlations between "Canopeo' living ground cover smart phone application software values and the Turfgrass CQD Summation Index. Concomitant measurements taken on 168 individual turfgrass plots per calendar date. Uni. Arizona, 2016.

	Chlorophyll Index Oct 1.	Chlorophyll Index Oct 1.	Chlorophyll Index Oct 14th	*Turfgrass*
CQD Turf Index	*0.8*	- -	- -	Bermudagrass
Oct. 1st	*0.79*	- -	- -	Buffalograss
CQD Turf Index	- -	*0.87*	- -	Bermudagrass
Oct 10th	- -	*0.87*	- -	Buffalograss
CQD Turf Index	- -	- -	*0.86*	Bermudagrass
Oct 15th	- -	- -	*0.86*	Buffalograss

1 Chlorophyll Index = (0-999) Increasing values indicate darker turfgrass color, higher density, taller canopy, or any combination therof.
2 CQD Index = sum of (1-9) values each, of turfgrass color, quality, density using NTEP visual rating scale.
3 Turf = Bermudagrass (4 cultivars N= 96 observations). Buffalograss (3 cultivars, 72 observations). Paired comparisons across all ET replacement levels within each grass species.

In order to purely replace visual turfgrass assessments completely with any digital parameters, the correlations between the digital and visual (or physical measurements) parameters should be at least 0.95 or greater. While the Chlorophyll Index meter values were much more closely related to visual turfgrass assessments than the Canopeo phone application, the Chlorophyll Index Meter alone still would not fully numerically capture the turf canopy conditions experienced under various level of irrigation.

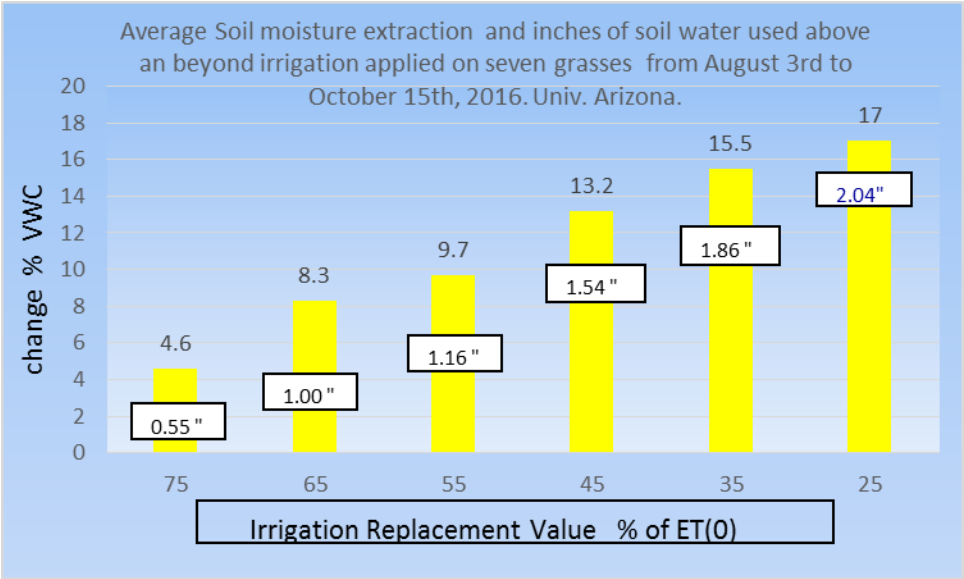
Realized Actual Water Use

The total amount of water "used from August 3rd to October 20th can be calculated as the total "Reference ET" inches (X) inch change in soil moisture over the 10 week period. Since volumetric water content was measured at the beginning and end of the test cycle (2 nozzle port upgrades, August to Mid-October), the actual water use on a per plot basis is reported as follows. The total evaporative demand from August 1st to October 15th was 15.22 inches. Therefore, the amount of water applied on average across each of the targeted ET replacement levels, was as follows.

75% = 11.41 inches
65% = 9.89 inches
55% = 8.37 inches
45% = 6.85 inches
35% = 5.32 inches
25% = 3.80 inches

Realized Water Use = [Irrigated amount applied (inch) + Rainfall(inch) - Change in Volumetric Water Content (inch)].
Since the base ET target amount entered daily in the Irrigation software was adjusted each day for any effective rain, the water use equation was simplified to:
Realized Water Use = (Irrigated inch + Inch decrease in soil water content)

The amount of soil moisture extracted was calculated as the difference in the volumetric water content, taken in early August, minus the final volumetric water content, taken the third week of October. Since the soil water content was lower in all the plots in October, each and every ET replacement treatment did use some soil water above and beyond the respective depth of water applied at each ET replacement level assigned. Turfs irrigated at 25% extracted, on average 2.54 inches of available soil water, while turfs irrigated at 75% ET extracted on average, 0.55 inches of soil moisture above and beyond irrigated ET.



<u>Therefore, total water used on a per plot basis was determined as follows:</u>

At 25% ET replacement, total water use ranged from 5.5 to 6.0 inches, as Numex Bermuda, Cheyenne II Bermuda, Sundancer Buffalograss, Topgun Buffalograss and Bison Buffalograss used the most water 5.9 - 6.0 inches, also extracting the most soil water of 2.1-2.2 inches. Jackpot and Wrangler bermudagrass cultivars used 5.5-5.7 inches and extracted slightly less soil water (1.7–1.9 inches). Wrangler bermudagrass used the least amount of water statistically, and Jackpot bermudagrass was the only grass which extracted the least amount of soil water (5.5 inches) at 25% ET replacement.

For all other ET replacement levels, grass "water use" and the inch amount of soil moisture "extracted" from the root zone profile was not significant, between all of the 7 grasses.

At 35% of reference ET, all grasses used 7.1 - 7.3 inches of water, extracting 1.8 - 2.0 inches of soil moisture, with no differences occurring between grasses for total water use or extracted amount.

At 45% replacement of reference ET, grasses used 8.2 - 8.6 inches of water, extracting 1.3 - 1.8 inches of soil moisture, with no differences occurring between all of the grasses for total water use of soil moisture extraction amount.

At 55% replacement of reference ET, grasses used 9.2 - 9.7 inches of water, extracting 0.9 - 1.4 inches of soil water. No differences existed between grasses for total water use or extraction at 55% ET replacement.

At 65% replacement of ET, actual water use ranged from 10.5 to 10.9 inches, extracting from 0.6 to 1.0 inches of soil water. No differences between grasses were realized for total water use or extracted soil water at the 65% replacement level.

At 75% replacement of ET, water use ranged from 11.8 to 12.2 inches, with only 0.4 - 0.8 inches of soil moisture extracted. No differences between grasses were realized for total water use or extracted soil water.

In summation, the only ET replacement level where the grasses themselves were different from each other for extracted water and total water used, occurred at the 25% ET replacement level (Table 8, **Appendix B**). This was due to the fact that Wrangler Bermudagrass used the least amount of water (5.7 inches) and extracted a lower amount of soil moisture (1.9 inches), which was similar to that of Jackpot bermudagrass (1.7 inches of soil water extraction).

When evaluating total water use and extracted soil water amount, total calculated water use increased linearly with applied ET amounts, as would be expected (Table 9). In these cases, soil moisture extracted ranged from 0.4 to 2.2 inches within all grasses and across all ET replacement levels.

The grasses which showed the most consistent soil moisture extraction amounts from plot to plot and across ET replacement values included that of Jackpot Bermudagrass, Numex Bermudagrass, and Wrangler Bermudagrass, as these three grasses generated low LSD statistic values. When this value is numerically low, it demonstrates minimal variation has occurred within the grass and ET replacement treatment itself across all respective plot replications. As differences in realized actual water use are obviously significant within each grass due to applied ET replacement level (as expected) (Table 9 **Appendix B**), differences between grasses for turf performance are better determined by comparisons of applied water levels to turfgrass quality as noted in the previous section of this report *(see Tables 1.8 and accompanying text).* Essentially, all grasses used the same amount of water within each respective and separate ET replacement level, but the overall turfgrass quality assessment to the ET replacement levels showed differences between grasses.

Conclude:
Based on a final irrigation period from August 3rd to October 22nd, 2016;

For end users, the following **bermudagrass cultivars** were maintained at nominal overall turfgrass quality (NTEP 5.0 minimal quality)

- 35% ET replacement
  Wrangler (5.3)

- 45% ET replacement.
  Jackpot (5.5)
  Cheyenne II (5.0)
  NuMex Sahara (5.0)

For end users, the following **bermudagrass cultivars** were maintained at fully acceptable overall turfgrass quality (NTEP 6.0, or greater)

- 55% ET replacement
  Wrangler (6.3)
  Cheyenne II (6.3)

- 65% ET replacement
  Jackpot (6.5)

- 75% ET replacement
  NuMex Sahara (6.5)

For end users, the following **buffalograss cultivars** were maintained at nominal overall turfgrass quality (NTEP 5.0 minimal quality)

- 45% ET replacement
  Bison (5.5)
  TopGun (5.5)
  SunDancer (5.5)

For end users, the following **buffalograss cultivars** were maintained at fully acceptable overall turfgrass quality (NTEP 6.0 or greater) .

- 55% ET replacement
  Bison (6.3)
  TopGun (6.0)
  SunDancer (6.3)

This same information is provided graphically below in Table 10.

Table 10. ET replacement irrigation level which maintained 7 seeded low maintenance grasses at **marginal** turfgrass quality (5.0 or greater) after 70 days of differential irrigation using the Linear irrigation gradient (LIGA), August 3rd to August Oct 15th, 2016, Univ. Arizona.

		ET replacement Level					
		25%	35%	45%	55%	65%	75%
Grass	Cultivar						
Buffalograss	Bison			[5.5]			
	TopGun			[5.5]			
	SunDancer			[5.5]			
Bermudagrass	Nu-Mex Sahara			[5.0]			
	Jackpot			[5.5]			
	Cheyenne II			[5.0]			
	Wrangler		[5.3]				

ET replacement value = Percentage of Reference ET(0) from on site weather station using standardized Penman Monteith equation. Total ET (0) from August 3rd to Oct 22nd = 16.04 inches

Quality value =(1-9) 1= dead, 4=poor, 5=marginal, 6= fully acceptable, 9= best possible.
Values are the mean of replications per each grass/ET replacement level combination.
Value in parenthesis is the grass mean turfgrass quality score at end of trial on October 15th, 2016.

Table 11. ET replacement irrigation level which maintained 7 seeded low maintenance grasses at **fully acceptable** turfgrass quality (6.0 or greater) after 70 days of differential irrigation using the Linear irrigation gradient (LIGA), August 3rd to August Oct 15th, 2016, Univ. Arizona.

		ET replacement Level					
		25%	35%	45%	55%	65%	75%
Grass	Cultivar						
Buffalograss	Bison				[6.3]		
	TopGun				[6.0]		
	SunDancer				[6.3]		
Bermudagrass	Nu-Mex Sahara						[6.5]
	Jackpot					[6.5]	
	Cheyenne II				[6.3]		
	Wrangler				[6.3]		

ET replacement value = Percentage of Reference ET(0) from on site weather station using standardized Penman Monteith equation. Total ET (0) from August 3rd to Oct 22nd = 16.04 inches

Quality value =(1-9) 1= dead, 4=poor, 5=marginal, 6= fully acceptable, 9= best possible.
Values are the mean of replications per each grass/ET replacement level combination.
Value in parenthesis is the grass mean turfgrass quality score at end of trial on October 15th, 2016.

- The" Canopeo" software phone application was not a substitute for visual estimates of percent living turfgrass canopy cover, and it's correlation to the turfgrass CQD Index (*the sum of NTEP visual estimates of turfgrass color, quality and density estimates combined)* was too variable to allow its use on turfgrass . These correlations were only moderate at best (r = 0.7), and as such, could not be used as a substitute or as a concomitant measurement with other response variables associated with turfgrass performance.

- The (C.I.) Chlorophyll Index reflectance (Spectrum Technology Model 1000) was more strongly correlated to visual estimates of visual percent plot cover and the CQD Index, ranging from r = 0.80, to r =0.87 for bermudagrass and buffalograss surfaces during the irrigation trial period. This instrument may be used as a concomitant response data measurement, but alone, cannot be a sole substitute for standard turfgrass response variable assignments derived from visual assessments.

***Recommendations*:**
Other spectral reflectance performance measurements should be evaluated for investigative use for determining if the measurements provided therein, are related to turfgrass canopy performance conditions during imposed irrigation levels, and if so, can they be used as a single response variable. These could include NDVI, Green Index, and other percent cover camera software which now may be converted into applications directly for turf.

Goals and Outcomes Achieved

See "Conclusions" section above, which describes outcomes in terms of low maintenance turfgrass performance relative to ET based irrigation. End users now have a basis for selection of commercially available seeded bermudagrass and buffalograss cultivars when supplemental irrigation is limited, as well baseline knowledge of the minimum amount of ET replacement required to achieve nominal or marginal, as well as fully acceptable quality turfs, in a low maintenance condition.

- Under further testing, see if C.I. values could be used to adequately quantify turf performance and thus allow data acquisition by a non-turf scientist.

- See turfgrass performance relative to ET replacement, as noted in previous section.

- If other scientists are to pursue LIGA experimental design in turf, they must be fully aware that the irrigation industry essentially no longer designs sprinkler profiles purely as a linear function of distance of throw, but has altered the output profile to now improve sprinkler uniformity when normal/prescribed head distances are not observed by installers.

Further evaluation is warranted to ideally confirm the performance reductions of these turfs under less than optimal irrigation conditions for full growing seasons of spring, summer and early fall which thus would include an additional year of performance data under the highest conditions of ET evaporative demand (May, June and July). This was pre-empted here by the need to conduct extensive calibration of the LIGA system itself, since the turfgrass sprinkler

manufacturing industry has recently changed the sprinkler output performance profiles to better accommodate poor installation practices (since improper head space distances predominate in the industry). To complete this experiment, individual sprinkler nozzle combinations had to be manipulated/tested /altered in order to approximate a standard sprinkler output profile.

Beneficiaries

This information is for golf course designers, superintendents. To date this information has not yet been released. Results to be submitted for presentation at Golf Course Supts. Assoc. America.

Lessons Learned

When long term deficit irrigation is practiced, soil salinity and/or soil sodicity can become limiting conditions for turf growth. While not used since 2009, this same field used here in a previous LIGA experiment, yielded a saline/sodic soil condition as the distance from the main line source increased. This unexpected condition arose even after the field was roto-tilled in preparation for this exact experiment. Six years of sub-standard rainfall and record high evaporation (from 2009 to 2014) most likely brought soil salts to the surface, causing the problems realized in 2014 and early 2015. The original grass pallet included other native bunchgrasses which unfortunately had poor establishment from these soil conditions, which thus resulted in attempted re-establishment, followed by soils remediation (gypsum and leaching), and then establishment of the other low maintenance grass cultivars, all within the time limits of this trial.

At no expense to the sponsor, the originally selected grasses were established in 2014 (prior to funding), in an effort to obtain two full years of ET based irrigation grass responses. The above soil conditions and soils renovation, and the need to modify new sprinkler head/nozzle combinations were a tremendous time factor.

Test areas which have had former irrigation trials using differential amounts of applied water (by any design) should have surface and subsurface soils tested for salinity and sodicity.

The industry trend has progressed to the use of sprinkler nozzles which now extend the profile for similar water outputs over a long distance of throw, in order to accommodate for improper head to head field spacing's, which are predominate in the industry. One must evaluate single head profiles and if necessary, change, alter or nullify nozzle(s), as was required here.

Contact Person

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Minimizing Crop Disturbance, Improving Nutrient Uptake

This project was completed on June 30, 2017

Project Summary

The goal of this project was to determine if alternative technologies and systems for cultivating and sidedressing that induce minimal soil disturbance and more optimally place fertilizer reduce fertilizer inputs and increase yields in Arizona specialty crops. Techniques investigated included leaving crop beds intact during cultivation and use of a point injection applicator, a device that intermittently injects fertilizer into the root zone. In romaine lettuce, trial results showed that although use of the point injection applicator did not improve nutrient uptake, there was a trend that crop yields were increased by 8% when the device was used. In broccoli, use of the point injection system in conjunction with cultivation techniques that either shaved sidewalls or left them intact increased nitrogen uptake by more than 27% and yield by 15% as compared to the standard applicator. In cantaloupe, conventional application techniques were superior to alternative methods. On-farm demonstrations, field days and presentations were made to educate growers about the systems investigated and project findings. These outreach efforts were successful in that several growers have stated that they plan to adopt point injection technology. This is in-line with the expected measurable outcomes of the project.

Project Purpose

New, low disturbance cultivating techniques and better technologies for placing fertilizer are needed in vegetable and melon production to reduce crop injury, lower nitrogen inputs and increase crop yield. In conventional production, weeds on bed sidewalls are controlled using side knives that shave the bed sidewalls near the plant rows. Following cultivation, the crop is side-dressed using knife blade applicators that deposit fertilizer at the outer edges of the bed wall. These practices induce high soil disturbance close to the plant, prune feeder roots and do not place fertilizer in an optimal location for plant uptake. As a result, crop growth, nitrogen use efficiency and yield can be negatively affected. As an alternative, crops could be side-dressed and cultivated using implements that minimize plant disturbance and more optimally place fertilizer. First, crops could be side-dressed using a rotary point injection fertilizer applicator. These systems utilize spikes attached to a rotatable wheel to intermittently inject liquid fertilizer into the plant root zone with minimal root damage and soil disturbance. Rolling cultivators (Lilliston) and bollas could then be used to control weeds on bed sidewalls and seal in fertilizer. The practice would leave beds intact, induce minimal plant disturbance, virtually eliminate root pruning and improve fertilizer placement. Lettuce, broccoli and cantaloupe require a significant amount of nitrogen (N), typically 150-200 pounds, at a cost of about $90-$120 per acre to be sidedressed during the growing season for optimum yield and quality. The goal of this project was to reduce fertilizer requirements and increase yields for these crops by examining alternative techniques and technologies for cultivating and applying fertilizer that minimize soil movement near the plant and place fertilizer more precisely. A further goal is to disseminate the knowledge gained and have growers adopt the system.

Project Activities

Virtually all of the specific tasks from the project's Work Plan were accomplished. The following describes these in detail.

Experimental Trials - Methods

In the fall of 2014, field trials with furrow irrigated romaine lettuce were initiated at the Yuma Agricultural Center. Three crop rows were planted on each bed top as is typical for romaine crops raised for hearts. This crop type was selected as it was thought that the effects of root pruning would be prevalent since the outer crop rows are positioned close to the edges of the bed. Broccoli trials were also established at the same site with two crop rows planted to each bed. For both experiments, experimental design was a randomized complete block design with three factors and four replications. Factors included four N application rates, two applicator types and two cultivation methods. Applied N rates during the first side-dress were 0% (check), 50%, 75% and 100% of the standard rate of N (100 lb/acre). Approximately 100 lb/ac of additional N in the form of UN 32 was applied by furrow irrigation approximately 4 weeks after the first side-dress. Applicator types examined were the point injection system and a conventional knife-blade applicator (Fig. 1). One spike wheel injector was utilized for each plant row and positioned so that the wheel operates on the bed sidewall. Cultivation methods included controlling weeds on bed sidewalls using a side knife (beds shaved) and the rolling cultivator (beds not shaved). The rolling cultivator was used only with the point injection applicator (point injection - non-shaved). Experimental unit plot size was 50 ft long by 4 beds wide. Plant N uptake was assessed by measuring leaf midrib nitrate-N levels prior to the first side-dress, two weeks after the first side-dress application and at maturity. At maturity, six romaine and four broccoli above ground, whole plant samples were collected and weighed from the center two beds of each four-bed plot. The samples were then dried, weighed and analyzed for total N content to determine crop N uptake in terms of lb/ac. For the romaine plots, crop yield was assessed by harvesting, trimming and weighing individual heads from 10 ft of row from the middle two beds of each 4-bed plot. A marketable head was taken to be a heart that weighed more than 0.35 lb. For the broccoli plots, crop yield was determined in the same manner except heads were harvested from 7.5 ft of row and a marketable head was considered to be a crown that weighed more than 0.30 lb.

In the spring of 2015, similar type experiments were conducted in cantaloupe. Experimental design was a randomized complete block design with two factors and four replications. Factors included four nitrogen application rates and two applicator types. Application rates were 0% (check), 50%, 75% and 100% (control) of the standard rate of N (100 lb/acre). These were applied in a split application. Applicator types examined were the point injection system and a conventional knife-blade applicator. Here, the effect of bed sidewall cultivation methods were investigated as the bed sidewalls are located far from the plant root zone and therefore cultivator induced root pruning is unlikely. The effect of root pruning however was ascertained, as delivering fertilizer with a conventional knife blade applicator is prone to root pruning. Experimental unit plot size will be 60 ft long by 1 bed wide. Cantaloupe nitrogen uptake and yield were assessed by measuring petiole nitrogen content as previously described and by harvesting and weighing individual melons from the center 25 ft of row from each plot. The romaine lettuce and broccoli trials were repeated in 2015 to obtain a second season of data. Due to a crop failure, the cantaloupe trial was repeated in 2017. Data were analyzed to determine differences between treatments for each crop.

Fig. 1. Four bed knife blade applicator a) operating in romaine lettuce and b) close up view of bed after application. Four bed point injection fertilizer applicator c) operating in romaine lettuce and d) close up view of bed after point injection.

Experimental Trials - Results

In the romaine lettuce trial, applicator type or cultivation method had no significant effect on midrib nitrate-N levels or N uptake (Fig. 2a, b, c). Despite this, there were yield differences. At the 75% and 100% applied rates of N, mean head weight was generally higher by more than 10% for the point injection - shaved treatment (Fig. 2d). This translated into higher total yields (>12%) and marketable yields (>17%) as compared to the conventional, knife blade – shaved treatment (Fig. 2e). Similar total and marketable yield increases of >13% and >11% respectively were found as compared to the point injection-non-shaved treatment (Fig. 2f). Marketable yields for the point injection – shaved treatment were also higher at the 50% level of applied N as compared to the other two treatments. These results were unexpected as it was hypothesized that shaving the bed sidewalls would prune roots, induce soil disturbance and consequently hinder crop growth and yield. A possible explanation for these results was that romaine was grown with three crop rows per bed. Yield parameters for the knife blade – shaved treatment were low due to root pruning on the outer two rows and poor fertilizer placement for the center row. In comparison, although the roots of the outer two rows were also pruned in the point

injection – shaved treatment, fertilizer was more optimally placed for the center row. The point injection – non-shaved treatments had low yield parameters because without bed shaving, fertilizer was placed too far from the center row to be effectively utilized. In future studies, outer and center row plant samples should be analyzed separately to correctly determine the effects of fertilizer placement, root pruning and soil disturbance on nutrient uptake

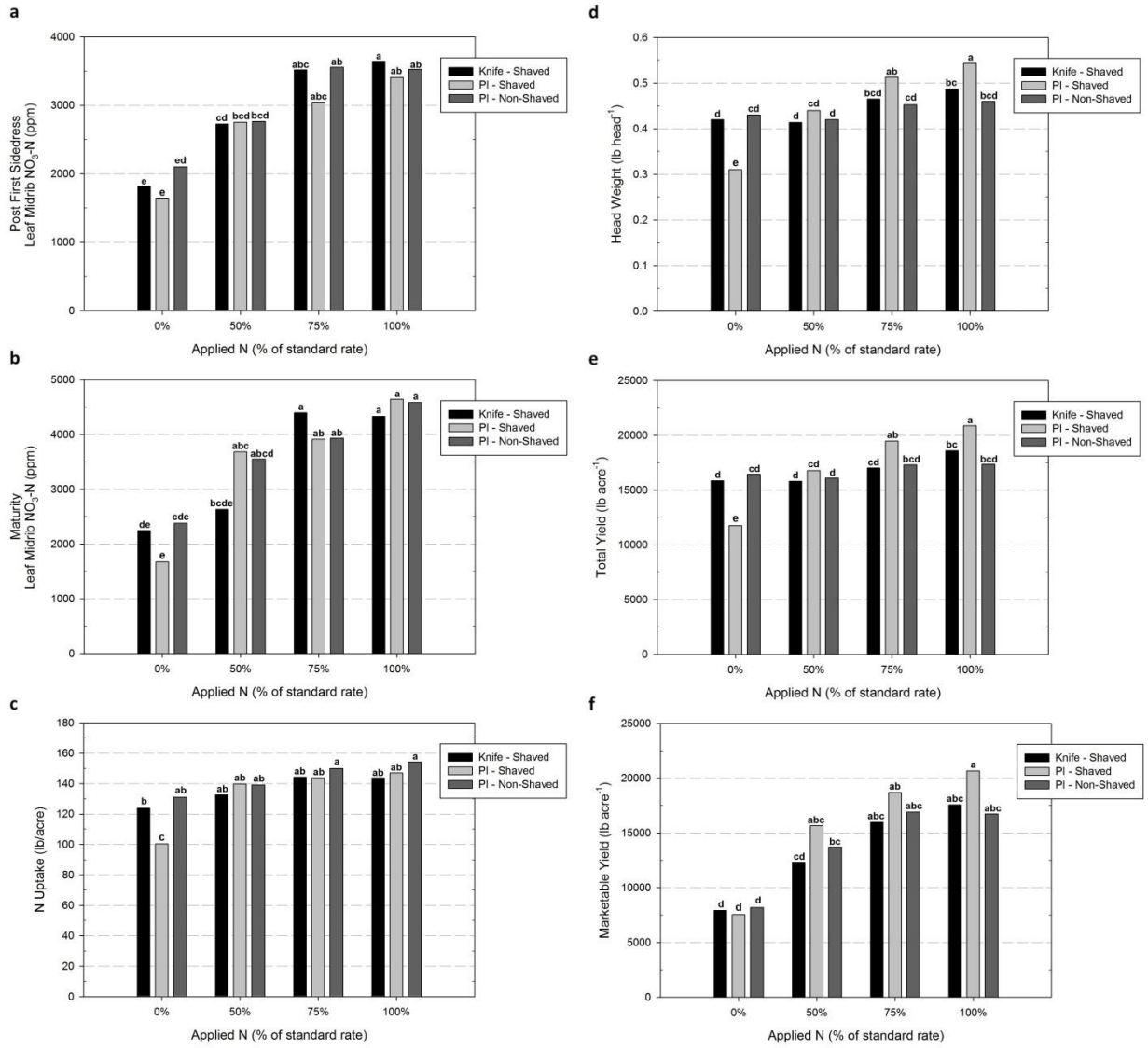

Fig. 2. Effect of fertilizer applicator type and cultivation method at various application rates of N on romaine lettuce (a) midrib nitrate-N content after first side-dress, (b) midrib nitrate-N content at maturity, (c) total N uptake by crop at maturity, (d) head weight, (e) total yield and (f) marketable yield in trials conducted at the Yuma Agricultural Center, Yuma, AZ. Applicator types were a conventional knife blade applicator (Knife) and a point injection system (PI). Cultivation methods were conventional cultivator equipped with side knives that shaved bed sidewalls (Shaved), and a conventional cultivator with side knives removed (Non-Shaved). Standard rate of N was 100 lb/ac, applied during the first sidedress operation.

In the broccoli trial, applicator type had a significant effect on midrib nitrate-N levels after the first side-dress (Fig. 3a). Use of the point injection applicator with or without bed shaving resulted in midrib nitrate-N levels that were higher than the knife blade – shaved treatment at the 50% rate (>27%), 75% rate (>36%), and 100% rate (>60%) of applied N. No significant differences between the point injection – shaved and non-shaved treatments were found. A logical explanation for why these differences did not also translate into higher midrib nitrate-N levels at maturity or total N uptake by the crop could not be formulated (Fig. 3b, c). Although there were few statistically significant differences in yield parameters (Fig. 3d, e, f), there was a trend that high disturbance cultivation results in lower yields. This is supported by the result that at the 50% rate of applied N, the point injection – non-shaved treatment had numerically higher total yields (>8%) and marketable yields (>15%) as compared to either shaved treatment. Similar results were found at the 75% rate of applied N where total and marketable yields were numerically higher by >9% and >16% respectively.

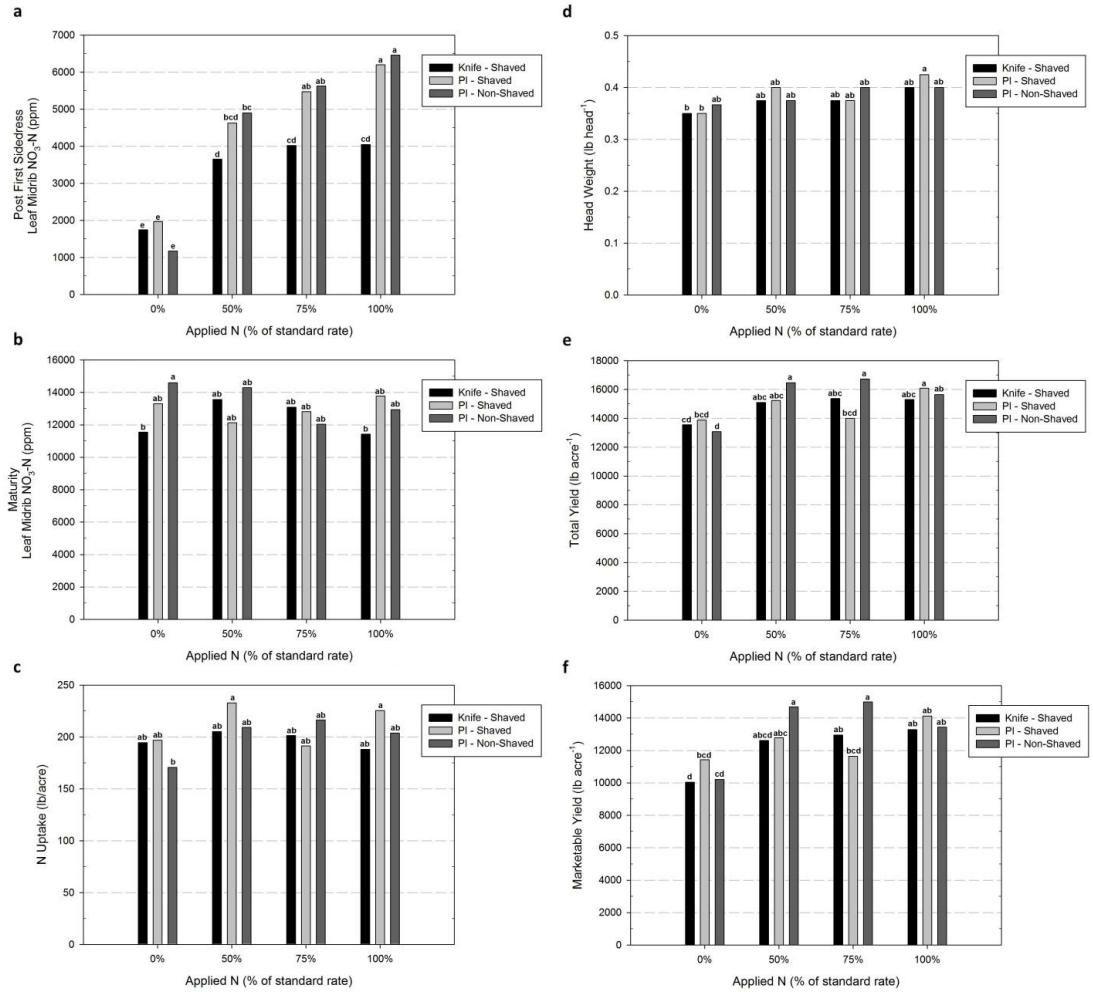

Fig. 3. Effect of fertilizer applicator type and cultivation method at various application rates of N on broccoli (a) midrib nitrate-N content after first side-dress, (b) midrib nitrate-N content at maturity, (c) total N uptake by crop at maturity, (d) head weight, (e) total yield and (f) marketable yield in trials conducted at the Yuma Agricultural Center, Yuma, AZ. Applicator types were a conventional knife blade applicator (Knife) and a point injection system (PI). Cultivation methods were conventional cultivator equipped with side knives that shaved bed

sidewalls (Shaved), and a conventional cultivator with side knives removed (Non-Shaved). Standard rate of N was 100 lb/ac, applied during the first sidedress.

In contrast, there was no advantage to using the point injection system in cantaloupe. In fact, use of the point injection system resulted in significantly lower nitrogen uptake and yield as compared to the conventional knife blade applicator (Fig. 4 a, b). At the 75% and 100% rates of applied N, midrib nitrate-N levels were more than 26% and 50% lower after the first sidedress and second sidedress respectively. This translated into crop yields that were 14% lower. The magnitude of the differences between applying fertilizer via point injection and conventional methods is quite large and a logical explanation for the differences could not be formulated. Perhaps it had something to do with the way water infiltrates and thus distributes fertilizer in wide beds in conjunction with the rooting pattern of cantaloupe. To understand this result better, it is suggested that trials be conducted with fertilizers that contain tracer elements so that fertilizer movement and uptake can be tracked.

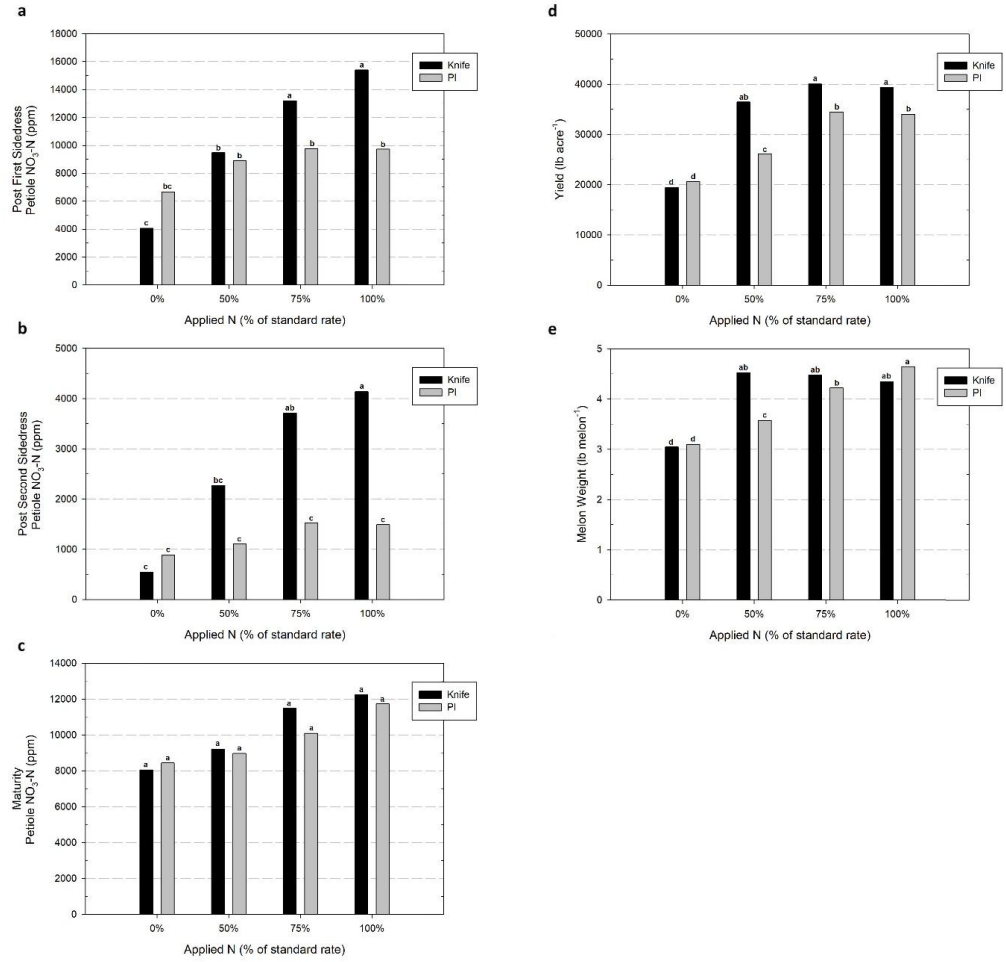

Fig. 4. Effect of fertilizer applicator type at various application rates of N on cantoloupe (a) midrib nitrate-N content after first side-dress, (b) midrib nitrate-N content after second side-dress, (c) midrib nitrate-N content at maturity, (d) yield and (f) melon weight in trials conducted at the Yuma Agricultural Center, Yuma, AZ. Applicator types were a conventional knife blade applicator (Knife) and a point injection system (PI). Standard rate of N was 50 lb/ac, applied during each sidedress.

Experimental Trials - Conclusions

Results of the study showed that applicator type, fertilizer placement and cultivation technique had significant effects on nutrient uptake and crop yield in raised bed lettuce, broccoli and cantaloupe production. In trials with romaine lettuce, use of the point injection applicator did not improve nutrient uptake as compared to the conventional knife blade applicator. Although not statistically significant, increases in head weight (>10%), total crop yield (>12%) and marketable yield (>11%) were found when the point injection applicator was used in conjunction with the standard cultivation technique where bed walls were shaved, but not when beds were left intact. These results were not expected as it was hypothesized that shaving bed sidewalls prunes plant roots and consequently retards nutrient uptake, crop growth and yield. A possible explanation for this was that since injection points were relatively short compared to the width of the bed top, the point injection applicator placed fertilizer more equidistantly between the outer and center rows when bed sidewalls were shaved. Further research utilizing the point injection applicator with different length injection points is merited to better understand how fertilizer placement affects nutrient uptake and crop yield in crops planted with three rows on each bed top.

In broccoli, use of the point injection applicator in conjunction with cultivation techniques that either shaved the sidewall or left it intact increased nitrogen uptake by more than 27% as compared to the standard applicator. This was true for all applied rates of nitrogen examined. This finding indicates that for efficient N uptake in broccoli, fertilizer placement is more important than cultivation method. Although these differences did not result in higher levels of plant N at maturity, total yield and marketable yield were numerically higher by >8% and >15% respectively when the beds were not shaved and the point injection system was used.

In summary, these results imply that fertilizer applicator and cultivation systems that place fertilizer in the root zone and induce minimal soil disturbance improve nutrient use efficiency and/or increase yield in lettuce and broccoli production. For reasons not well understood, similar results were not found in cantaloupe.

Outreach Activities

The knowledge gained and findings of the project were disseminated to growers, researchers and industry by making presentations at the 2014 Southwest Ag Summit, 2014 Early Summer La Paz County Agronomic Workshop and by presenting a paper at the 2016 ASABE Annual International Meeting. On-farm and hosted field demos further served to educate growers about the systems investigated. Activities included conducting an on-farm demo/trial at Top-Flavor Farms in 2014, and demonstrating the device at the 2014 Yuma Agricultural Center Tour for the Walton Foundation, 2014 Southwest Ag Summit Field Day, 2015 Southwest Ag Summit Field Day, and 2015 Lettuce Days. Attendance at these events was approximately 600 individuals. Many more were reached via research and popular press publications. A detailed listing of these outreach activities and products is provided in the Additional Information Section.

Goals and Outcomes Achieved

The overall goal of this project is to determine if alternative cultivating and side-dressing systems that leave beds intact, minimize plant disturbance and place fertilizer in a more optimal location can be used to reduce fertilizer inputs and increase crop yields in lettuce, broccoli and cantaloupe. Specific goals were to 1) decrease the amount of side-dressed nitrogen required

(GOAL) from current levels (BENCHMARK) by 25% (TARGET) while maintaining yield as measured by recording nitrogen use and yield in field trials (PERFORMANCE MEASURE), 2) increase crop yield (GOAL) from current levels (BENCHMARK) by 5% (TARGET) as measured by recording yield in field trials (PERFORMANCE MEASURE), 3) conduct outreach program and on-farm field demonstrations to increase the number of growers using this system (GOAL) from 0 (BENCHMARK) to at least 1 and preferably 5 (TARGET) as measured by grower surveys (PERFOMANCE MEASURE).

Specific Goals 1 and 2 were not achieved for all crops. Goal 1 was achieved for broccoli only. For this crop, nitrogen uptake was increased by more than 27%. There were trends that Goal 2 was exceeded for romaine lettuce and broccoli. Study results showed trends of increased yields of more than 8%. It is the author's opinion that Goal 1 and 2 would have conclusively been achieved for lettuce and broccoli if data variability were lower. This could be achieved by collecting more samples and conducting the experiment over more crop years. Based on study results, it is unlikely Goals 1 and 2 can be achieved for cantaloupe. For this crop, conventional fertilizer application methods were far superior to alternative techniques. A rational reason for this result could not be formulated. Further study is warranted to better understand this conflicting and unexpected finding. Goal 3 was accomplished. From a personal survey, two growers have stated that they plan to adopt point injection technology.

Beneficiaries

This project benefits the majority if not all of the more than 100 lettuce and broccoli growers in Arizona. Study results showed that through use of point injection systems, applied nitrogen rates in broccoli could be reduced by at least 25%. This would reduce fertilizer input costs by approximately $25/acre. If such a system were used on the roughly 9,000 acres of broccoli raised in Arizona, growers would save about $250,000 annually. Gross farm revenues increase by about $75 and $50 per acre in lettuce and broccoli respectively for each 1% improvement in yield. If yields of these crops were improved by 8% as indicated in this study, Arizona farm revenues would increase by over $15 million. This estimate is based on the roughly 29,000 acres of romaine lettuce and broccoli raised in Arizona. The information/findings from this project was disseminated to over 600 researchers, growers, and industry personnel. This has increased the awareness and knowledge about alternative methods of cultivating and sidedressing fertilizer.

Lessons Learned

In this study, expected measures of increased nitrogen use efficiency were not obtained in romaine lettuce. In addition, use of point injection systems and alternative cultivation methods increased yields in romaine and broccoli, but differences were not always statistically significant. This was due to high variability in the data. To avoid this problem, the number of samples collected should be increased in future studies. Collecting data from additional crop years is also recommended. This will not only increase the amount of data available, but also help address issues with year-to-year variability, which was high in this study. Precise methods for measuring and tracking nitrogen movement and uptake should be used if possible. This would allow the complicated effects of tillage and nitrogen placement on nutrient uptake efficiency to be more readily understood. The most effective form of "tech transfer" was on-farm demonstrations where individual growers could assess the merits of alternative fertilizer application and

cultivation practices on their own farm. This approach is time consuming and inefficient because only one grower is "reached" at a time. However, long term, it is a viable approach in that typically, growers readily adopt new practices once they see others having success. An alternative point injection configuration that merits investigation would be to orient the units vertically and position one or more of them between the crop rows. This may facilitate better nitrogen use efficiency as compared to placing it on bed edges where it can be washed away during furrow irrigation. It would also reduce stress on the unit's bearings and prolong the life of the device.

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Additional Information

A detailed listing of the outreach activities conducted and products developed to disseminate the knowledge gained from this project is presented below.

Publications:

Siemens, M.C. & Gayler. R.R. (2016). Alternative systems for cultivating and side dressing specialty crops for improved nitrogen use efficiency. ASABE paper No. 162456725, pp. 9. St. Joseph, Mich: ASABE.

Siemens, M.C., Nolte, K.D., Gayler, R.R. Gayler & Wang, S. (2014). Point injection systems for improved chemical application. Poster presentation. 2014 Southwest Ag Summit, Yuma, Ariz., 26-27 February.

Publication Downloads from ResearchGate website (https://www.researchgate.net/home.Home.html):

Publication	Downloads to date
Siemens, M.C. & Gayler. R.R. (2016). Alternative systems for cultivating and side dressing specialty crops for improved nitrogen use efficiency. ASABE paper No. 162456725, pp. 9. St. Joseph, Mich: ASABE.	25
Siemens, M.C., Nolte, K.D., Gayler, R.R. & Wang, S. (2014). Point injection systems for improved chemical application. Poster presentation. 2014 Southwest Ag Summit, Yuma, Ariz., 26-27 February.	36
Total	61

Presentations:

Alternative systems for cultivating and side dressing specialty crops for improved nitrogen use efficiency. 2016 ASABE Annual International Meeting, Orlando, Fla., July 19. 15 minutes. Attendance - 19. (Volunteered)

Rotary Soil Injection Approaches for Improved Side Dress Applications. Early Summer La Paz County Agronomic Workshop, Parker, Ariz., May 2, 2014. 30 minutes. Attendance - 42. (Invited)

Rotary Point Injection Fertilizer/Pesticide Application. 2014 Southwest Ag Summit, Yuma, Ariz., February 26, 2014. 15 minutes. Attendance - 17. (Volunteered).

Field Days/Demonstrations:

Innovative Cultural Practices for Improving Nutrient Use Efficiency. 2015 Southwest Ag Summit Field Demonstration, Yuma, Ariz., February 25. 4 hours. Attendance - 300.

Rotary Point Injection – Innovative Technologies for Fertilizer/Pesticide Application. Field demonstration, poster and oral presentation. 2015 Lettuce Days, Yuma, Ariz., February 26-27. 14 hours. Attendance - 600. (Volunteered)

Rotary Point Injection Fertilizer/Pesticide Application. 2014 Southwest Ag Summit Field Demonstration, Yuma, Ariz., February 26, 2014. 4 hours. Attendance - 175.

Field Demonstration of Rotary Point Injection Fertilizer/Pesticide Applicator. 2014 Yuma Agricultural Center Tour for the Walton Foundation, Yuma, Ariz., October 9, 2014. 15 minutes. Attendance - 15.

On-Farm Demonstration of Point Injection System Fertilizer Applicator. Top-Flavor Farms, Bard, Calif., Nov. 19, 2014. 8 hours. Attendance - 5.

Popular Press:

Andrade, K.G. 2015. Planting Seed of the Future: Yuma Ag Center Making Inroads with Agricultural Technology. *Yuma Daily Sun*, August 30, p. 1, 3. Yuma, Ariz.: The Sun.

Blake, C. 2014. Lucky 7: The number for success in western alfalfa production. *Western Farm Press* 3(12): 8-9. New York, N.Y.: Penton Media Inc.

Mitigation of Heavy Metals in Produce

This project was completed on September 30, 2016

Project Summary

Existing and emerging heavy metal compliance challenges in the leafy vegetable industries prompted us to evaluate potential mitigation strategies. Strategies evaluated included evaluation of soil tests that growers can use to predict the potential for soil to produce crops with problematic levels of metals, screen spinach germplasm for a possible genetic strategy to reduce heavy metal accumulation, and evaluation of zinc (Zn) fertilization as a potential strategy to reduce cadmium (Cd) accumulations in spinach. While a simple Cd soil test was not sufficiently predictive to serve as a tool for predicting Cd concentrations of spinach, in this study we have identified other soil test properties to incorporate into a predictive soil test algorithm. The calibration of this test is the focus of on-going studies. A more effective long term solution should be aimed at developing spinach cultivars with a lower propensity for Cd accumulation and this research showed genetic variation in spinach germplasm. The data collected in these studies show that the application of large rates of Zn to mitigate Cd uptake are inconsistent, only marginally effective, and cannot be economically justified. However, more modest rates of Zn fertilizer to correct Zn nutrient deficiencies appears justified for many desert soils.

Project Purpose

The production of vegetable crops in the low desert is over a 2 billion dollar industry. Most of these vegetables are irrigated with water and grown on soils that contain low levels of several heavy metals. Consumers of produce are increasingly seeking assurances from industry that their product is safe. Growing trends in monitoring and regulating heavy metals in food are producing similar concerns. Spinach presents a particular concern due to its propensity to accumulate contaminants.

Cadmium in excessive amounts can cause hypertension, kidney impairment, genetic toxicity, immunotoxicity, neurotoxicity, and carcinogenicity (ATSDR, 1990). Cadmium (Cd) is naturally present in many soils and in most phosphate fertilizers (Mortvedt, 1981; 1987). Food is the major source of Cd exposure to humans (Gartrell et al., 1986; Gunderson. 1988; Pennington et al., 1986). Adult exposure to Cd has been estimated to range from 4 to 84 µg per day (Hallenback, 1984). The World Health Organization (WHO) has established a provisional daily intake of cadmium at 1 µg/kg body weight (Walker and Herman, 2000). Based on consumption estimates and cumulative exposure projections, the EU has recommended maximum levels (MLs) for various food commodities. For example, the ML for fruits, rooting vegetables, wheat, and leafy vegetables are 50, 100, 200, and 200 µg/kg FW Cd, respectively (Berg and Licht 2002). The levels of Cd in Colorado River water are generally less than 1 µg/L. However, we have found levels of Cd in phosphate fertilizers used in the low desert as high as 150 mg/kg.

Lead (Pb) has multiple toxic effects on the human body (ATSDR, 1990). Non-carcinogenic effects include decreased intelligence in children (Needleman 1982; Hutton 1987; Bellinger et al., 1992; Canfield et al., 2003), increased blood pressure in adults (Schwartz and. Otto, 1991), kidney impairment, and reproductive effects (Chowdhury et al., 1984). Long-term accumulation of Pb in the biosphere, including human tissue, has resulted largely from anthropogenic activities, particularly mining and leaded gasoline. Gasoline, as a Pb source has declined with the adaptation of unleaded gasoline (OEHHA, 1997). The average concentration of Pb in adults and children is 100 times greater than the natural encumbrance, and existing rates of Pb absorption are 30 times the level in pre-industrial society. Biotic exposure may also increase in the southwestern US, where arid conditions and episodic torrential rainfall produce barren, highly eroded mine sites. Other sources of Pb to the environment include smelters, refiners, and paint products. Surveys in the United States have found Pb soil levels ranged from 10 mg/kg to 700 mg/kg (Shacklette et al., 1971; Lovering, 1976).

While lead concentrations in the Colorado River water are generally less than 1 µg/L, concentrations in suspended sediments can be as high as 40 µg/g (USGS, 2004). Many of the agricultural soils in the region are derived from river sediments deposited before the construction of the network of Dams to manage the river. The WHO has established a Pb RfD of 7 ug/kg body weight-day. The European Union MCL for Pb in leafy vegetables is 300 µg/kg FW (Berg and Licth, 2002). The Center for Disease Control (CDC) has suggested a blood level of 10 ug/dL as the level of concern in children (CDC, 1991). The FDA PTTI are based on estimated projections of prolonged daily intakes that would raise blood levels in children by 1 ug/dL, then dividing by 10 for uncertainties (Carrington and Bolger, 1992).

In a previous survey funded by the Arizona specialty crop block grant program (SCBG 07) we found accumulations of heavy metals were generally higher in edible leafy vegetables, such as lettuce and spinach, compared to fruiting crops such as citrus, tomato, and dates. However, with the exception of spinach and leaf lettuce, most products sampled were generally below EU MLs for Pb and Cd. The DEEM (Dietary Exposure Evaluation Model) model was used to derive an estimate of the 2-day average intakes of these metals in food and water. Drinking Colorado River water was found to be a significant relative source for As compared to food but not for Pb and Cd. The cumulative exposures from all fruits and vegetables to Pb, Cd, and As, were always less than 5, 10, and 80%, their respective RfDs. The 95%tile exposure estimates, but not the mean exposure estimates for lead, do exceed the FDA PTTI for young children.

Studies have shown soil tests to be potentially useful for predicting Cd accumulation by plants (Oliver et al., 1994; Norvell et al., 2000). The development of a reliable pre-plant soil test for Cd in the desert would be a valuable tool for making management decisions which could limit Cd accumulation in leafy vegetables. However, Cd accumulation by crops is often affected by other soil properties. Some studies have shown more complex models, including some measure of soil Cd as well as other soil properties such as pH (Adams et al., 2004) or soil chloride (Norvell et al., 2000), were required to predict Cd concentrations in plants. We had no information regarding soil properties affecting plant Cd concentrations in the desert to modify our soil test algorithm.

As noted above, soil pH can affect Cd availability thereby increasing plant uptake (Tiller et al., 1979; Alloway et al., 1984; Christensen, 1984; King, 1988). However, in the desert, soil pH is buffered to a narrow range by calcium carbonate and we do not believe soil pH is likely to emerge as an important variable affecting plant Cd concentration in the desert.

Soil texture can also affect Cd solubility and plant uptake since increased soil texture increases exchangeable Cd. However, increased soil texture also increases potential reactions to non-exchangeable Cd which is generally not available for plant uptake (Forbes et al, 1976; Abd-Elfattah and Wada, 1981). Many authors (Street et al. 1977; Gusenleitner et al. 1982; Hansen and Tjell, 1983) have found that solubility and plant uptake of Cd was lower in fine textured compared to coarse textured soils. Ziper el al. (1988) found that high charge density edge and planar sites of biotite adsorbed the most and desorbed the least amount of Cd, while interlayer sites of montmorillonite and vermiculite appeared to be least Cd-specific. Limited information exist to indicate what effect, if any, soil texture has on Cd uptake in desert soils.

A number of studies have shown Cd accumulation by crops to be influenced by Zn availability (Haghiri, 1974; Abdel-Sabour et al., 1988; Chaney et al., 1994). In one particularly relevant study, the application of Zn rates up to 5 kg/ha were found to substantially decrease Cd concentrations in wheat produced on soils prone to Zn deficiency (Oliver et al., 1994). In another study, the tendency for increased Cd uptake with increased salinity was reduced by Zn fertilization (Khoshogoftar et al., 2004). Soils in Arizona are generally marginal with respect to Zn.

Studies show that Cd uptake is enhanced by elevated levels of salinity, or specifically high soil chloride (Bingham et al., 1984; Li et al., 1994; Norvell et al., 2000; Khoshgoftarmanesh et al., 2006). It is possible that variation in the salinity of soils and irrigation waters used for spinach production in the desert southwest affect Cd accumulation in the desert.

Studies in Australia have shown high levels of cumulative P fertilization increased the Cd accumulation by crops (Williams and David, 1976). However, another study reported long-term P fertilization from experimental plots in the Midwestern and southern United States did not increase Cd levels in plants (Mortvedt, 1987). Similarly, in England, Cd uptake by crops was only increased by P fertilization in un-limed acid soils (Nicholson et al., 1994). Clearly, Cd does accumulate in agricultural land due to P fertilization but in some cases it may take up to a century or longer for Cd to reach problematic levels in the soil (De Boo, 1990; Modaihsh et al., 2001). Assuming an average P fertilization rate of 600 kg MAP/ha, Cd removal by crops was less than 5% of that applied, indicating a potential for accumulation. Generally, Cd is not leached from soil but much of the Cd added to soil with P fertilizers appears to be irreversibly fixed into non-bioavailable pools (Hamon et al., 1998). Based on preliminary evidence we collected to date, we do not believe P fertilizer is a major source of Cd to our crops. However, we wish to explore this further as an ancillary objective of our intensive sampling.

The objectives of the project were to develop tools and explore management strategies to reduce heavy metals in leafy vegetable crops. Studies included, collecting data aimed toward the development of a soil test that growers can use to predict the potential for soils to produce crops with problematic levels of Pb, Cd; an evaluation of Zn fertilization as a potential strategy to reduce Cd accumulations in leafy vegetable crops, and screen spinach for a possible genetic strategy to reduce heavy metal accumulations in vegetable crops. The project has to potential to enhance competitiveness, through the development of tools to reduce heavy metals concerns by shippers, buyers, and consumers. Survey work collected in a previous SCBG project (SCBG 07) provided data on the status of Arizona vegetable crops with respect to heavy metals. This project sought to develop management tools to reduce heavy metal risk and future compliance challenges.

Project Activities

SOIL TEST EVALUATION

Sampling

Paired composite soil samples were collected from multiple spinach production units in the desert. The planting schedules were obtained from the growers. The cultivar in each planting block was recorded. Soil samples were collected before planting and tissue samples were collected immediately before harvest. The composite soil sample represented 15 to 20 individual samples collected across the production block. The composite tissue samples were also the composite of 15 to 20 sub-samples.

In addition to these paired samples, we collected high resolution soil samples from eight production blocks. This additional sampling was undertaken with additional funding provided by the Yuma Center for Excellence in Desert Agriculture (YCEDA) and the Center for Produce Safety (CPS). These samples were based on points set by a grid or zone sampling scheme. All

grid or zone sample points in each production block were GPS referenced. Each GPS referenced point in all fields represented 7 to 10 composited sub-samples over the area represented by each point. In five of these eight sites, we collected corresponding tissue samples. The tissue samples all represent a composite of 7 to 10 tissue samples over the area represented by each point.

Sample processing

All soil samples collected were placed in an empty greenhouse for drying. All tissue samples were washed with DI water to remove dust, weighed, placed in a sterile paper bag, dried in a drying oven at 65C, and weighed again. These data were used to convert all Cd and Pb data back to a fresh weight basis. Soil and tissue samples are typically ground in metal mechanical mills. However, because we were concerned about potential contamination from these metal mills, all samples were ground by hand in ceramic crucibles.

Soil Analysis

In 2013-2014 we evaluated four soil test extractants including the Mehlich I, the Mehlich III, the DPTA, the Ammonium bicarbonate DPTA, as well as total soil Cd after digestion. The MIII and AB-DPTA are multi-nutrient extractants employed by some commercial soil testing laboratories. Overall, we found the DPTA, AB-DPTA, and the total after digests equally effective for prediction of plant Cd levels. In 2015 and 2016 we focused on the DPTA soil test extractant.

Soils were extracted for metals using the DPTA method (Amacher, 1996). The concentrations of Zn, Cd, and Pb in the extracts was determined using inductively coupled plasma mass spectroscopy. Saturation percentage was used as an estimate of soil texture and was determined as described by Stiven and Khan, (1966). Soil pH was determined according to Thomas, (1996), salinity using the electrical conductance method described by Rhoades et al. (1996), and chloride using the silver titration method described by Frankenberger et al., (1996). Soil P was determined colorimetrically after sodium bicarbonate extraction (Kuo, 1996).

Plant Tissue Analysis

All plant tissue was digested by microwave digestion using nitric acid and peroxide. The Zn, Cd, and Pb concentration were determined using inductively-coupled plasma mass spectroscopy. By convention, tissue concentrations used for nutritional diagnosis are reported on a dry weight (DW) basis. However, concentrations of health concern are reported on a fresh (FW) weight basis since product is consumed fresh. Therefore, we will present Zn concentrations on a dry weight basis and Cd and Pb concentrations on a fresh weight basis.

Statistical Analysis

All data were analyzed using the SAS statistical package (**SAS Institute, 2011**). Relationships between soil tests and plant concentrations were evaluated using regression analysis. Differences in the Zn fertilization studies were evaluated using the ANOVA routine. Correlations between tissue metal concentration and soil properties were evaluated using the PROC CORR routine.

ZINC FERTILZATION STUDIES
These studies were conducted in 2014, 2015 and 2016. Only two or three Zn fertilization studies were budgeted for in this specialty crop block grant. However, with additional funding from YCEDA/CPS we were able to conduct a total of six. All these studies included Zn fertilizer rates of 0, 25, 50, 100, 200, and 400 kg Zn/ha in a randomized complete block design. Yield, soil test Cd, and Zn, and spinach tissue Cd and Zn were determined in all studies.

GENETIC VARIATION STUDIES
We obtained a collection of spinach germplasm from the Plant Introduction Center in Iowa. We augmented this collection with many commercial cultivars currently used Arizona. We used a soil collected in Yuma that we had identified produced spinach with high Cd concentrations. All lines and cultivars were planted into this soils with four replications. At maturity the spinach was harvested and fresh and dry weighs as well as tissue Cd and Zn concentrations were determined.

Goals and Outcomes Achieved

Current Situation with Respect to Compliance

The DPTA soil test Cd and Pb levels and corresponding spinach tissue levels across the desert production region from 2013 to 2016 are shown in Table 1. The European Union (EU) is enforcing maximum levels (MLs) of cadmium in edible tissue of leafy vegetables of 200 µg/kg FW. The FDA has not yet chosen to regulate Cd in food crops but the California Department of Public Health (CDPH) is considering an ML of 550 µg/kg FW (Personal Communication, Western Growers Association). The shippers in California would mandate that all growers in the desert, including those in Arizona, comply with any CDPH ML. Of all the spinach samples we collected from 2013 through 2016, 54% would exceed the EU ML for Cd of 200 ug/kg FW but none would approach the proposed CDPH ML of 550 ug/kg FW (Tables 1 and 3 and Figures 5b and 6b). In fact, less than 2% of the spinach in the desert would exceed concentrations of 400 ug/kg FW Cd.

Many shippers are requiring growers in Arizona to only plant spinach in fields testing less than 2 mg/kg total Cd (personal communication, Yuma growers). For reasons discussed below, we focused on the DPTA soil test rather than total soil Cd. DPTA soil test Cd values are approximately 50% those total Cd levels measured after acid digestion (see Figure 1a and discussion below). The highest values we observe in the desert from DPTA extractions is 0.3 or less mg/kg, and doubling that would be well below the 2 mg/kg total soil Cd soil test threshold mandated by some shippers (Tables 1 and 2 and Figures 2b, 3b, 4b).

The EU has adopted a standard of Pb in leafy vegetables of 300 ug/kg FW. The average Pb concentration of spinach tissue in the desert is 32.5 ug/kg FW (Tables 1and 3 and Figures 5c and 6c). Of all the samples we collected in the desert growing region, less than 0.1% would approach or exceed the EU ML of 300 ug/kg FW. The FDA is currently looking closely at Pb in all food crops and will likely base any compliance thresholds on the FDA PTTI noted above. These are not currently based on MLs but average daily intakes for sensitive sub-populations. An estimate of where we stand with respect to the FDA PTTI would have to be based on dietary exposure estimates calculated from models and the measured spinach Pb concentration data. This is

beyond the scope of this study but is an exercise we plan to undertake in the future as we expand our database.

The soil test Pb levels are more variable than those for Cd (Tables 1 and 2 and Figures 2c, 3c, and 4c). The DPTA soil test Pb levels are approximately 25% of those obtained after acid digestion of the soil (Figure 1b). The EPA soil test guidelines for soil test Pb were developed for urban and industrial contamination (ASTDR, 2011) and are far above the levels we observed.

Cd, Pb, and Soil Testing

As noted above, soil testing is one possible management tool to select fields that have a lower probability of resulting in metal compliance issues. However, a pre-requisite to using soil testing is having a predictive test. As noted above, we evaluated four soil test extractants including the Mehlich I, the Mehlich III, the DPTA, the Ammonium bicarbonate DPTA, as well as total soil Cd after digestion. The MIII and AB-DPTA are multi-nutrient extractants employed by some commercial soil testing laboratories. Overall, we found the DPTA, AB-DPTA, and the total after digests equally effective for prediction of plant Cd levels. The DPTA is currently used by most commercial soil testing laboratories to make metal micronutrient fertilizer recommendations and can be utilized for Cd with minimal expense. The AB-DPTA is not used by most commercial soil testing facilities. Typically, total soil elements are poorly correlated with plant uptake because only a small pool is bioavailable, and total soil contents are rarely used as indices to predict uptake. This does not seem to be the case for Cd where the DPTA and total Cd after digestion are highly correlated (Figure 1). Overall DPTA extraction seems to give values 50% those of Cd levels measured after acid digestion of soil. Some reports in the literature suggest that the DPTA test is a better predictor of plant Cd concentrations than measurements of total Cd because it is a direct measurement of bioavailability. However, based on the limited data we have collected in our studies, both DPTA extractable and total soil Cd seem to be equally reliable. However, acid digests are more costly, result in waste disposal issues, and commercial soil testing laboratories currently use DPTA tests for micronutrient recommendations. Therefore, for logistical and economic reasons, we selected the DPTA test for further evaluation and all subsequent discussion will be based on the DPTA test.

Funding from YCEDA/CPS was used to expand these studies to evaluate spatial variation of Cd, and to a lesser extent Pb, in commercial spinach fields. A summary of the data collected during 2016 are shown in Table 2 and 3. Selected data are plotted in Figures 2, 3, 4, 5, and 6. As expected, soil test variation at the field level is much lower than that across the region, especially for Zn and Cd. The close means and medians shows that data are also generally normally distributed. This lower variation and normal distribution suggest that a good composite representative soil sample can be collected from the 5 to 10 acre spinach production blocks typically used in the region. Nevertheless, it is important that due diligence be implemented to collect good representative samples across the production block. This would involve composting about 20 soil cores collected in a zig-zag pattern across the block. Soil sampling for Pb would present greater challenges. In general the data show more variation and often produced skewed distributions. We may need to explore alternative extractants for Pb.

While the DPTA soil test was among the best evaluated it is far less than perfect. There is variation, suggesting some factors other than just bioavailable Cd affect Cd accumulation by the plants. These may include soil chemical and physical properties as well as plant genetics. These are discussed in more detail below. In order to interpret soil test Cd levels, we need to use probability for making management decisions with respect to compliance challenges. For this we need a target reference point. As noted above, no spinach in the desert seems to accumulate Cd concentrations that approach 550 mg/kg FW. Although we do not generally export spinach into EU markets we will use their ML as an example. As shown in Table 4, to have a 90% and 70% probability that our spinach would be lower than 200 mg/kg Cd FW, we would have to plant into soils that have pre-plant soil test levels of less than 0.1 and 0.125 mg/kg DPTA Cd, respectively. Even planting into soils with 0.125 to 0.15 mg/kg DPTA Cd would result in a 50% chance of producing spinach exceeding 200 ug/kg FW Cd. This limits its application as a management tool, so work was needed to identify other important soil properties affecting spinach Cd concentrations and utilize these data to improve the predictive soil test algorithm.

Cd and Zn

We need to discuss Cd soil testing and plant uptake in relationship to soil and plant zinc nutritional status because as noted above Cd plant accumulation is influenced by Zn. Probability of crop response to Zn fertilization is related DPTA extractable soil test levels. Generally, a growth and yield response is probable when soils DPTA Zn levels are less than 0.5 mg/kg. Responses are possible in the range 0.5 to 1.5 mg/kg and improbable when levels exceed 1.5 mg/kg. A review of all the data we collected in the desert as part of these studies show no sites with DPTA Zn levels <0.5 mg/kg (Tables 1 and 2 and Figures 2a, 3a, and 4a). However, 49% of the sites we sampled were in the range of 0.5 to 1.5 mg/kg where response is possible and the remainder of the sites exceeded 1.5 mg/kg where response is unlikely. A range of 50 to 70 mg/kg Zn in spinach leaves is considered adequate. Of all the sites we sampled, 13% of the spinach samples had Zn leaf concentration less than 50 mg/kg, 39% had Zn leaf concentrations in the range 50 to 75 mg/kg, and the remainder had leaf Zn concentrations exceeding 75 mg/kg (Table 3 and Figures 5a and 6a). Overall, these data indicate that spinach production fields in the desert straddle the margin between Zn adequacy and deficiency with most sites having adequate Zn for crop production.

A simple correlation of spinach Cd concentration to a range of soil properties for all paired soil and tissue samples we collected to date show spinach Cd concentrations negatively correlated to DPTA soil test Zn level (Table 6). In order to explore possible crop responses to Zn and the possibility of Zn fertilization reducing Cd tissue concentrations we conducted six Zn fertilizer experiments in 2015-2016. Three of the six studies resulted in significant yield responses to Zn fertilization, usually to rates lower than 50 kg Zn/ha (Table 5). Although Zn tissue concentration increased in these studies, high rates of Zn fertilization were not particularly effective in reducing Cd concentration to reasonable levels (Figure 7).

Other Soil Factors Affecting Spinach Cd and Pb Concentration

There were no significant relationships between spinach Cd concentration and soil pH. The range of soil pH in all the samples we evaluated ranged from 7.3 to 8.4 (Table 6). As noted above, we did not expect soil pH to be a factor of prevailing importance due to the narrow range

of pH values in desert soils. It should be noted that many of the studies in the literature where pH effects were reported were based on liming acid to neutral soils and all desert soils have free lime. There was no significant correlation to SP, which is an indirect measure of soil texture. Soils we evaluated ranged from loamy sand to silty clay loam. It seems other soil properties are more important in the desert than soil texture.

The negative correlation between spinach Cd concentration and soil test Zn is noted above. Spinach Cd concentrations were also negatively correlated to soil test P. Soil test P would be a reflection of P fertilization history and the MAP fertilizer used in the region contains Cd. However, the amounts of Cd applied with P fertilizer are low relative to the natural soil pool of plant available Cd. It seems the major effect of P in desert soil is to reduce Cd uptake. To what extent this is a result of P rendering Cd less soluble in the soil (Kim et al., 2015) or to antagonize the uptake of Cd by the plant, as it does with Zn, is not known.

Spinach Cd concentrations were positively correlated to DPTA extractable Pb. We believe this is due to the fact that a number of the soil factors that affected Cd uptake also affect Pb uptake. As reported by others (Bingham et al., 1984; Li et al., 1994; Norvell et al., 2000; Khoshgoftarmanesh et al., 2006), spinach Cd concentrations were positively correlated to soil Cl concentrations. Interestingly, it was more strongly correlated to total salinity as determined by electrical conductance, which would include Cl, but also include other salts.

Overall, these data show that in addition to spinach Cd concentrations being correlated to soil test Cd, they were equally negatively and positively correlated to other soil properties routinely measured in soil testing laboratories. This indicates that as we enhance our data base we will be able to use step-wise regression to identify the most important parameters affecting spinach Cd concentrations, and compose a predictive algorithm that provides a much better prediction than soil test Cd alone.

Overall, the situation with Pb is less promising. Of all the soil parameters, only soil test P, in addition to soil test Pb, was correlated to tissue Pb concentrations. As noted above, we may have to explore for additional soil test extractants for Pb.

Genetic Variation

We obtained a collection of spinach germplasm from the Plant Introduction Center in Iowa. Evaluating this collection in a greenhouse study we found significant genetic variation in Cd concentrations (data not shown). This observation is consistent with that reported by others (Grant et al., 2008; Wang et al., 2007) and shows the potential for using plant breeding as a strategy to reduce Cd exposure. However, it also potentially complicates using soil testing as a management tool. In 2014, we began tracking cultivars used in our paired samplings. The number of spinach cultivars used in the desert is large and as of this reporting we have insufficient numbers of all the cultivars utilized to determine if cultivar would significantly confound soil test interpretation. As we continue to enlarge our database we will be able to discern any meaningful differences among commercial cultivars used. Developing a breeding program for reduced Cd or Pb accumulation was beyond the scope of this study.

Summary, Conclusions, and Recommendations

It seems that except for the EU ML, nearly all the soil used for spinach production, and the spinach itself produced in the in the desert, tests below most emerging public and industry self-imposed standards for Cd. The industry in the desert should not be overburdened with excessive sampling and monitoring costs related to Cd compliance at this time. Most spinach in the desert s below the EU ML for Pb and there are no other compliance standards on the immediate horizon. However, the FDA is scrutinizing Pb in all food, and more aggressive monitoring for Pb in the future is likely. Continued research to fully develop a predictive soil test is needed now that we have identified important soil properties affecting Cd uptake. Work is also needed to explore soil test options for Pb, where results were less promising than with Cd. We will continue this effort with funding from a new Arizona Specialty Crop block grant than begins October 1, 2016. The development of this test will provide a short term management solution. A more effective long term solution should be aimed at developing spinach cultivars with a lower propensity for Cd accumulation and this research show genetic variation in spinach germplasm. Implementation of a breeding program was beyond the scope of these studies. The data collected in these studies show that the application of large rates of Zn to mitigate Cd uptake are inconsistent, only marginally effective, and cannot be economically justified. However, more modest rates of Zn fertilizer to correct Zn nutrient deficiencies appears justified for many desert soils.

Beneficiaries

In this study we focused on spinach because the challenges for compliance with existing and emerging industry and governmental standards are more daunting. However, that data set provide a path for mitigating heavy metal challenges for other leafy vegetable crops produced in Arizona.

Because of the anxiety created by current and emerging standards we have been invited to speak on this issue in several venues. In these presentations we shared data generated as part of this project. We made presentations to a total of over 400 individuals but there may have been some whom attended more than one of our presentations. In addition we have been contacted directly by growers and food safety coordinators for many produce companies in the Yuma area. We estimate we have impacted over 90% of the industry.

These individual benefited from the background information regarding emerging regulations, explanations of sampling protocols, and providing mitigation tools to the extant they are developed.

Lessons Learned

We found that Cd accumulation in spinach is related to other soil factors in addition to soil test Cd. Therefore, a simple Cd test is insufficient for predictive purposes. However, the identification of these soil factors provides a path forward in developing a predictive soil test.
Incorporating other important soil test properties into a predictive algorithm is a focus of SCBG which began October 1, 2016.

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Additional Information

Please refer to **Appendix C** for literature cited and all tables and figures referenced in this section.

Nutrient Management of Southwestern Pecans

This project was completed on December 31, 2016

Project Summary

Efficient crop fertilization requires nutrient management that is based on quantitative field research. Otherwise, nutrient over-application can result in waste and environmental degradation, or under-application leading to sub-optimal yields and inefficient use of water resources. To date there have been relatively few studies of nutrient requirements for pecans grown in the desert southwest. We evaluated nitrogen, phosphorus, and zinc demands of newly established Arizona pecan orchards.

In evaluations of early tree growth, we have not seen benefit from nitrogen injected into irrigation water (fertigated) during the growing season at rates ranging from 5 to 270 lb/ac. Arizona orchards apply phosphorus at rates from 5 to 200 lb /ac of P_2O_5. Leaf tissue analyses suggest that most Arizona pecan trees are phosphorus deficient. We applied 0 to 200 lb/ac P_2O_5. Optimum tree growth occurred where 100 lb/ac of P_2O_5 was applied; no improvement was gained from higher application rates. Arizona pecan production usually includes repeated foliar zinc applications, typically between 5 and 13 per season, requiring considerable labor and expense. We have proved that zinc can be successfully supplied to young pecan trees with fertigation. Zinc applications of 2 to 4 lb/ac maximized photosynthesis, growth, and early nut yield.

Project Purpose

Pecan acreage is expanding rapidly and growers are increasingly seeking recommendations for which we do not have research-based information. In light of the recent expansion of pecan acreage, there is a need for orchard nutrient response and nutrient requirement data. Most new plantings rely on pressurized irrigation systems that are appropriate for irrigation injected (fertigated) nutrients, which is the method employed in our studies. Our project explored zinc, phosphorus, and nitrogen requirements of desert-grown pecans during orchard establishment.

Zinc deficiency is prevalent in pecans grown on high pH soils and adequate zinc nutrition is a critical component of commercial pecan production in the desert southwest. Zinc nutrition has traditionally been provided foliar zinc applications (between 4 and 13/year) at a cost of approximately $30/ac for each application. Furthermore, this method does not reliably provide adequate zinc nutrition to all parts of the tree. Previously, we demonstrated the effectiveness of single application of soil-applied chelated zinc (Zn-EDTA) in a greenhouse study and in a field

study in a newly planted commercial orchard. These single applications were effective for a finite length of time. Under a previous Specialty Crop Block Grant (SCBGP-FB-11-05, Zinc Fertigation for Arizona Pecans), we initiated a field study to evaluate repeated fertigation applications of Zn-EDTA in a replicated, scientifically-designed field study. Early results showed the potential for this zinc application method. The current study expands on earlier work by evaluating longer term tree responses, and allowing us to study effects of fertigated zinc on tree growth, photosynthesis rates, plant tissue zinc accumulation, and nut yield and quality.

Field studies of effects of nitrogen and phosphorus fertilization on pecans are surprisingly scarce. Nitrogen is a particularly significant production input, with typical Arizona application rates ranging from 100 to 500 lb N/acre, even though there are no conclusive data documenting tree response. There are no studies that evaluate effects of nitrogen from time of planting to production.

Similarly, significant questions exist concerning phosphorus. Although essentially all Arizona growers apply phosphorus, no one has documented positive effects on tree growth or productivity. On the other hand, leaf tissue analyses suggest that southwestern pecan trees generally lack sufficient phosphorus for optimum performance. According to a survey we conducted of commercial Arizona pecan orchards, average Arizona pecan leaf phosphorus concentrations are 0.13%, compared to recommendations for irrigated pecans of 0.14% to 0.30%.

Specific objectives of this project are

1. To determine nitrogen fertilizer requirements for early establishment of desert pecan orchards. Young trees fertilized with a range of nitrogen rates are evaluated for rate of growth and photosynthesis, and leaf tissue nitrogen concentrations.
2. To determine phosphorus fertilizer requirements for early establishment of desert pecan orchards, to evaluate optimum leaf phosphorus concentrations. Young trees fertilized with a range of phosphorus rates are evaluated for leaf tissue phosphorus concentrations, and growth and photosynthesis rates.
3. To evaluate and demonstrate efficacy of fertigated zinc, evaluate specific fertigation rates, determine optimum leaf zinc concentrations, and to evaluate effects of fertigated zinc on tree growth rate, leaf zinc concentrations, zinc distribution within the tree, photosynthesis, and nut yield and quality.

Project Activities

This project covered the 2015 and 2016 growing seasons and encompassed three separate field trials in San Simon, Arizona. One study evaluated varying nitrogen application rates in a continuous function design (6 fertigated nitrogen levels [0.1 up to 0.6 lb N/inch of trunk diameter/tree], 2 varieties [Western Schley and Wichita], 2 replications). A second studied responses to phosphorus in a randomized complete block design field study (4 rates of fertigated phosphorus [0, 90, 180, 275 lb/acre P_2O_5], 2 varieties [Western Schley and Wichita], 5 replications). The third contained varying rates of zinc application in a randomized complete block design (3 Zn-EDTA fertigation treatments [0, 2, 4 lb/ac Zn], 2 varieties [Western Schley and Wichita], 4 replications).

Each study required design, construction, calibration, repair, maintenance, and operation of nutrient fertigation systems, as well as careful measurement of applied materials. In each study leaf samples were collected and analyzed at least once per season. In the zinc study, branch and root tissues were also collected and analyzed. Individual trees were selected for additional leaf sampling and analysis, as well as photosynthesis rate measurements. Nuts were harvested from trees in the zinc study; trees in the other two studies are too young to bear nuts.

Collected data were statistically analyzed. Results have been presented to grower groups in Arizona and New Mexico. Results have been published in two peer-reviewed publications (in press), four conference proceedings, and one popular press article.

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J.L. Walworth and R. Heerema. 2015. Soil Application of Zinc to Pecans in Calcareous Soils. Western Nutrient Management Conference Proceedings. March 5-6, 2015. Reno, NV. pp. 72-78.

R. Heerema and J. Walworth. 2015. Soil Zinc Applications in the West can Work. Pecan South: 24-27 June, 2015.

Goals and Outcomes Achieved

Evaluate the ability of Zn-EDTA fertigation to supply adequate zinc to trees of nut-bearing age: The performance measures will be leaf zinc concentrations, photosynthesis, tree growth rate, and nut production. Our target is to identify zinc application levels that will eliminate signs of zinc deficiency and maximize plant growth and function.

Our studies have clearly demonstrated that fertigated Zn-EDTA can supply the zinc needs of rapidly growing young pecan trees, eliminate pecan deficiency symptoms, and enhance both nut yield and quality. Photosynthesis rate, tree growth, and nut yield were maximized by fertigation with 2 lb/ac Zn. A minimum leaf zinc concentration of 15 ppm was needed to maximize photosynthesis. Our studies also showed the ability of fertigated zinc to increase tissue zinc concentrations in stems and roots, as well as leaves.

Document tree responses to varying rates of nitrogen and phosphorus: Performance measures will be leaf nitrogen and phosphorus concentrations, and photosynthesis and tree growth rate measurements. Desired outcomes consist of determining application rates that will achieve standard leaf nutrient concentrations (2.5 to 3.2% N; 0.14 to 0.30% P), maintain high photosynthesis rates (>15 µmol C m^{-2} s^{2}), and result in the most rapid tree growth (i.e. to identify optimum fertilization rates).

To date, we have not seen growth or photosynthesis responses or leaf tissue concentration changes in response to nitrogen application. In the phosphorus study, application of phosphorus has generally not changed leaf phosphorus concentrations. Photosynthesis measurements suggest that photosynthesis is maximized with leaf phosphorus concentrations of at least 0.12%. Tree growth was greatest in trees fertilized with at least 100 lb/ac P_2O_5, but could not yet be related to specific leaf phosphorus concentrations.

Refine pecan leaf tissue analysis standards for these three nutrients: Zinc, nitrogen, and phosphorus leaf concentrations resulting in maximum photosynthesis, tree growth, and nut production (in older zinc study trees) will be identified to provide refined leaf tissue standards.

We have demonstrated that the minimum zinc leaf concentration needed to maximize photosynthesis in an individual tree is about 15 ppm; that needed to maximize growth rate and nut yield are about 25 ppm in an orchard block. These are both much lower than the 40 or 50 ppm generally recommended and demonstrate that existing standards are inaccurate. Photosynthesis appears to occur at a minimum leaf phosphorus concentration of 0.12%, somewhat lower than the current recommendation of 0.14%, although more years of data are needed for confirmation. To date, we have not made progress on identifying optimum leaf nitrogen concentrations.

Demonstrate to growers the efficacy of the zinc management we have developed, and encourage broader adoption: The outcome will be gauged by monitoring acreage fertigated with Zn-EDTA. Over ⅔ of sprinkler-irrigated Arizona pecan acreage is managed by about 5 producers; these will be surveyed annually to determine their use of Zn-EDTA. Our target is to have all appropriate pecan acreage using Zn-EDTA.

All of the largest pecan growers in Arizona have adopted zinc fertigation on their orchards equipped with pressurized irrigation systems needed for fertigation, except in organic pecan production where regulations prohibit the use of Zn-EDTA. However, none of these growers have completely abandoned foliar spray applications, and instead use a hybrid system incorporating both fertigation and foliar application. Our long-term goal is to get growers to

replace foliar application with fertigation, for which purpose a demonstration trial is being established on more mature trees in 2017.

The zinc study will be terminated in 2017. The nitrogen and phosphorus studies will continue. It is expected that as the trees in those studies attain greater size their demand for nutrients will increase and that we will see more pronounced responses to fertigated nitrogen and phosphorus so that we can achieve goals associated with those nutrients.

Beneficiaries

Arizona and other desert pecan growers are the primary beneficiaries of this project. In Arizona, there are about 35 commercial pecan producers. Beneficiaries in other areas is difficult to ascertain. We are aware of several New Mexico growers who have changed practices as a result of our studies, however most New Mexico orchards are flood irrigated and thus not appropriate for fertigation. Numerous growers from Sonora, MX have requested information about zinc fertigation and report that they are using this practice.

Growers switching to zinc fertigation benefit economically from the reduced cost of application of fertigated versus foliar-applied zinc. According to one Arizona pecan grower, each individual foliar zinc application costs about $30/ac or between $120 and $360/ac each year. The cost of fertigation is approximately $60/ac annually. We believe that zinc fertigation also results in healthier, better fertilized trees, although this is based on visual observations, and not quantitative measurements.

Fertilizer dealers in Arizona report large increases in sales of Zn-EDTA by pecan growers.

Lessons Learned

The main lesson learned is that pecan trees establish in the field very slowly such that responses in early years are difficult to document. Our broader objective, beyond this project, is to continue the nitrogen and phosphorus studies for several more years. Research on slow growing, long-lived, tree crops may not be achievable in a two or three year study, but may take a longer, concerted effort.

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Pecan and Pistachio Chemical Weed Control

This project was completed on March 31, 2017

Project Summary

Four-year herbicide studies were established at Red Rock Pecans (Pinal County), Green Valley Pecans (Sahuarita, Pima County), Chase Farms (Kansas Settlement, Cochise County) and Robb Farms Pistachios (Kansas Settlement, Cochise County) in 2013. The spring preemergence herbicide treatments were Pindar GT (3 pt./A), Prowl H2O (4 qt./A), Prowl+Chateau (4 qt./A + 6

oz./A), Prowl H2O in spring followed by (fb) Matrix in summer (4 qt./A fb 4 oz./A), Prowl H2O in spring fb Prowl H2O in summer (4 qt./A fb 2 qt./A), and Pindar GT in spring fb Prowl H2O in summer (3 pt./A fb 2 qt./A) and no preemergence herbicide. Plots received the same herbicide treatments each year. Glyphosate (1 qt./A) or glufosinate (4 pt./A) were sprayed to control weed escapes in all plots on an as needed basis. Percent weed control was visually assessed and percent weed ground cover was calculated from digital nadir photographs. The most effective preemergence herbicide treatments were Pindar GT and Prowl H2O + Chateau. Weed populations declined over time due to the use of preemergence herbicides. However, we were unable to consistently reduce the number of annual postemergence herbicide applications where preemergence herbicides were used for logistical reasons.

Project Purpose

Weed control in Arizona's irrigated pecan and pistachio orchards is a significant production problem. Orchard managers over relied on the postemergence herbicide glyphosate, spraying 4 to 8 times per year, for 10 to 20 years. This selected for glyphosate tolerant weed species (e.g., junglerice, sprankletop, little mallow, spurred anoda and lambsquarter) and for glyphosate resistant weeds (e.g., hairy fleabane and Palmer amaranth). The primary objective of this project is to compare the efficacy of long-term preemergence herbicide treatments at four orchard sites and measure declines in weed population densities and the number of postemergence spray operations needed annually. A secondary objective is to evaluate glufosinate as alternative to glyphosate for postemergence weed control in tree nuts. The over-arching goal is to demonstrate effective weed control programs in pecan and pistachios that include a greater diversity of herbicide mechanisms of action. Greater herbicide diversity will minimize the risk of developing herbicide resistant weed populations. Additionally, the studies were designed to determine the most effective herbicides and herbicide programs for tree nut weed management to support Extension recommendations to growers.

Weeds are ubiquitous and are always present in agroecosystems. Modern herbicides are specific in their mechanism of action and usually target a single enzyme or biophysical process. Thus, they exert selection pressure on weed populations that results in herbicide resistant weed populations and species shifts to more difficult to control, tolerant weeds. After 20 years of extensive glyphosate use in Arizona tree and row crops, glyphosate resistant weeds such as Palmer amaranth and hairy fleabane developed in Arizona and are spreading in the state. Many weeds are also now more common because they are naturally tolerant and difficult to control with glyphosate (e.g., little mallow, lambsquarter, Russian thistle and kochia) resulting in weed species population shifts in orchards. This project is timely because of the urgent need to increase the diversity of herbicide mechanisms of action used in Arizona tree crops and the need to control glyphosate resistant and tolerance weed populations.

This project builds upon the results and experience gained in a previous SCBGP pecan project that developed and used nadir photographs to measure percent ground cover in orchards. A digital camera was mounted on a pole and nadir photographs of the ground were taken using a remote shutter trigger. The nadir photographs were analyzed to determine the number green pixels and this data was converted to percent groundcover or weed leaf area based on the total number of pixels in the image and the area visible in the picture. The photographs can be batch

processed using various software programs reducing the time and labor needed to analyze the data. This project in part used nadir photographs along with visual estimates of weed control to determine the efficacy of the various preemergence plus postemergence herbicide programs.

Project Activities

The project activities accomplished during the grant period were essentially as proposed in the activity table in the proposal (see below) although there were delays in the timeline.

Project Activity	Timeline
Spray herbicide treatments, collect and analyze data in year 1 (year 3 of studies)	Spring, summer, fall of 2015
Spray herbicide treatments, collect and analyze data in year 2 (year 4 of studies)	Spring, summer, fall of 2016
Request no-cost extension to June 2017	Summer 2016
Analyze and write final report and Extension Bulletin	November 2016 to March 2017

We successfully applied the preemergence herbicides at all sites and in all years. Since we were working with commercial growers in these experiments, we could not just apply the preemergence herbicides and then allow unchecked weed growth the reminder of the season. Not only would this result in weed seed production and future weed control problems, the first flush of weeds would suppress subsequent weed emergence. Thus, data was collected and then postemergence herbicides were sprayed when the weeds reached a size that would prompt growers to spray their weeds. This periodic weed control allowed more weeds to emerge and allowed us to observe weed emergence throughout out the year. Visual weed control data which was based on both weed ground cover and biomass was collected, in some situations weeds were counted weeds by species in each plot, and several nadir photographs were taken per plot (each photo was a subplot) to determine percent ground cover. Not all types of data were collected at each evaluation date; the situation at the site was assessed to determine the type of data collected. All data were entered into a database program (Agricultural Research Manager) for analysis.

The flood-irrigated Red Rock study site was representative of all study sites although there were nuances that made each site unique. A randomized complete block design with four replications was used at all study sites. Plots sizes were large but were different at each site depending on the planting configuration and field size. The Red Rock plots contained 20 trees that were 0.41 acres in size. The comparison treatment (referred to as the untreated as in untreated with preemergence herbicide) at each site was the grower's weed management strategy of spraying multiple times per year with glyphosate. In this project, the untreated plots were sprayed on as needed basis with glyphosate at 1.125 or 1.5 lb ae/A plus ammonium sulfate at 8.5 lb/100 gallons. The glyphosate rate depended on the size of the weeds at the time we sprayed.
The most objective, straightforward way to follow trends in weed populations over time at the different study sites was to compare the percent ground cover data derived from the nadir photographs. The size of the weeds when the nadir photographs were taken depended on the interval between the last glyphosate application (either when tank mixed with the preemergence herbicides in the spring or the maintenance glyphosate applications later in the year) and the date the picture data was collected. As weeds get larger, percent ground cover does not change in

direct proportion to how much biomass is present. Thus, visual weed control rating are a useful adjunct to evaluating the efficacy of the treatments. In spring and early summer, in the first few months after spraying preemergence herbicides, weed control was generally very good in all preemergence herbicide treatments with the only differences in weed populations being between the "untreated" plots (untreated with preemergence herbicide) versus treatments receiving any of the preemergence herbicides. Later in the summer, particularly after monsoon rainfall began, there were differences between treatments on some dates.

Percent weed ground cover at Red Rock in 2013, 2014, 2015 and 2016 are shown in Tables 1 to 4. Annual cumulative percent ground cover at Red Rock and the 4-year cumulative percent ground cover for Red Rock are show in Table 5. The data indicate that the preemergence treatments with Pindar GT provided significantly better weed control than other treatments. However, on many individual evaluation dates there was little difference between the preemergence herbicide treatments with all of them providing far better weed control than the grower standard practice of not using a preemergence herbicide. Percent weed control was visually estimated at various times at Red Rock to compliment the percent groundcover data (Table 6) and this data was largely consistent with the weed groundcover data.

The percent weed ground cover at Chase Farms in 2013, 2014 and 2015 (Tables 7 and 8) were similar to the data at Red Rock. (A technical problem with processing the 2016 nadir photographs prevented analysis but the problem may be correctable with more work.) The estimates of visual weed control at Chase Farms were largely consistent with the weed groundcover data. Similar to the data collected at Red Rock, the Pindar GT treatments provided the greatest season long reduction in weed populations compared to other preemergence herbicide treatments. Similar results were obtained at Green Valley pecans and at Robb's pistachios although these two study sites had some nuances not present at Red Rock or Chase Farms. For example, at Green Valley Pecans the tree rows were oriented east-west. Thus, the south side of trees received much more sunlight than the north side and purple nutsedge thrived on the south side of the tree line. None of the herbicide treatments used in this experiment were effective on purple nutsedge so we were not able to use nadir photographs on the south side of the trees to quantify weed control. Thus, the visual weed control ratings were more important in comparing treatments along with the nadir photographs and percent groundcover on the north side of the trees. The Robb pistachio site was a course silty loam soil and relatively dry compared to the other sites. The primary weed at this site was Russian thistle.

At Red Rock and Green Valley Pecans, we compared a glyphosate only postemergence herbicide program with one that alternated glufosinate with glyphosate. The limited data that we collected did not show that alternating herbicides provided superior weed control. Rather the performance of either herbicide depended on the species present in the plots at the time that the herbicides were sprayed. The best strategy appeared to be to spray glyphosate early in the season, usually one to 3 applications and then use glufosinate to kill weed species that were tolerant to the glyphosate in early summer. Glufosinate performed better when relative humidity was higher during the monsoon and when there was more sunlight on the orchard floor.

In the first season (2013) of this project as data collection began and we started applying the maintenance postemergence glyphosate sprays, it became clear that we would be unable to treat the control plots on a different schedule from the plots treated with preemergence herbicides. This was primarily due to the logistics of having 4 study sites and being constrained by the irrigation schedule at each of the orchards. It took about five days for the orchard floors to dry enough to support the tractor-mounted sprayer used in this study without causing compaction. In addition, even in the best treatments there were weed escapes. Although there might have been few escaped weeds in some treatments they needed to be sprayed to stop seed production and to be able kill them before they got too big to be susceptible to herbicide treatment. Thus, we were not able to document a reduction in the number of postemergence herbicide sprays during the seasonal although our grower cooperators commented that they thought the preemergence herbicide treatments would save them as least one postemergence herbicide spray per year.

Table 1. Percent weed groundcover at Red Rock Pecans in 2013. The preemergence herbicide treatments were applied on May 21, 2013 and glyphosate was sprayed on 6/14, 7/9, 8/16 and the grower applied of glyphosate at the end of the season (trees were non-bearing in 2013). Data are means ± standard deviations; means in a column followed by the same letter do not significantly differ (P=0.05, Student-Newman-Keuls).

		Red Rock % Ground Cover		
Preemergence Herbicide	Rate	8/9/2013	10/4/2013	Cumulative
	lb ai/a	(%)	(%)	(%)
Untreated	0	7.31 ± 7.29 a	0.77 ± 4.64 a	9.35 ± 7.1 a
Pindar GT	1.5	0.12 ± 0.99 b	0.06 ± 0.51 b	0.21 ± 0.18 b
Prowl H2O	3.8	0.16 ± 0.98 b	0.11 ± 0.96 b	0.32 ± 0.27 b
Prowl H2O Chateau	3.8 0.375	0.14 ± 0.69 b	0.11 ± 1.05 b	0.29 ± 0.29 b
Prowl H2O Matrix	3.8 0.0625	0.16 ± 0.74 b	0.11 ± 2.5 b	0.44 ± 1.42 b
Prowl H2O Prowl H2O (August)	2.85 1.9	0.2 ± 0.77 b	0.17 ± 2.24 b	0.5 ± 1.03 b
Pindar GT Prowl H2O (August)	1.5 1.9	0.16 ± 0.71 b	0.1 ± 0.41 b	0.26 ± 0.12 b

Table 2. Percent weed groundcover at Red Rock Pecans in 2014. The preemergence herbicide treatments were applied on April 8, 2014 and glyphosate was sprayed on 5/24, 6/3, 7/3, 8/4 and 9/5/2014. Data are means ± standard deviations; means in a column followed by the same letter do not significantly differ (P=0.05, Student-Newman-Keuls).

		Red Rock % Ground Cover			
Preemergence Herbicide	Rate	5/23/2014	7/8/2014	8/14/2014	9/15/2014
	lb ai/a	(%)	(%)	(%)	(%)
Untreated	0	1.3 ± 0.2 a	28.6 ± 0.3 a	6.5 ± 0.3 a	1.4 ± 0.3 a
Pindar GT	1.5	0.01 ± 0.008 b	0.05 ± 0.09 b	0.9 ± 0.04	0.05 ± 0.04 b

					a	
Prowl H2O		3.8	0.1 ± 0.04 b	0.19 ± 0.1 b	3.2 ± 0.4 a	0.75 ± 0.24 a
Prowl H2O Chateau		3.8 0.375	0.03 ± 0.04 b	0.44 ± 0.2 b	3.6 ± 0.4 a	1 ± 0.27 a
Prowl H2O Matrix		3.8 0.0625	0.21 ± 0.13 b	0.2 ± 0.1 b	5.8 ± 0.3 a	0.17 ± 0.06 a
Prowl H2O Prowl (August)	H2O	2.85 1.9	0.1 ± 0.05 b	0.2 ± 0.1 b	4.6 ± 0.3 a	0.03 ± 0.009 a
Pindar GT Prowl (August)	H2O	1.5 1.9	0.009 ± 0.004 b	0.26 ± 0.17 b	0.2 ± 0.12 b	0.04 ± 0.015 b

Table 3. Percent weed groundcover at Red Rock Pecans in 2015. The preemergence herbicide treatments were applied on April 29, 2015 and glyphosate was sprayed on 5/14, 6/26, 8/3, and 9/15/2015. Data are means ± standard deviations; means in a column followed by the same letter do not significantly differ (P=0.05, Student-Newman-Keuls); a hyphen indicates the means did not differ within a column.

Preemergence Herbicide	Rate	Red Rock % Ground Cover			
		6/25/2015	8/4/2015	9/8/2015	11/7/2015
	lb ai/a	(%)	(%)	(%)	(%)
Untreated	0	0.85 ± 0.3 a	0.59 ± 0.15 ab	10.14 ± 0.5 ab	0.22 ± 0.09 -
Pindar GT	1.5	0.06 ± 0.03 b	0.02 ± 0.01 b	0.15 ± 0.09 c	0.1 ± 0.06 -
Prowl H2O	3.8	0.07 ± 0.02 b	0.25 ± 0.19 ab	1.92 ± 0.4 bc	0.12 ± 0.05 -
Prowl H2O Chateau	3.8 0.375	0.14 ± 0.06 b	0.18 ± 0.18 ab	2.83 ± 0.39 abc	0.25 ± 0.09 -
Prowl H2O Matrix	3.8 0.0625	0.08 ± 0.07 b	0.95 ± 0.32 ab	6.88 ± 0.38 ab	0.1 ± 0.03 -
Prowl H2O Prowl (August)	H2O 2.85 1.9	0.08 ± 0.05 b	1.21 ± 0.33 a	12.18 ± 0.38 a	0.14 ± 0.04 -
Pindar GT Prowl (August)	H2O 1.5 1.9	0.06 ± 0.02 b	0.03 ± 0.02 b	0.46 ± 0.2 c	0.08 ± 0.04 -

Table 4. Percent weed groundcover at Red Rock Pecans in 2016. The preemergence herbicide treatments were applied on April 13, 2016 and glyphosate was sprayed on 5/13, 6/22, 8/17, and the grower applied glyphosate at the end of the season in 2016. Data are means ± standard deviations; means in a column followed by the same letter do not significantly differ (P=0.05, Student-Newman-Keuls).

Preemergence Herbicide	Rate	Red Rock % Ground Cover		
		5/12/2016	6/22/2016	8/17/2016
	lb ai/a	(%)	(%)	(%)
Untreated	0	0.18 ± 0.08 a	2.4 ± 0.24 a	54.67 ± 0.21 a
Pindar GT	1.5	0.00 ± 0.001 b	0.03 ± 0.02 b	0.07 ± 0.06 c
Prowl H2O	3.8	0.003 ± 0.004 b	0.1 ± 0.05 b	5.35 ± 0.57 b
Prowl H2O Chateau	3.8 0.375	0.005 ± 0.006 b	0.2 ± 0.14 b	5.7 ± 0.48 b
Prowl H2O Matrix	3.8 0.0625	0.005 ± 0.004 b	0.08 ± 0.05 b	5.55 ± 0.42 b
Prowl H2O Prowl H2O (August)	2.85 1.9	0.009 ± 0.007 b	0.1 ± 0.17 b	8.06 ± 0.36 b
Pindar GT Prowl H2O (August)	1.5 1.9	0.002 ± 0.002 b	0.06 ± 0.06 b	0.07 ± 0.06 c

Table 5. Annual and four-year cumulative percent groundcover (2013 to 2016) at Red Rock. See Tables 1-4 for details. Data are means ± standard deviations; means in a column followed by the same letter do not significantly differ (P=0.05, Student-Newman-Keuls).

Preemergence Herbicide	Red Rock Cumulative % Ground Cover				
	2013	2014	2015	2016	4-yr Cumulative
	(%)	(%)	(%)	(%)	(%)
Untreated	9.35 ± 7.1 a	46.5 ± 0.2 a	12.66 ± 0.45 a	58.02 ± 0.2 a	135.93 ± 0.17 a
Pindar GT	0.21 ± 0.18 b	0.24 ± 0.1 c	0.33 ± 0.11 c	0.09 ± 0.06 c	0.82 ± 0.15 c
Prowl H2O	0.32 ± 0.27 b	4.6 ± 0.4 b	2.52 ± 0.4 bc	5.49 ± 0.6 b	12.65 ± 0.5 b
Prowl H2O Chateau	0.29 ± 0.29 b	5.2 ± 0.41 b	3.67 ± 0.36 abc	5.96 ± 0.5 b	14.38 ± 0.44 b
Prowl H2O Matrix	0.44 ± 1.42 b	6.5 ± 0.3 b	8.45 ± 0.36 ab	5.71 ± 0.4 b	21.06 ± 0.31 b
Prowl H2O Prowl H2O (Aug.)	0.5 ± 1.03 b	5.3 ± 0.3 b	14.33 ± 0.35 a	8.11 ± 0.4 b	30.75 ± 0.3 b
Pindar GT Prowl H2O (Aug.)	0.26 ± 0.12 b	0.5 ± 0.18 c	0.65 ± 0.18 c	0.14 ± 0.07 c	1.56 ± 0.26 c

Table 6. Percent weed control at Red Rock based on visual estimates on selected dates in late summer. See Tables 1 for herbicide treatment rates. Data are means ± standard deviations; means in a column followed by the same letter do not significantly differ (P=0.05, Student-Newman-Keuls).

	Red Rock % Weed Control				
Preemergence Herbicide	8/16/2013 Weeds	10/4/2013 Weeds	9/3/14 Weeds	8/17/2016 Broad Leaves	8/17/16 Grasses
	(%)	(%)	(%)	(%)	(%)
Untreated	32 ± 10 b	77 ± 18 b	72 ± 12 c	0 ± 0 e	0 ± 0 c
Pindar GT	96 ± 11 a	98 ± 14 a	92 ± 9 ab	99 ± 0 a	99 ± 0 a
Prowl H2O	94 ± 15 a	98 ± 18 a	75 ± 14 bc	92 ± 7 bc	86 ± 11 b
Prowl H2O Chateau	95 ± 0 a	98 ± 6 a	75 ± 14 bc	95 ± 4 cd	81 ± 7 b
Prowl H2O Matrix	92 ± 23 a	98 ± 9 a	86 ± 5 abc	87 ± 5 cd	76 ± 8 b
Prowl H2O Prowl H2O (Aug.)	90 ± 42 b	92 ± 6 a	98 ± 10 a	83 ± 4 d	69 ± 5 b
Pindar GT Prowl H2O (Aug.)	93 ± 35 b	97 ± 16 a	99 ± 0 a	99 ± 0 a	99 ± 0 a

Table 7. Percent groundcover at Chase Farms in 2013 and 2014. The preemergence herbicide treatments were applied on May 31, 2013 and June 4, 2014 and glyphosate was sprayed on 7/11/13, at the end of the 2013 season by grower, 7/1/14, 8/23/14 and 10/3/214. Data are means ± standard deviations; means in a column followed by the same letter do not significantly differ (P=0.05, Student-Newman-Keuls).

		Chase Farms % Ground Cover	
Preemergence Herbicide	Rate	10/16/2013	6/24/2014
	lb ai/a	(%)	(%)
Untreated	0	1.11 ± 0.15 a	3.13 ± 0.49 a
Pindar GT	1.5	0.316 ± 0.06 b	0.1 ± 0.03 b
Prowl H2O	3.8	0.95 ± 0.2 ab	0.33 ± 0.15 b
Prowl H2O Chateau	3.8 0.375	0.45 ± 0.07 ab	0.28 ± 0.23 b
Prowl H2O Matrix	3.8 0.0625	0.6 ± 0.12 ab	0.32 ± 0.14 b
Prowl H2O Prowl H2O (August)	2.85 1.9	0.56 ± 0.05 ab	0.45 ± 0.19 b
Pindar GT Prowl H2O (August)	1.5 1.9	0.31 ± 0.06 b	0.22 ± 0.14 b

Table 8. Percent groundcover at Chase Farms in 2015. The preemergence herbicide treatments were applied on May 17, 2015 and glyphosate was sprayed on 6/18, 7/16 and 9/19/2015. See Table 7 for herbicide rates. Data are means ± standard deviations; means in a column followed by the same letter do not significantly differ (P=0.05, Student-Newman-Keuls).

	Chase Farms % Weed Ground Cover			
Preemergence Herbicide	6/17/2015	7/7/2015	9/19/2015	2015 Cumulative
	(%)	(%)	(%)	(%)
Untreated	3.16 ± 0.35 a	18.64 ± 0.43 a	18.3 ± 0.3 a	43.2 ± 0.3 a
Pindar GT	0.06 ± 0.02 b	0.11 ± 0.05 b	1.1 ± 0.3 b	1.3 ± 0.27 bc
Prowl H2O	0.1 ± 0.03 b	0.4 ± 0.25 b	2.7 ± 0.41 b	3.33 ± 0.41 bc
Prowl H2O Chateau	0.09 ± 0.05 b	0.15 ± 0.1 b	0.74 ± 0.27 b	0.97 ± 0.29 c
Prowl H2O Matrix	0.09 ± 0.04 b	0.33 ± 0.18 b	2.25 ± 0.32 b	2.71 ± 0.3 bc
Prowl H2O Prowl H2O (Aug.)	0.3 ± 0.12 b	0.7 ± 0.21 b	4.84 ± 0.4 b	5.94 ± 0.37 b
Pindar GT Prowl H2O (Aug.)	0.06 ± 0.02 b	0.11 ± 0.06 b	1.71 ± 0.33 b	1.95 ± 0.31 bc

Table 9. Percent weed control at Chase Farms based on visual estimates on selected dates. Data are means ± standard deviations; means in a column followed by the same letter (or hyphen) do not significantly differ (P=0.05, Student-Newman-Keuls).

		Red Rock % Weed Control			
Preemergence Herbicide	Rate	10/14/2013 Weeds	9/1/2014 Weeds	10/7/2016 Broad Leaves	10/7/16 Grasses
	lb ai/a	(%)	(%)	(%)	(%)
Untreated	0	90 ± 10 bc	10 ± 10 c	54 ± 7 b	76 ± 4 -
Pindar GT	1.5	99 ± 1 a	89 ± 6 a	82 ± 3 a	83 ± 2 -
Prowl H2O	3.8	87 ± 9 c	57 ± 28 b	46 ± 2 b	88 ± 3 -
Prowl H2O Chateau	3.8 0.375	96 ± 2 ab	87 ± 4 a	73 ± 5 ab	86 ± 4 -
Prowl H2O Matrix	3.8 0.0625	93 ± 14 abc	60 ± 24 ab	54 ± 15 b	86 ± 8 -
Prowl H2O Prowl H2O (Aug.)	2.85 1.9	96 ± 3 ab	66 ± 16 ab	73 ± 4 ab	86 ± 2 -
Pindar GT Prowl H2O (Aug.)	1.5 1.9	99 ± 1 a	90 ± 8 a	86 ± 10 a	88 ± 3 -

The research conducted in this project did not benefit crops other than specialty crops. The herbicide performance documented in this project will also be useful to wine grape growers in Arizona.

Goals and Outcomes Achieved

The value of preemergence herbicide use in pecan and pistachio orchards was a goal of the project and was achieved as discussed above. Unfortunately were not able to document a reduction in the number of postemergence herbicide applications per year but our grower cooperators told us that they thought they could save at least one postemergence herbicide spray per season. Herbicide recommendations supported by the data collected in this study were presented to an audience of about 70 people at the 2017 Arizona Pecan Growers Annual Meeting on August 25, 2017 at the Desert Diamond Hotel and Casino in Tucson, AZ (see supplemental file sent with this report **Appendix D**). In addition, the results and recommendation of this study were also presented to an audience of 50 people at the 2016 Western Pecan Production Short Course held in Las Cruces, NM on October 17-19, 2016. The attendees received both a paper copy and electronic copy of the PowerPoint presentation. Lastly, a Cooperative Extension Bulletin on herbicide use in Arizona tree nut crops that contains recommendations based in part on data from this project is being revised and will be resubmitted this spring.

The value of rotating postmergence herbicide mechanism of action in orchard settings was a goal and this was explored in studies as Red Rock and Green Valley Pecans as described above. A set of guidelines for using the products was developed that indicated simply rotating the glyphosate and glufosinate was not the best way to use the herbicides.

The goal of surveying growers about their attitudes regarding herbicide resistance and the value of using preemergence herbicides was not achieved. Although discussions with faculty with expertise in conducting surveys were held, there was an unanticipated time commitment and funding hurdled that could not be met with the funding available in this grant. I remain interested in conducting some sort of survey but I am unsure of how to proceed.

In summary, Pindar GT was the most effective treatment in reducing weed emergence followed by the Prowl + Chateau treatment. The percent groundcover data and visual estimates of weed control across all four study sites were fairly consistent. All of the preemergence herbicide treatments were more effective at reducing weed densities compared to the grower standard practice of using only postemergence herbicides. Any of the spring preemergence herbicide treatments consistently applied over years would perform well. However, the treatments that included sequential preemergence herbicide applications (spring and summer) did not consistently perform better than the spring only preemergence herbicide treatments. Lastly, at Red Rock and Robb Pistachios, weed density appeared to decline over time while at Green Valley Pecans, weed density was about the same each year. This was likely due to the surface irrigation system and the transport of weed seed in irrigation water. We were not able to document that using preemergence herbicides reduced the number of postemergence herbicide sprays needed each season. This was due to the logistics of having four study sites, the time it took the orchard floors to dry after an irrigation and the need to spray weed escapes. However, our grower cooperators commented that they thought the preemergence herbicide treatments

would save them as least one postemergence herbicide spray per year. The data obtained in this project provided important information for producing a draft Cooperative Extension Bulletin on weed management and herbicide use in pecans and pistachios.

At Red Rock and Green Valley Pecans, we compared a glyphosate only postemergence herbicide program with one that alternated glufosinate with glyphosate. The best strategy appeared to be to spray glyphosate early in the season, usually one to 3 applications and then use glufosinate to kill weed species that were tolerant to the glyphosate in early summer. Glufosinate performed better when relative humidity was higher during the monsoon and when there was more sunlight on the orchard floor.

Beneficiaries

The beneficiaries of this project were the pecan and pistachio growers in Arizona. There are about 10 to 12 Pistachio producers (many with multiple owners) primarily located in Cochise County and about 25 to 30 pecan producers mainly in Pinal, Pima and Cochise Counties. As of 2017, there are an estimated 26,000 acres of pecans (14,000 bearing acres) and about 3,000 acres of pistachios. Based on the data collected in this project, tree nuts growers benefitted from educational presentations, conversations at Arizona Pecan Growers Association annual meeting and in one-on-one meetings in their orchards, and through demonstration plots in the experiments in their orchards that lead to adoption. The herbicide recommendations stemming from this project will help growers reduce weed competition in their orchards, provide guidance in the choice of preemergence herbicides, reduce the risk of developing herbicide resistant weed populations by rotating herbicide mechanisms of action and potentially lower their costs.

Lessons Learned

Conducting a good survey of growers is time consuming and expensive. The best approach may be to collaborate with other faculty with expertise in conducting surveys and develop a separate proposal to conduct the survey.

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Spatial/Temporal Sampling of Irrigation Water

This project was completed on December 31, 2015

Project Summary

The quality of irrigation waters drawn from surface water sources can vary greatly. This is particularly true for waters that are subject to intermittent contamination events such as runoff or direct entry of livestock upstream of use. Such pollution in irrigation systems increases the risk of food crop contamination. A single water sample does not adequately characterize the risk potential present in large irrigation systems oft
en utilized in the Southwestern US. This project aimed to define optimal monitoring strategies for irrigation water quality and to develop guidelines for the irrigation of specialty food crops. Following the analysis of 1,361 samples for *Escherichia coli*, the following key irrigation water collection approaches are suggested: 1) Sample before noon; 2) Collect samples at any point across the canal where safe access is available; 3) Collect samples at the water surface; and 4) Composite multiple samples for a single test rather than collecting a single sample/multiple samples tested individually. These recommendations consider the entirety of our data as well as sampling costs, personnel effort, and scientific knowledge of water quality characterization in the Southwest. These guidelines will better characterize risks from contamination in irrigation waters and aid in risk reduction practices for agricultural water.

Project Purpose

Pollution in irrigation systems increases the risk of food crop contamination. Recent guidelines for monitoring irrigation waters are based on epidemiological studies undertaken at ocean and freshwater beaches, despite a lack of evidence linking risk associated with recreational water activities and irrigation waters. Although these guidelines aim to establish science-based standards for agricultural processes, they fail to grasp the complexity of irrigation systems and offer few suggestions for appropriate monitoring of irrigation water safety. Furthermore, these guidelines focus on single grab samples to characterize the risk potential present in large irrigation systems. Multiple studies undertaken in other surface waters have identified differences in microorganism concentrations throughout the vertical and horizontal water columns in addition to changes over time. There are also potentially dangerous ramifications of using a single sample as the basis for management actions (e.g., the opening or closing of a beach). The goal of this study was to assess the spatial and temporal occurrence of microorganisms in irrigation systems to determine the most appropriate sampling strategies that aid in risk reduction practices for agricultural water used for food crops. The specific project objectives were to: 1) determine the appropriate time of day for irrigation water monitoring based on the comparison of morning and afternoon samples collected on the same day, 2) determine the appropriate sample collection point within the canal based on multiple spatial samples collected, 3) determine if it is more appropriate to collect a single sample, multiple samples, or composite samples, and 4) define an overall sampling strategy to include in project outreach.

Project Activities

The project was completed during the time period described in the original proposal. The specific objectives were also accomplished during the project period.

Site locations

Sampling sites were selected following discussions with scientists from the University of Arizona (Tucson, AZ), Maricopa Agriculture Center (Maricopa, AZ), Yuma Agricultural Center (Yuma, AZ), and cooperating grower partners. Twelve sites were sampled in Imperial Valley CA, 12 in Maricopa AZ, and 26 in Yuma AZ. Sampling sites included a mixture of main, lateral, and sub-lateral canals and lined or unlined canals (in Yuma) with varying flow dynamics.

Sample Collection

Grab samples were collected between December 2014 and June 2015 to account for seasonal variations in microbial concentrations, climate variation, crop production, and water use practices using sterilized 1L wide-mouth HDPE bottles (Nalgene Co., Rochester, New York). Depth below surface, distance from the bank, and time of day when and where samples were collected was objective dependent and detailed below. Conductivity, air and water temperature, and total dissolved solids were measured in field using handheld field probes. Samples were placed on ice in a cooler and transported to the Yuma Agriculture Extension (Imperial Valley and Yuma sites) or University of Arizona (Maricopa sites) for microbial processing and additional physical characterization.

Laboratory Analysis

Escherichia coli and total coliforms were enumerated in all water samples using Colilert Quanti-Tray® (IDEXX Laboratories, Westbrook, ME) most probable number (MPN) method following manufacturer instructions. Following incubation at 37°C for 24±2 hours, yellow wells were recorded as positive for total coliforms and wells fluorescing "blue" under UV light were recorded as positive for *E. coli*. All water samples were tested for turbidity, salinity, and pH in the laboratory. Data on environmental variables (air temperature, wind speed and direction, relative humidity, barometric pressure, and antecedent precipitation) are collected continuously at automated weather stations managed as part of The University of Arizona Meteorological Network (AZMET, http://ag.arizona.edu/azmet/, accessed on 10 December 2015). Data for Yuma/Imperial Valley and Maricopa sites were retrieved from stations Yuma Valley and Maricopa, respectively.

Statistical Analysis

All bacterial data were log transformed to minimize the effects of skewed data. Pearson Correlation analysis was used to identify relationships between microbial concentrations and independent variables (e.g., physical, chemical, weather, canal discharge rates). A significance level cutoff of $\alpha = 0.05$ was used for all correlative statistical tests. Stata Statistical Software (StataCorp, College Station, TX) was used for traditional statistical analyses, including Two-sample t-tests and Analysis of Variance (ANOVA) and Kruskal-Wallis tests. Classification And Regression Tree (CART) analysis was used to identify associations between *E. coli* (dependent variable) and the independent hydrological, physical, and environmental variables. Following methods presented by Martin et al. (2011) and Verhougstraete and Rose (2013), CART recursively split dependent variables into homogeneous groups based on analysis of all independent variables using a partitioning algorithm, a 10-fold cross validation criterion, and a minimum stopping criterion of five observations per subgroup (Martin et al. 2011). CART

outputs were trimmed using the one-standard error rule (De'ath and Fabricius 2000). All CART analyses were performed using R software system (R foundation for Statistical Computing).

RESULTS

A total of 1,361 samples were collected and measured for *E. coli*, total coliforms, pH, conductivity, turbidity, dissolved organic solids, and water temperature. Summary results for these water quality measurements are provided in Table 1 and all results are presented in Table S2. Overall, there were 88 unique sites with an average of 15 samples per site. With respect to the latest Food Safety Modernization Act (FSMA), two sites had *E. coli* geometric means > 126 MPN/100ml. When a statistical threshold value (STV) of 410 *E. coli* MPN/100ml was applied to all sites, one site exhibited a 31% violation rate (12/38 samples). Across all sites, statistically significant correlations ($P < 0.001$), although weak, were identified between *E. coli* and air temperature (r = 0.1414), water temperature (r = 0.2472), relative humidity (r = -0.1799), pH (r = 0.1521), and dissolved organic solids (r = -0.1888). While CART analyses were performed for each objective, the results did not provide useful insight into the development of irrigation water monitoring guidelines. Future efforts will include further exploration and analysis of the dataset using CART.

Table 1. Summary statistics of water quality measurements

Region	*E. coli* (MPN/100ml)			Total coliforms (MPN/100ml)			pH	Conductivity	Turbidity	DOS	Temp. air	Temp. water	% relative humidity
	Min	Mean	Max.	Min	Mean	Max.	Mean (min-max)						
Imperial Valley	<1.0	48	1553	211	1255	2420	8.67 (8.28-9.16)	1190 (1145-1232)	4.37 (0.43-213)	845 (813-873)	23.9 (12.3-32.1)	17.0 (12.7-22.2)	34.8 (8.80-87.3)
Maricopa	<1.0	80	1203	102	912	2420	8.63 (8.0-10.9)	1235.6 (810-1720)	10.3 (0.17-405)	876 (580-1220)	22.7 (13.1-31.2)	22.4 (15.6-29.4)	31.9 (7.10-94.5)
Yuma	<1.0	45	2420	77	1256	2420	8.48 (5.28-8.89)	1468 (1099-2260)	7.85 (0.34-817)	847 (561-1440)	29.3 (6.98-47.2)	21.9 (10.8-36.6)	26.8 (2.10-86.3)
TOTAL	<1.0	53	2420	77	1183	2420	8.55 (5.28-10.9)	1360 (810-2260)	7.63 (0.17-817)	854 (561-1440)	26.7 (6.98-47.2)	20.9 (10.8-36.6)	29.6 (2.10-94.5)

Objective 1

For the first objective, grab samples were collected 0.15 m below the water surface near the canal bank at the same site four times per day to determine the appropriate time of day for irrigation water monitoring. Samples (n = 802) were collected at the same location and day at four different time points: 07:00-09:00 (n = 185), 09:00-12:00 (n = 222), 12:00-13:00 (n = 173), and 13:00-16:00 (n = 222). Overall, *E. coli* ranged from 0.5 MPN/100 ml to >2419.6 MPN/100 ml (mean = 64.3 MPN/100 ml). Total coliforms ranged from 77.1 MPN/100 ml to >2419.6 MPN/100 ml (mean = 1199.7 MPN/100 ml). Descriptive statistics for *E. coli* and total coliforms in samples collected for this objective are shown in Table 2. The only statistically significant difference in time of day sampling identified was between morning (07:00-12:00) and afternoon (12:00-16:00) samples (Two-sample t-test: $P < 0.0001$).

Table 2. Time of day statistics

Time of day	*E. coli* (MPN/100ml)			Total coliforms (MPN/100ml)		
	Min.	Arithmetic Mean	Max.	Min.	Arithmetic Mean	Max.
07:00-09:00	<1.0	93.6	>2419.6	137.4	1299.6	>2419.6
09:00-12:00	<1.0	61.6	770.1	102.2	1176.9	>2419.6
12:00-13:00	<1.0	56.3	770.0	77.1	1297.6	>2419.6
13:00-16:00	<1.0	48.9	1203.3	77.1	1063.1	>2419.6

Objective 2

The second objective was to determine the appropriate sample collection point within the canal based on multiple spatial samples taken at cross sections of the canal. For determining specific collection point in a canal cross section, grab samples were collected vertically through the canal water column (at the water surface, 0.61 m below the surface, and 1.22 m below the surface) and horizontally across canal transects (left bank, ¼ of the distance of the canal width from the left bank, ¼ the distance from the right bank, and right bank). A schematic of this sampling approach is presented in Figure 1.

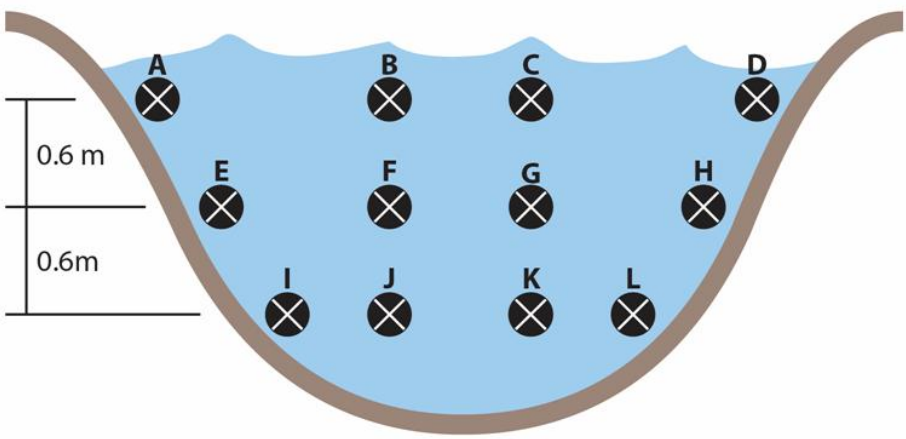

Figure 1. Sampling and labeling schematic for addressing appropriate canal transect sample collection point.

A total of 309 samples were collected under this objective. *E. coli* measures were grouped in all combinations of depth and distance to bank and means were compared. Overall, *E. coli* ranged from <1.0 to 1553.1 MPN/100 ml (geometric mean = 8.1 MPN/100 ml). *E. coli* in the top, middle, and bottom horizontal transects ranged from <1.0 to 1553.1 MPN/100 ml (geometric mean = 18.7 MPN/100 ml), <1.0 to 161.6 MPN/100 ml (geometric mean = 7.7 MPN/100 ml), and <1.0 to 77.6 MPN/100 ml (geometric mean = 3.7 MPN/100 ml), respectively. *E. coli* ranged from <1.0 to 1553.1 MPN/100 ml (geometric mean = 12.8 MPN/100 ml) near the canal banks and from <1.0 to 77.6 MPN/100 ml (geometric mean = 5.30 MPN/100 ml) in the center of the canals. There were no statistically significant differences between any groups (Kruskal-Wallis and ANOVA tests). Descriptive statistics for *E. coli* measurements at cross section points are provided in Table 3.

Table 3. Descriptive statistics for *E. coli* (MPN/100 ml) at each spatial point in canal cross sections

ID	Vertical / Horizontal Position	N	Minimum	Mean	Maximum	Std. Dev.	Median
A	Top / Left Bank	24	3	429.1	1553	519.9	129.0
D	Top / Right Bank	25	16	73.1	152	43.8	48.8
B	Top / Left Center	25	1	10.6	36	9.4	7.5
C	Top / Right Center	25	1	15.3	47	15.8	16.9
E	Middle / Left Bank	25	5	65.8	162	43.5	52.0
H	Middle / Right Bank	25	1	3.5	14	3.6	2.0
F	Middle / Left Center	35	2	7.0	15	3.1	6.3
G	Middle / Right Center	25	1	8.4	17	4.4	8.6
I	Bottom / Left Bank	25	1	4.2	11	2.3	4.1
L	Bottom / Right Bank	24	1	5.7	13	4.6	4.1
J	Bottom / Left Center	26	1	4.6	16	4.3	4.8
K	Bottom / Right Center	25	1	9.7	78	14.6	7.4
Total		**309**	**1**	**50.4**	**1553**	**182.1**	**7.3**

Objective 3

To determine the best collection, processing, and results representation approach, samples were collected in parallel to each other and perpendicular to the flow of the irrigation water. Three sample approaches were incorporated as part of this objective (Figure 2). Approach 1 included collecting a single sample from a single collection point and assayed individually in the laboratory. Approach 2 involved collecting five samples from the same canal stretch (2 m apart) and assaying each sample individually in the laboratory then calculating a geometric mean of the five individual samples. Approach 3 involved collecting five samples from the same canal stretch (2 m apart) then adding equal volumes of well-mixed aliquots from each discrete sample to a sterile bottle to form a composite sample. The composite sample was then assayed identically to a single sample and reported as a single value.

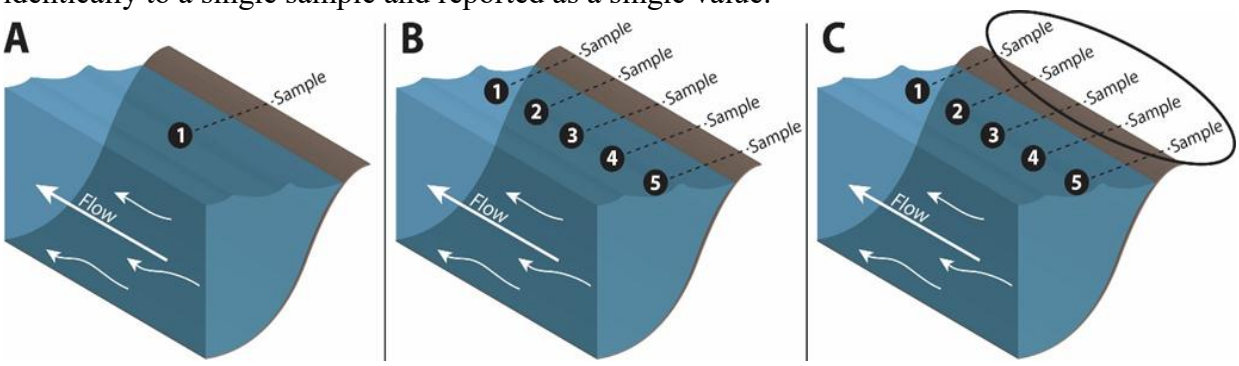

Figure 2. Sampling schematic for addressing A) single sample, B) multiple samples, assayed individually then calculate geometric mean, and C) composite samples into a single sample and assay

A total of 250 samples were collected under this objective. There was no statistically significant difference between the three types of samples (i.e., a single sample, the geometric mean of five samples, or a composite sample). However, when comparing individual groups, statistical differences were identified between a single sample and a composite sample ($P = 0.036$) and the geometric mean of five samples and a composite sample ($P = 0.005$) as shown in the box and whisker plot in Figure 3. Monitoring approaches that collect a single water sample typically will fail to meet a very broad coefficient of variation. However, collecting and processing multiple samples to provide adequate representation of water quality may be cost prohibitive. A composite sample is an alternative to single sample or multiple sample approaches.

In the current study, a composite sample appears to be more representative of the water quality within a canal than either a single sample or multiple samples in that it provides more information than a single sample while minimizing the effects of outlying data (high or low bacterial numbers that can lead to a misrepresentation of the water quality in a single sample or in multiple samples that are heavily influenced by one sample with outlying numbers). In addition, a composite sample requires only nominally more time and money compared to a single sample.

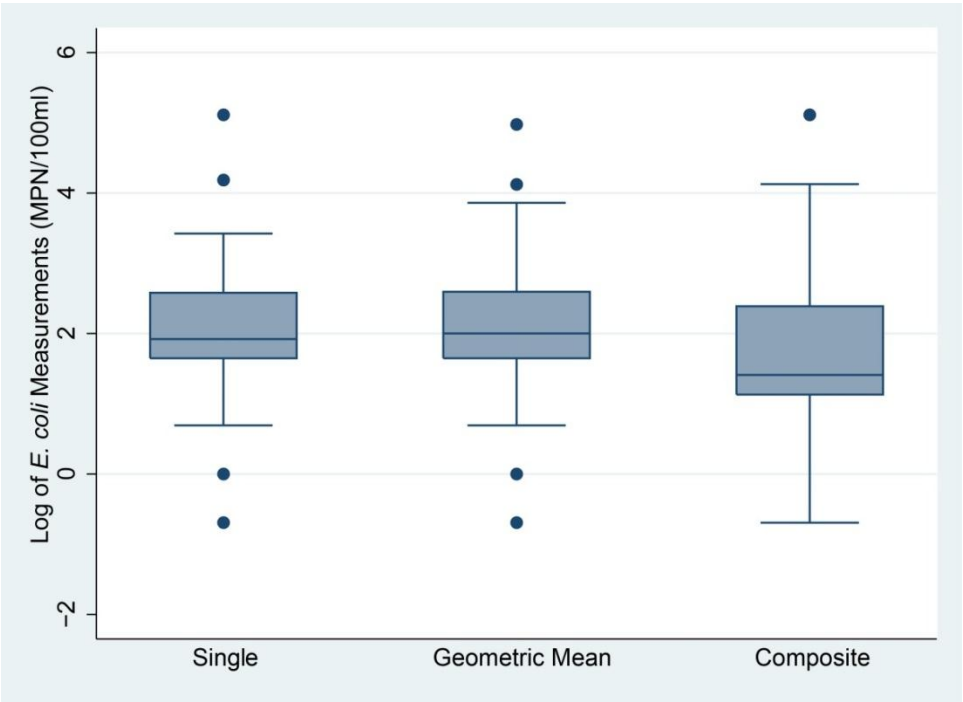

Figure 3. Box and whisker plot of *E. coli* measurements from 1) single sample, 2) geometric mean of five samples, and 3) a composite of five samples. The box represents the 25th and 75th percentiles; the horizontal line within the box represents the median concentration; the vertical

lines extending from each box represent the range of *E. coli* concentrations (excluding outliers); and the dots represent outliers.

Goals and Outcomes Achieved

All of the goals of this project were achieved during the project period. A total of 1,361 samples were collected and examined for *E. coli*. This is more than the number originally proposed (1,240). A total of 802 samples were collected under objective 1 (800 proposed), 309 samples were collected under objective 2 (240 proposed), and 250 samples were collected under objective 3 (200 proposed). The increased sample sizes provided additional scientific support to the recommended guidelines. The final and most important objective was to define an overall sampling strategy that produces the most relevant data for determining the risks of microbial pathogen contamination of food crop waters by taking a comprehensive examination of the data gathered in objectives 1 through 3. Cumulatively, our data suggests microbial water quality is homogenous in short spatial scales (e.g., canal transects), but varies temporally (morning and afternoon). Through careful consideration of the entirety of our data as well as sampling costs, personnel effort, and scientific knowledge of water quality characterization, we suggest all open canal irrigation water sampling in the Southwest Region be undertaken with the following measures:

- Sample before noon (significantly higher bacterial numbers)
- Collect samples at any point across the canal where safe access is available
- Collect samples at the surface of the water (On average higher bacterial numbers)
- Composite multiple samples for a single test (no statistical difference between the geometric mean of 5 samples and a single sample). Composite samples yield better representation of water quality while keeping costs low.

In general, we recommend adopting a conservative approach of sampling at locations and times where higher bacterial numbers are expected (based on the project data) to ensure that specialty crop growers are confident of the quality of the water they are using to irrigate food crops.

Outreach efforts are currently underway. We will be meeting with numerous growers in Yuma over the next few months to share the results of this study. We are also currently working on a flyer containing the results and our subsequent recommendations (English and Spanish versions) that will be distributed to growers / producers in the southwest region of the US. We felt the results and suggested guidelines would have the greatest impact on growers and farmers if they were thus made readily available in a simple format. This pamphlet clearly informs them of our proposed best monitoring strategies for irrigation water use.

These guidelines will eventually be conveyed to regional and national stakeholders via websites/social media, an informational text service through the University of Arizona's Yuma Agricultural Center, and presentation of findings in peer-reviewed scientific journals and at national and regional conferences related to food safety. A peer reviewed manuscript of this work is in preparation and will be submitted by the summer of 2016 to the Journal of Total Environment.

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Beneficiaries

California ranks first in the nation for numerous specialty crops; Arizona ranks third in the production of fresh vegetables and second in the production of lettuce, broccoli, spinach, and melons. Approximately 55% of cash receipts from Arizona commodities are from crops. This work will benefit growers of various leafy greens, carrots, melons, and broccoli in the Southwest agricultural regions. It also has generated data and recommendations that can be used nationally by growers utilizing surface water for irrigation purposes. This information will benefit the approximately 1,750 Arizona farms growing specialty crops. In addition, farmers of specialty crops in other states will also be benefitted, but the number is difficult to measure accurately, but will likely measure in the thousands.

Lessons Learned

It is important to have regular meetings with project collaborators to ensure that the project is completed on time and to discuss any problems or difficulties that have arisen during the field collection of samples. Such meetings help with problem solving / resolution and making sure that everyone is on the same page.

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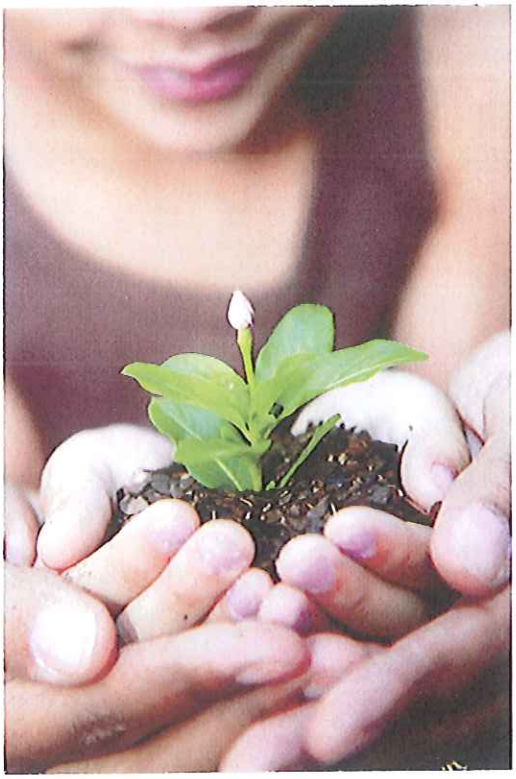
Appendix A
referenced on page 31



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Appendix B
referenced on page 76 and 83

Table 1.8. Mean Turfgrass quality at six KC [ET(0) replacement] levels for three seeded buffalograss cultivars in a Linear Irrigation Gradient design, August to October 2016. University of Arizona.

grass	SPECIES	Kc	8-Aug	31-Aug	20-Sep	5-Oct	15-Oct	20-Oct
			|---------- Quality ----------|					
|------ Bison -----|	Buffalograss	25%	7.3	5.3	5	3	3.3	3
		35%	7.5	6	5.8	5	4.8	4.8
		45%	7	6.3	6	5.3	5.3	5.5
		55%	6.5	6.5	6.8	6.3	6.3	6.3
		65%	6	7	6.8	6.3	6.5	6.3
		75%	6.3	6.8	7	6.8	6.5	7.3
		Test mean	6.8	6.3	6.2	5.4	5.4	5.5
		LSD	ns	1.1	1.2	0.9	1.1	1.3
|---- Top gun ----|	Buffalograss	25%	7.8	6	5.3	3.5	3.8	3.5
		35%	7.8	6.3	6	4.8	4.8	4.8
		45%	7	6.8	6.5	5.8	5.5	5.5
		55%	6.8	7	6.5	6.3	6	6
		65%	6.3	6.8	7	7	6.3	6.8
		75%	6.5	7.3	6.8	7	6.5	6.3
		Test mean	7	6.7	6.3	5.7	5.5	5.5
		LSD	1	ns	1	1.4	1.5	1.3
|-- Sundancer --|	Buffalograss	25%	8.3	6.5	5.3	3.5	3	3
		35%	8.5	7	6	4.5	4	4.3
		45%	8.5	8	7	6.3	5.8	5.5
		55%	8	8	6.8	7	6.3	6.3
		65%	7.8	8	7	7	6.8	7
		75%	7.8	8	7.8	7	6.8	6.8
		Test mean	8.1	7.6	6.6	5.9	5.4	5.5
		LSD	ns	0.7	0.9	1.1	1.1	1.2

1 Quality (1-9). 1= dead, 4= poor, 5= marginal, 6= acceptable 9=best possible. Values are the mean of 4 replications.
2 Test mean = mean of all quality values across all ET(0) replacement value levels.
3 LSD= least significant difference statistic, mean separation value. Means which differ in absolute value greater than the LSD are statistically different from each other.

Table 1.8 *(contn'd)* Mean Turfgrass quality at six KC [ET(0) replacement] levels for four seeeded bermudagrass cultivars in a Linear Irrigation Gradient design, August to October 2016. University of Arizona.

grass	SPECIES		|---------- Quality ----------|					
			8-Aug	31-Aug	20-Sep	5-Oct	15-Oct	20-Oct
|-- Cheyenne 2 --|	Bermudagrass	25%	6	5	4.3	3	3	3
		35%	6.3	5.8	5	4	3.8	3.5
		45%	5.8	6.8	6.3	5.8	5	5
		55%	6.5	6.8	6.3	6.3	5.8	6.3
		65%	6	6.5	7	6.5	6.3	6.3
		75%	6.5	7.5	6.8	7	6.3	6.3
		Test mean	6.2	6.4	5.9	5.4	5	5
		LSD	ns	1.1	1	0.9	0.7	1.1
|--- NewMex ---|	Bermudagrass	25%	6.5	5.5	5	3.3	3	2.8
		35%	5.8	5.8	5.5	4.3	3.5	4.3
		45%	7	6.5	6.3	5.3	4.8	5
		55%	6.3	6.8	6.8	5.8	6	5.8
		65%	6.5	7	6.8	6.5	6.3	5.8
		75%	6.3	7.5	7	6.3	6.3	6.5
		Test mean	6.4	6.5	6.2	5.2	5	5
		LSD	ns	0.9	1.2	0.7	0.8	1.3
|--- Jackpot ---|	Bermudagrass	25%	6.5	5.8	4.8	3.8	3	3
		35%	6.8	6	5.5	4.5	4	3.8
		45%	6.5	6.3	6	5.3	5	4.8
		55%	6.3	7	7	6.3	5.8	5.5
		65%	6.8	7.3	6.8	6.8	6	6.5
		75%	6.3	8	6.8	7.3	6.8	6.8
		Test mean	6.5	6.7	6.1	5.6	5.1	5
		LSD	ns	0.7	0.7	0.8	0.6	0.9
|--- Wrangler ---|	Bermudagrass	25%	8.5	6	5.8	4.5	3.8	3.8
		35%	8	6.3	6.5	5.5	5.3	5.3
		45%	7.5	6.3	6.5	5.8	6	5.8
		55%	7.3	6.8	6.8	6.8	6.5	6.3
		65%	6.8	7.3	7	6.8	6.5	6.3
		75%	6.5	7.8	7.5	7.5	6.8	6.3
		Test mean	7.4	6.7	6.7	6.1	5.8	5.6
		LSD	1.2	0.5	ns	0.9	1.1	1.1

1 Quality (1-9). 1= dead, 4= poor, 5= marginal, 6= acceptable 9=best possible. Values are the mean of 4 replications.

2 Test mean = mean of all quality values across all ET(0) replacement value levels.

3 LSD= least significant difference statistic, mean separation value. Means which differ in absolute value greater than the LSD are statistically different from each other.

Table 2.8. Mean quality values of seven cultivars of buffalograss and bermudagrass at each of six ET(0) Kc irrigation replacement values. August to October 2016. University of Arizona.

Kc	grass	SPECIES	8-Aug	31-Aug	20-Sep	5-Oct	15-Oct	20-Oct
			|---------- Quality	----------	----------	----------	----------	----------|
25%	Cheyenne 2	bermudagrass	6	5	4.3	3	3	3
	Jackpot		6.5	5.8	4.8	3.8	3	3
	NewMex		6.5	5.5	5	3.3	3	2.8
	Wrangler		8.5	6	5.8	4.5	3.8	3.8
	Bison	buffalograss	7.3	5.3	5	3	3.3	3
	Sundancer		8.3	6.5	5.3	3.5	3	3
	Top gun		7.8	6	5.3	3.5	3.8	3.5
	test mean		**7.3**	**5.7**	**5**	**3.5**	**3.3**	**3.1**
	LSD		**1.2**	**0.8**	**ns**	**ns**	**ns**	**ns**
35%	Cheyenne 2	bermudagrass	6.3	5.8	5	4	3.8	3.5
	Jackpot		6.8	6	5.5	4.5	4	3.8
	NewMex		5.8	5.8	5.5	4.3	3.5	4.3
	Wrangler		8	6.3	6.5	5.5	5.3	5.3
	Bison	buffalograss	7.5	6	5.8	5	4.8	4.8
	Sundancer		8.5	7	6	4.5	4	4.3
	Top gun		7.8	6.3	6	4.8	4.8	4.8
	test mean		**7.2**	**6.1**	**5.8**	**4.6**	**4.3**	**4.4**
	LSD		**1.2**	**ns**	**ns**	**0.9**	**0.9**	**1**
45%	Cheyenne 2	bermudagrass	5.8	6.8	6.3	5.8	5	5
	Jackpot		6.5	6.3	6	5.3	5	4.8
	NewMex		7	6.5	6.3	5.3	4.8	5
	Wrangler		7.5	6.3	6.5	5.8	6	5.8
	Bison	buffalograss	7	6.3	6	5.3	5.3	5.5
	Sundancer		8.5	8	7	6.3	5.8	5.5
	Top gun		7	6.8	6.5	5.8	5.5	5.5
	test mean		**7**	**6.7**	**6.4**	**5.6**	**5.3**	**5.3**
	LSD		**1.3**	**0.9**	**ns**	**ns**	**0.6**	**ns**

1 Quality (1-9). 1= dead, 4= poor, 5= marginal, 6= acceptable 9=best possible. Values are the mean of 4 replications.

2 Test mean = mean of all quality values across all grass cultivars.

3 LSD= least significant difference statistic, mean separation value. Means which differ in absolute value greater than the LSD are statistically different from each other.

Table 2.8 (contn'd). Mean quality values of seven cultivars of buffalograss and bermudagrass at each of six ET(0) Kc irrigation replacement values. August to October 2016. University of Arizona.

Kc	grass	SPECIES	8-Aug	31-Aug	20-Sep	5-Oct	15-Oct	20-Oct
			|---------- Quality ----------|					
55%	*Cheyenne 2*	*bermudagrass*	6.5	6.8	6.3	6.3	5.8	6.3
	Jackpot		6.3	7	7	6.3	5.8	5.5
	NewMex		6.3	6.8	6.8	5.8	6	5.8
	Wrangler		7.3	6.8	6.8	6.8	6.5	6.3
	Bison	buffalograss	6.5	6.5	6.8	6.3	6.3	6.3
	Sundancer		8	8	6.8	7	6.3	6.3
	Top gun		6.8	7	6.5	6.3	6	6
	test mean		**6.8**	**7**	**6.7**	**6.4**	**6.1**	**6**
	LSD		**1.1**	**0.5**	**ns**	**ns**	**ns**	**ns**
65%	*Cheyenne 2*	*bermudagrass*	6	6.5	7	6.5	6.3	6.3
	Jackpot		6.8	7.3	6.8	6.8	6	6.5
	NewMex		6.5	7	6.8	6.5	6.3	5.8
	Wrangler		6.8	7.3	7	6.8	6.5	6.3
	Bison	buffalograss	6	7	6.8	6.3	6.5	6.3
	Sundancer		7.8	8	7	7	6.8	7
	Top gun		6.3	6.8	7	7	6.3	6.8
	test mean		**6.6**	**7.1**	**6.9**	**6.7**	**6.4**	**6.4**
	LSD		**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
75%	*Cheyenne 2*	*bermudagrass*	6.5	7.5	6.8	7	6.3	6.3
	Jackpot		6.3	8	6.8	7.3	6.8	6.8
	NewMex		6.3	7.5	7	6.3	6.3	6.5
	Wrangler		6.5	7.8	7.5	7.5	6.8	6.3
	Bison	buffalograss	6.3	6.8	7	6.8	6.5	7.3
	Sundancer		7.8	8	7.8	7	6.8	6.8
	Top gun		6.5	7.3	6.8	7	6.5	6.3
	test mean		**6.6**	**7.5**	**7.1**	**7**	**6.5**	**6.6**
	LSD		**ns**	**ns**	**ns**	**ns**	**ns**	**ns**

1 Quality (1-9). 1= dead, 4= poor, 5= marginal, 6= acceptable 9=best possible. Values are the mean of 4 replications.

2 Test mean = mean of all quality values across all grass cultivars.

3 LSD= least significant difference statistic, mean separation value. Means which differ in absolute value greater than the LSD are statistically different from each other.

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Table 8 . Inches irrigation applied, percent change in soil moisture, inches soil water extracted, and total water used from August 3rd to October 22nd, 2016.

grass	Kc LEVEL	SPECIE	Inch irrigation Applied	% VWC extracted	Inch water extracted	Inch total water used
Bison	25	**Buffalograss**	**3.8**	**17.3**	**2.1**	**5.9**
Top gun		**Buffalograss**	**3.8**	**18.5**	**2.2**	**6.0**
Sundancer		**Buffalograss**	**3.8**	**18.4**	**2.2**	**6.0**
Cheyenne II		**Bermudagrass**	**3.8**	**17.7**	**2.1**	**5.9**
Nu-Mex		**Bermudagrass**	**3.8**	**17.4**	**2.1**	**5.9**
Jackpot		**Bermudagrass**	**3.8**	**14.1**	**1.7**	**5.5**
Wrangler		**Bermudagrass**	**3.8**	**15.9**	**1.9**	**5.7**
Test mean			**3.8**	**17.0**	**2.0**	**5.8**
LSD				**2.2**	**0.3**	**0.3**
Bison	35	**Buffalograss**	**5.3**	**15.3**	**1.8**	**7.2**
Top gun		**Buffalograss**	**5.3**	**16.4**	**2.0**	**7.3**
Sundancer		**Buffalograss**	**5.3**	**15.2**	**1.8**	**7.2**
Cheyenne II		**Bermudagrass**	**5.3**	**16.3**	**2.0**	**7.3**
Nu-Mex		**Bermudagrass**	**5.3**	**14.7**	**1.8**	**7.1**
Jackpot		**Bermudagrass**	**5.3**	**14.8**	**1.8**	**7.1**
Wrangler		**Bermudagrass**	**5.3**	**16.1**	**1.9**	**7.3**
Test mean			**5.3**	**15.5**	**1.9**	**7.2**
LSD				**ns**	**ns**	**ns**
Bison	45	**Buffalograss**	**6.8**	**13.9**	**1.7**	**8.5**
Top gun		**Buffalograss**	**6.8**	**14.9**	**1.8**	**8.6**
Sundancer		**Buffalograss**	**6.8**	**12.0**	**1.4**	**8.3**
Cheyenne II		**Bermudagrass**	**6.8**	**14.3**	**1.7**	**8.6**
Nu-Mex		**Bermudagrass**	**6.8**	**13.2**	**1.6**	**8.4**
Jackpot		**Bermudagrass**	**6.8**	**13.0**	**1.6**	**8.4**
Wrangler		**Bermudagrass**	**6.8**	**11.2**	**1.3**	**8.2**

Table 8 (contn'd) . Inches irrigation applied, percent change in soil moisture, inches soil water extracted, and total water used from August 3rd to October 22nd, 2016.

Test mean			6.8	13.2	1.6	8.4
LSD				ns	ns	ns
Bison	55	Buffalograss	8.4	10.9	1.3	9.7
Top gun		Buffalograss	8.4	9.7	1.2	9.5
Sundancer		Buffalograss	8.4	7.3	0.9	9.2
Cheyenne II		Bermudagrass	8.4	11.3	1.4	9.7
Nu-Mex		Bermudagrass	8.4	8.8	1.1	9.4
Jackpot		Bermudagrass	8.4	10.7	1.3	9.7
Wrangler		Bermudagrass	8.4	9.4	1.1	9.5
Test mean			8.4	9.7	1.2	9.5
LSD				ns	ns	ns
Bison	65	Buffalograss	9.9	6.3	0.8	10.6
Top gun		Buffalograss	9.9	8.3	1.0	10.9
Sundancer		Buffalograss	9.9	4.9	0.6	10.5
Cheyenne II		Bermudagrass	9.9	6.4	0.8	10.7
Nu-Mex		Bermudagrass	9.9	5.7	0.7	10.6
Jackpot		Bermudagrass	9.9	6.2	0.7	10.6
Wrangler		Bermudagrass	9.9	6.7	0.8	10.7
Test mean			9.9	6.3	0.8	10.7
LSD				ns	ns	ns
Bison	75	Buffalograss	11.4	6.6	0.8	12.2
Top gun		Buffalograss	11.4	5.1	0.6	12.0
Sundancer		Buffalograss	11.4	3.0	0.4	11.8
Cheyenne II		Bermudagrass	11.4	3.6	0.4	11.8
Nu-Mex		Bermudagrass	11.4	5.2	0.6	12.0
Jackpot		Bermudagrass	11.4	4.0	0.5	11.9
Wrangler		Bermudagrass	11.4	5.1	0.6	12.0
Test mean			11.4	4.6	0.6	12.0
LSD				ns	ns	ns

Inches applied = Reference ET X (Kc) replacement level as applied by LIGA field design.

% change in soil moisture= VWC beginning-VWC end in 12 inches soil root depth.

Extract (in) = amount of water removed from root zone from Aug 3rd to Oct 22, 2016.

Total water use = Inches applied + Extracted (in).

Table 9 (contn'd). Inches irrigation applied, percent change in soil moisture, inches soil water extracted, and total water used from August 3rd to October 22nd, 2016.

Nu-Mex	Bermudagrass	25	3.8	17.4	2.1	5.9
		35	5.3	14.7	1.8	7.1
		45	6.8	13.2	1.6	8.4
		55	8.4	8.8	1.1	9.4
		65	9.9	5.7	0.7	10.6
		75	11.4	5.2	0.6	12.0
Test mean			7.6	10.8	1.3	8.9
LSD			N.A.	2.3	0.3	0.3
Sundancer	Buffalograss	25	3.8	18.4	2.2	6.0
		35	5.3	15.2	1.8	7.2
		45	6.8	12.0	1.4	8.3
		55	8.4	7.3	0.9	9.2
		65	9.9	4.9	0.6	10.5
		75	11.4	3.0	0.4	11.8
Test mean			7.6	10.1	1.2	8.8
LSD			N.A.	3.5	0.4	0.4
Top gun	Buffalograss	25	3.8	18.5	2.2	6.0
		35	5.3	16.4	2.0	7.3
		45	6.8	14.9	1.8	8.6
		55	8.4	9.7	1.2	9.5
		65	9.9	8.3	1.0	10.9
		75	11.4	5.1	0.6	12.0
Test mean			7.6	12.1	1.5	9.1
LSD			N.A.	4.4	0.5	0.5
Wrangler	Bermudagrass	25	3.8	15.9	1.9	5.7
		35	5.3	16.1	1.9	7.3
		45	6.8	11.2	1.3	8.2
		55	8.4	9.4	1.1	9.5
		65	9.9	6.7	0.8	10.7
		75	11.4	5.1	0.6	12.0
Test mean			7.6	10.7	1.3	8.9
LSD			N.A.	2.6	0.3	0.3

Inches applied = Reference ET X (Kc) replacement level as applied by LIGA field design.
% change in soil moisture= VWC beginning-VWC end in 12 inches soil root depth.
Extract (in) = amount of water removed from root zone from Aug 3rd to Oct 22, 2016.
Total water use = Inches applied + Extracted (in.)

Table 9. Inches irrigation applied, percent change in soil moisture, inches soil water extracted, and total water used from August 3rd to October 22nd, 2016.

grass	SPECIE	Inch irrigation Applied	Inch irrigation Applied	% VWC extracted	Inch total water used	Inch total water used
Bison	**Buffalograss**	**25**	**3.8**	**17.3**	**2.1**	**5.9**
		35	**5.3**	**15.3**	**1.8**	**7.2**
		45	**6.8**	**13.9**	**1.7**	**8.5**
		55	**8.4**	**10.9**	**1.3**	**9.7**
		65	**9.9**	**6.3**	**0.8**	**10.6**
		75	**11.4**	**6.6**	**0.8**	**12.2**
Test mean			**7.6**	**11.7**	**1.4**	**9.0**
LSD			N.A.	**5.0**	**0.6**	**0.6**
Cheyenne II	**Bermudagrass**	**25**	**3.8**	**17.7**	**2.1**	**5.9**
		35	**5.3**	**16.3**	**2.0**	**7.3**
		45	**6.8**	**14.3**	**1.7**	**8.6**
		55	**8.4**	**11.3**	**1.4**	**9.7**
		65	**9.9**	**6.4**	**0.8**	**10.7**
		75	**11.4**	**3.6**	**0.4**	**11.8**
Test mean			**7.6**	**11.6**	**1.4**	**9.0**
LSD			N.A.	**3.5**	**0.4**	**0.4**
Jackpot	**Bermudagrass**	**25**	**3.8**	**14.1**	**1.7**	**5.5**
		35	**5.3**	**14.8**	**1.8**	**7.1**
		45	**6.8**	**13.0**	**1.6**	**8.4**
		55	**8.4**	**10.7**	**1.3**	**9.7**
		65	**9.9**	**6.2**	**0.7**	**10.6**
		75	**11.4**	**4.0**	**0.5**	**11.9**
Test mean			**7.6**	**10.5**	**1.3**	**8.9**
LSD			N.A.	**1.6**	**0.2**	**0.2**

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Tables and Figures

Table 1. Metal concentrations of soil and spinach produced in paired soil and tissue samples collected over three growing seasons.

Season	Number	Metal	Mean	Standard Deviation of Mean	Median	Minimum	Maximum
Soil DPTA (mg/kg)							
2013-2014	25	Cd	0.11	0.04	0.10	0.04	0.19
		Pb	1.51	1.29	1.29	0.19	4.86
2014-2015	45	Zn	1.89	0.79	1.57	1.09	3.82
		Cd	0.13	0.02	0.13	0.07	0.17
		Pb	1.38	0.67	1.16	0.31	3.50
2015-2016	76	Zn	1.49	0.54	1.33	0.74	3.41
		Cd	0.16	0.05	0.15	0.07	0.32
		Pb	1.90	1.09	1.65	0.5	6.13
Spinach Tissue Metal Concentration (mg/kg DW for Zn and ug/kg FW for Cd and Pb)							
2013-2014	25	Cd	127	90.4	94.0	40.7	407.2
		Pb	11.9	5.7	11.3	4	25.5
2014-2015	45	Zn	86	30.5	73.7	51.4	165.5
		Cd	207.8	83.0	200.0	97.3	448.9
		Pb	86.0	30.5	73.7	51.4	165.5
2015-2016	76	Zn	63.4	22.9	60.7	22.3	122
		Cd	226.5	86.3	220.5	63.2	453.4
		Pb	16.1	14.4	11	2.3	84.3

Table 2. Soil test metal concentration from high resolution soil samples collected in 2016.

Site	Production Block Size (ha)	Sample Resolution (ha)	Metal	Mean	Standard Deviation of Mean	Median	Minimum Value	Maximum Value
Soil DPTA (mg/kg)								
1	1.1	0.07	Zn	5.0	1.1	4.6	4.1	8.6
			Cd	0.11	0.01	0.11	0.10	0.13
			Pb	0.32	0.03	0.32	0.27	0.37
2	0.5	0.02	Zn	2.3	0.24	2.3	1.8	3.1
			Cd	0.17	0.01	0.17	0.14	0.22
			Pb	3.07	0.56	2.95	2.27	4.9
3	3.1	0.15	Zn	1.74	0.25	1.74	1.25	2.44
			Cd	0.21	0.02	0.20	0.17	0.28
			Pb	2.91	0.62	2.91	1.89	4.68
4	1.6	0.05	Zn	1.78	0.40	1.62	1.32	2.98
			Cd	0.20	0.02	0.20	0.18	0.28
			Pb	3.92	0.81	3.93	2.60	5.94
5	1.3	0.04	Zn	0.98	0.17	0.97	0.72	1.65
			Cd	0.13	0.01	0.12	0.11	0.16
			Pb	1.15	0.31	1.13	0.52	1.99
6	2.5	0.125	Zn	1.30	0.13	1.27	1.06	1.60
			Cd	0.15	0.010	0.15	0.13	0.20
			Pb	1.38	0.22	1.33	1.07	2.31
7	2.6	0.16	Zn	1.10	0.08	1.09	0.98	1.23
			Cd	0.14	0.01	0.14	0.12	0.15
			Pb	0.15	1.28	1.12	1.73	
8	1.2	0.05	Zn	1.52	0.73	1.31	0.89	3.71
			Cd	0.17	0.05	0.15	0.11	0.31
			Pb	1.15	0.09	1.12	1.03	1.37

Table 3. Spinach metal concentrations from high resolution spinach tissues samples collected in 2016.

Site	Production Block Size (ha)	Sample Resolution (ha)	Metal	Mean	Standard Deviation of Mean	Median	Minimum Value	Maximum Value
Spinach Tissue Metal Concentration (mg/kg DW for Zn and ug/kg FW for Cd and Pb)								
1	1.1	0.07	Zn	135.0	7.8	134.0	122.6	147.0
			Cd	82.4	14.3	79.8	63.4	127.0
			Pb	9.9	6.6	6.6	4.6	28.3
4	1.6	0.05	Zn	85.6	8.9	85.8	67.9	102.7
			Cd	297.6	30.9	293.3	224.9	359.5
			Pb	67.6	110.7	30.7	12.5	538.9
5	1.3	0.04	Zn	86.6	19.8	83.7	62.5	116.6
			Cd	136.8	34.3	130.1	58.8	253.1
			Pb	65.0	68.5	45.7	12.2	331.6
7	2.6	0.16	Zn	59.2	11.2	56.1	51.8	98.2
			Cd	241.9	28.3	244.7	200.1	287.5
			Pb	13.3	15.7	8.9	5	70.0
8	1.2	0.05	Zn	68.4	34.0	91.6	20.5	106.7
			Cd	197.5	91.7	243.4	71.1	311.6
			Pb	13.1	9.2	13.9	2.4	40.9

Table 4. Relationship between DPTA soil-test Cd and predicted tissue concentration.

Soil Test Cd (mg/kg)	Predicted Mean Tissue Cd mg/kg FW	Probability Tissue< 200 mg/kg FW (%)
<0.1	136	90
0.1 – 0.125	152	70
0.125-0.150	193	50
0.150-0.175	239	29
0.175-0.200	243	27
>0.200	237	13

Table 5. Response of spinach to Zn fertilization in six field experiments conducted in the desert during 2015-2016.

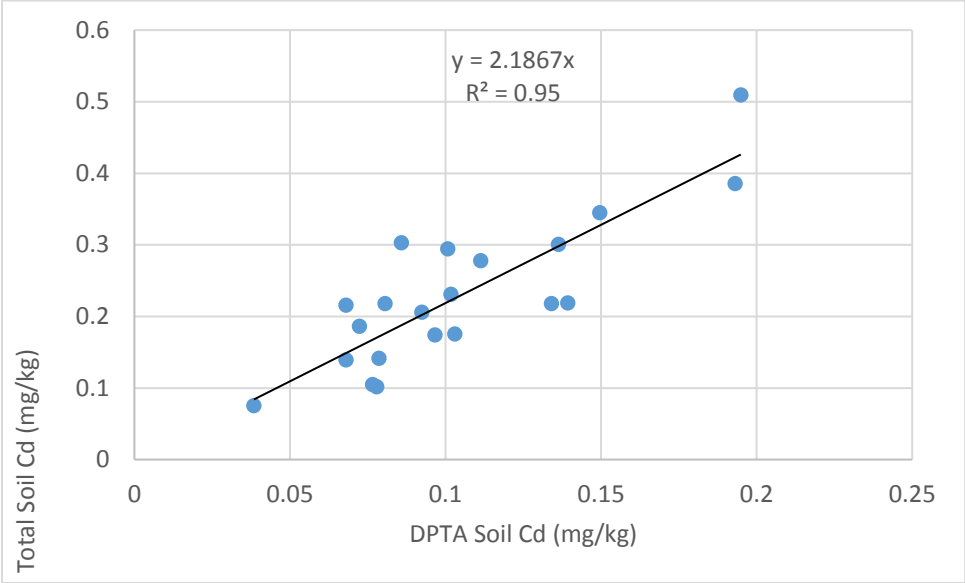
	Experiment					
Zn Rate (kg/ha)	1	2	3	4	5	6
0	19.4	26.4	6.2	12.8	13.4	7.6
25	21.1	32.0	6.3	13.5	13.8	8.8
50	20.8	35.1	6.4	13.4	13.8	10.0
100	21.6	37.1	7.0	14.2	14.7	9.9
200	22.5	41.4	6.7	13.7	12.8	8.5
400	20.7	39.5	6.7	14.4	12.8	10.8
	L*Q*	L**Q**	NS	NS	NS	L*

*,**. Significance at the 5 and 10% levels, respectively. Not Significant (NS) =P>0.05.

Table 6. Correlation of spinach Cd and Zn concentrations to other tissue concentrations and soil properties.

Parameter	Response	Tissue Cd	Tissue Pb
Soil Test Zn	Correlation Coefficient	-0.37	-0.01
	Significance	<0.01	NS
Soil Test Cd	Correlation Coefficient	0.37	0.13
	Significance	<0.01	NS
Soil Test Pb	Correlation Coefficient	0.56	0.32
	Significance	<0.01	<0.01
Tissue Zn	Correlation Coefficient	0.02	0.17
	Significance	NS	0.01
Tissue Cd	Correlation Coefficient		23
	Significance		<0.01
Tissue Pb	Correlation Coefficient	0.23	
	Significance	<0.01	
Soil pH	Correlation Coefficient	.01	0.11
	Significance	NS	NS
Soil Saturation Percentage (SP)	Correlation Coefficient	0.08	0.01
	Significance	NS	NS
Soil EC	Correlation Coefficient	0.32	0.08
	Significance	<0.01	NS
Soil Cl	Correlation Coefficient	0.17	0.11
	Significance	0.02	NS
Soil Test P	Correlation Coefficient	-0.33	-0.20
	Significance	<0.01	NS

Significance to 0.05 reported. Not significant (NS) of P>0.05. These correlations are based on 205 paired comparisons.



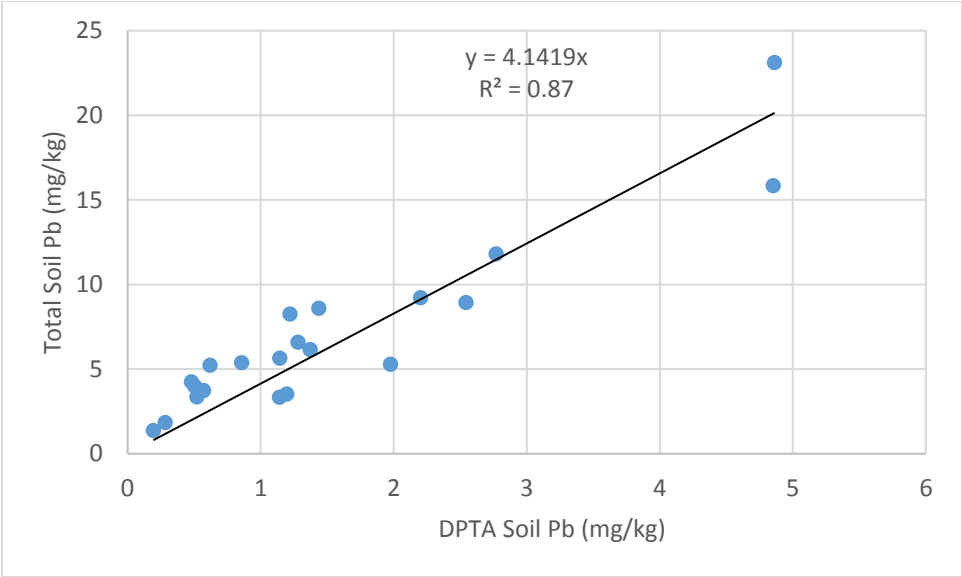


Figure 1. Relationship between (a) DPTA Soil Cd and Total Soil Cd and, (b) DPTA Soil Pb and Total soil Pb.

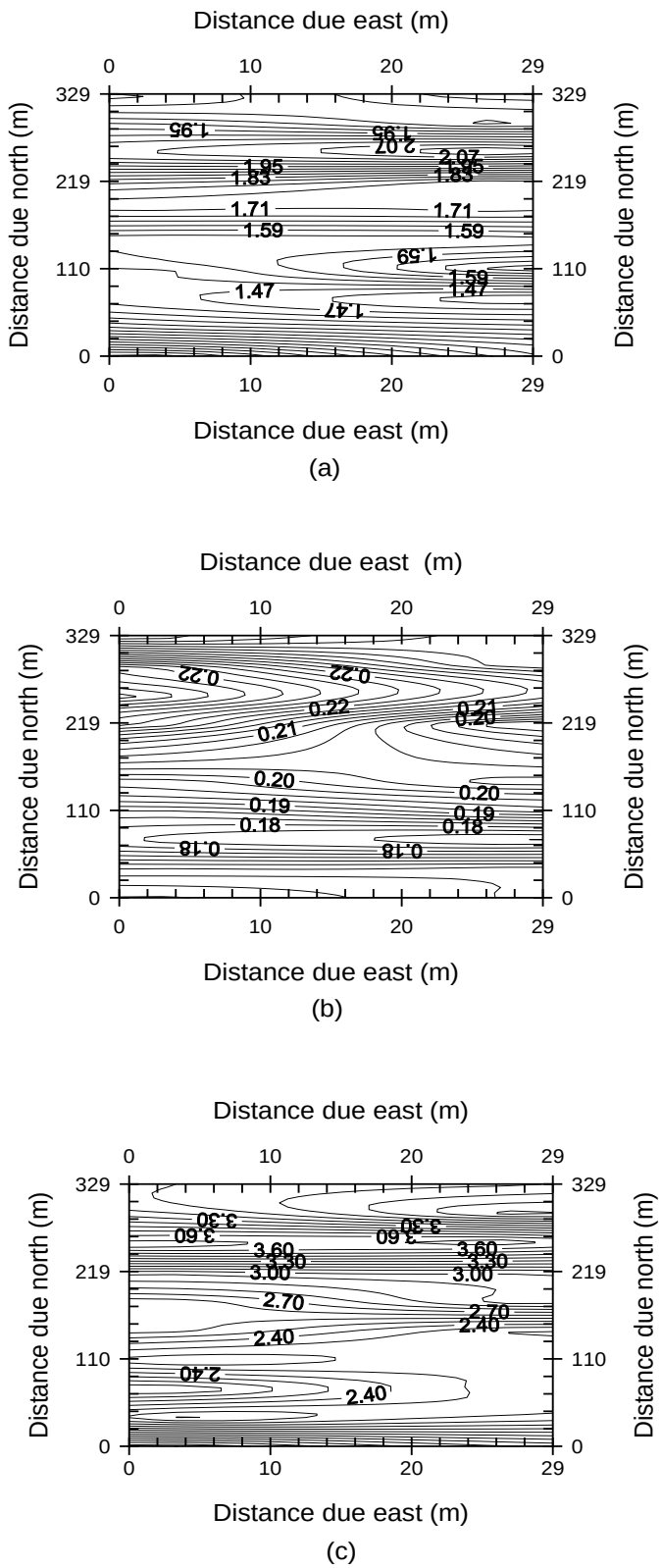


Figure 2. Soil test DPTA Zn (a) Cd (b) and Pb (c) in site 6.

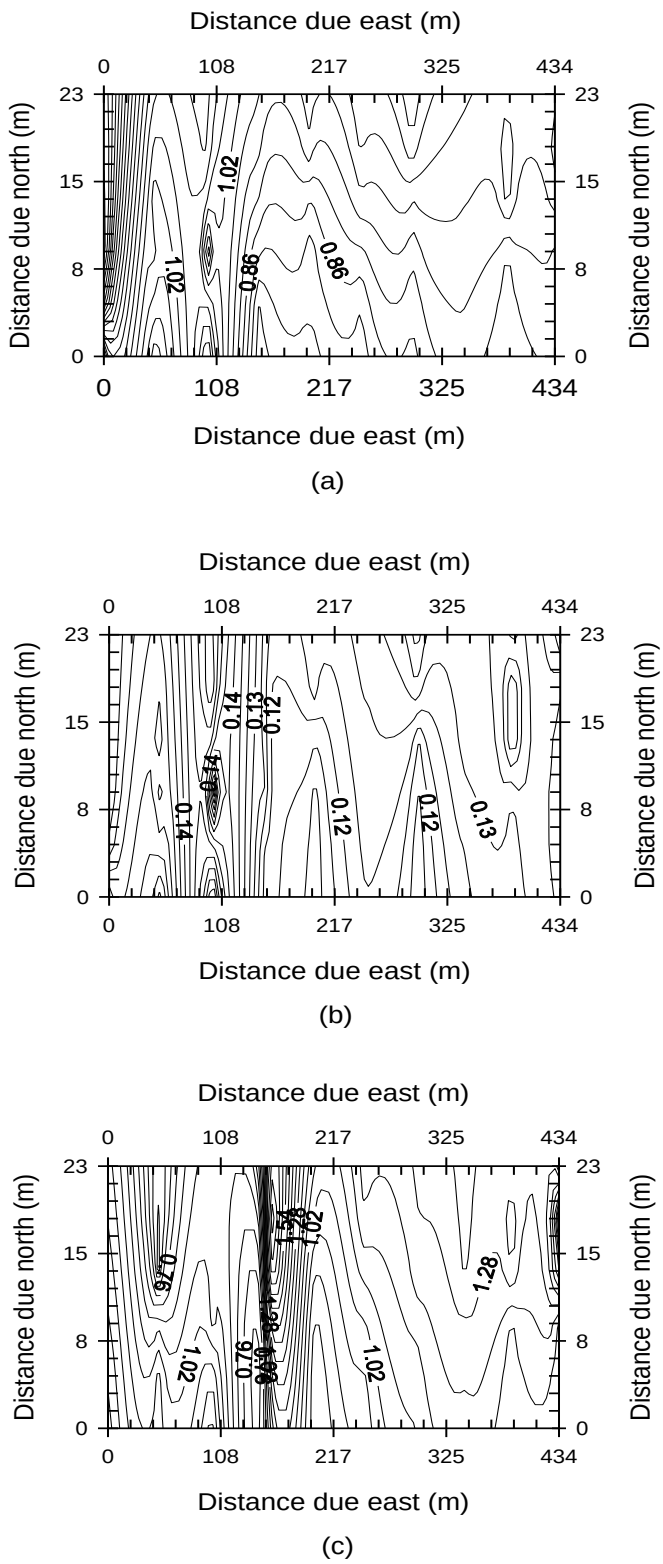
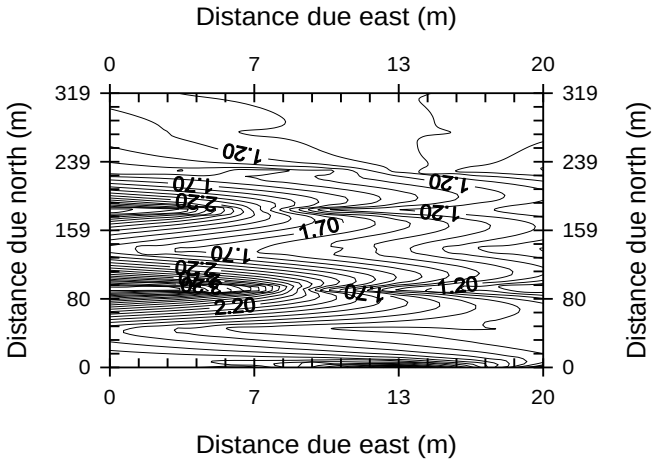
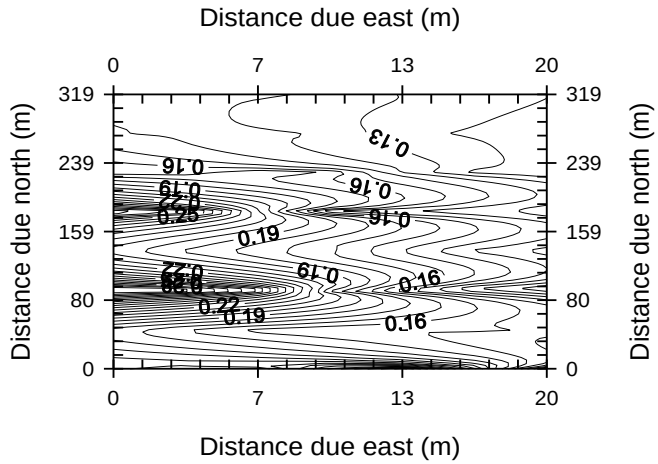


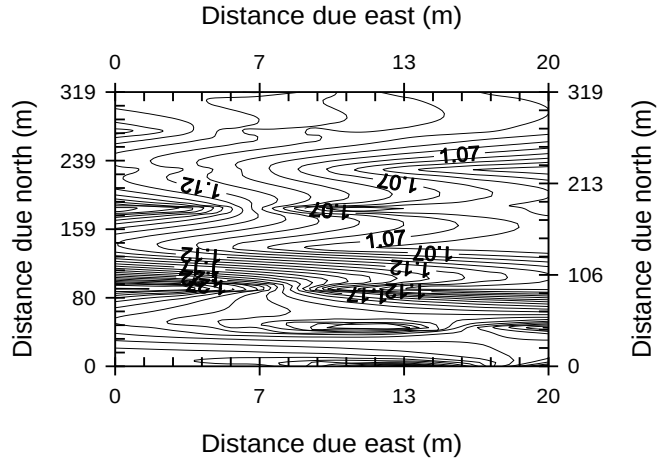
Figure 3. Soil test DPTA Zn (a), Cd (b) and Pb (c) for site 5.



(a)

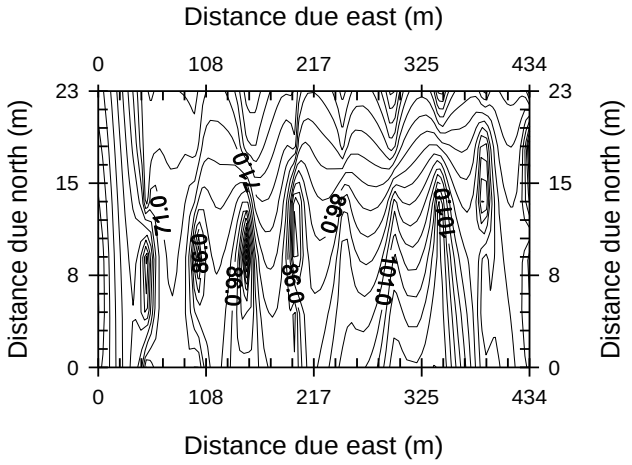


(b)

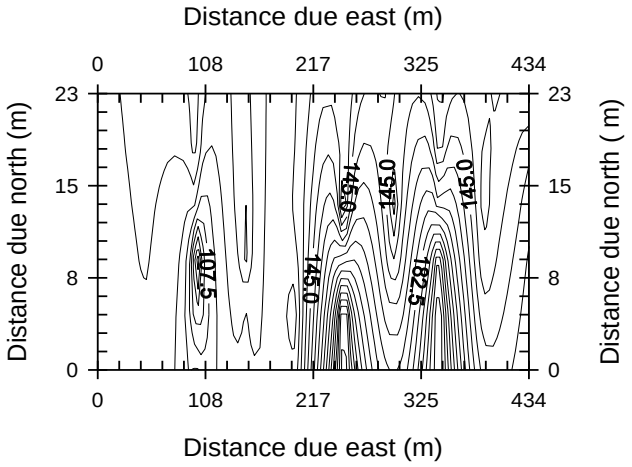


(c)

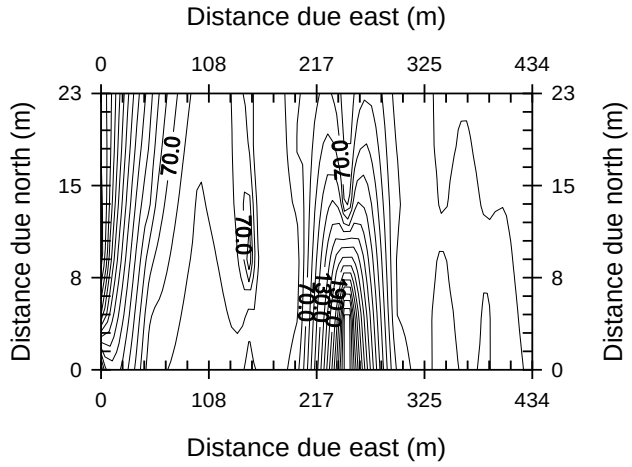
Figure 4. Soil test Zn (a), Cd (b) and Pb for site 8..



(a)

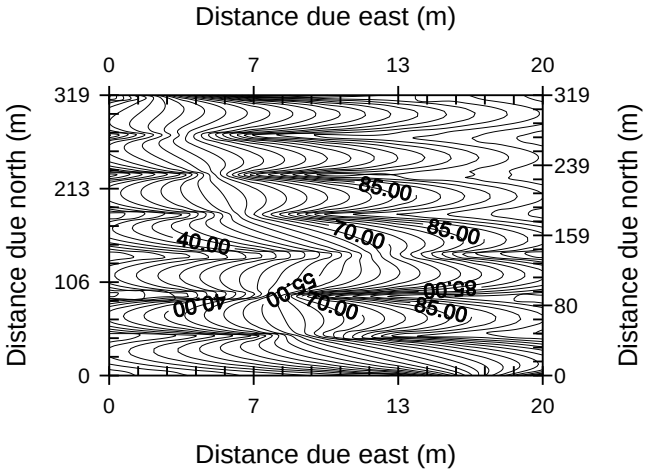


(b)

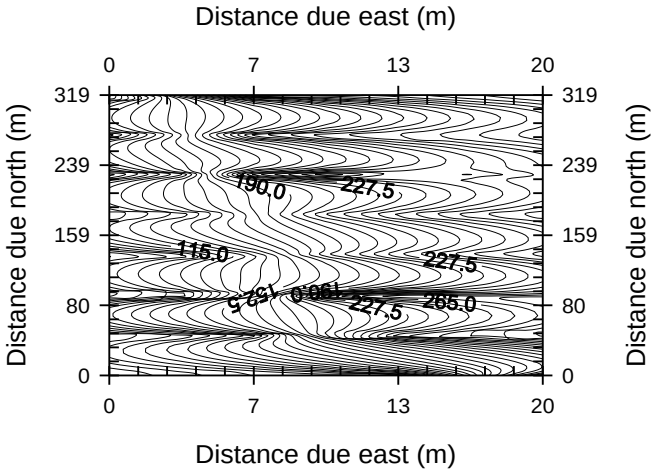


(c)

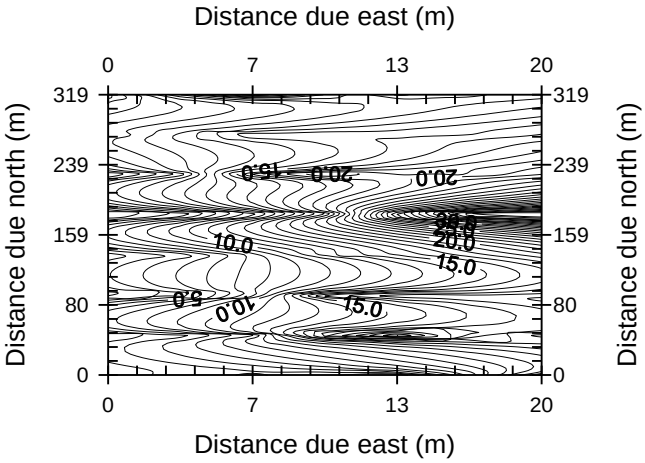
Figure 5. Spinach tissue Zn (a), Cd (b) and Pb (c) for site 5.



(a)



(b)



(c)

Figure 6. Spinach tissue Zn (a), Cd (b) and Pb (c) for site 8.

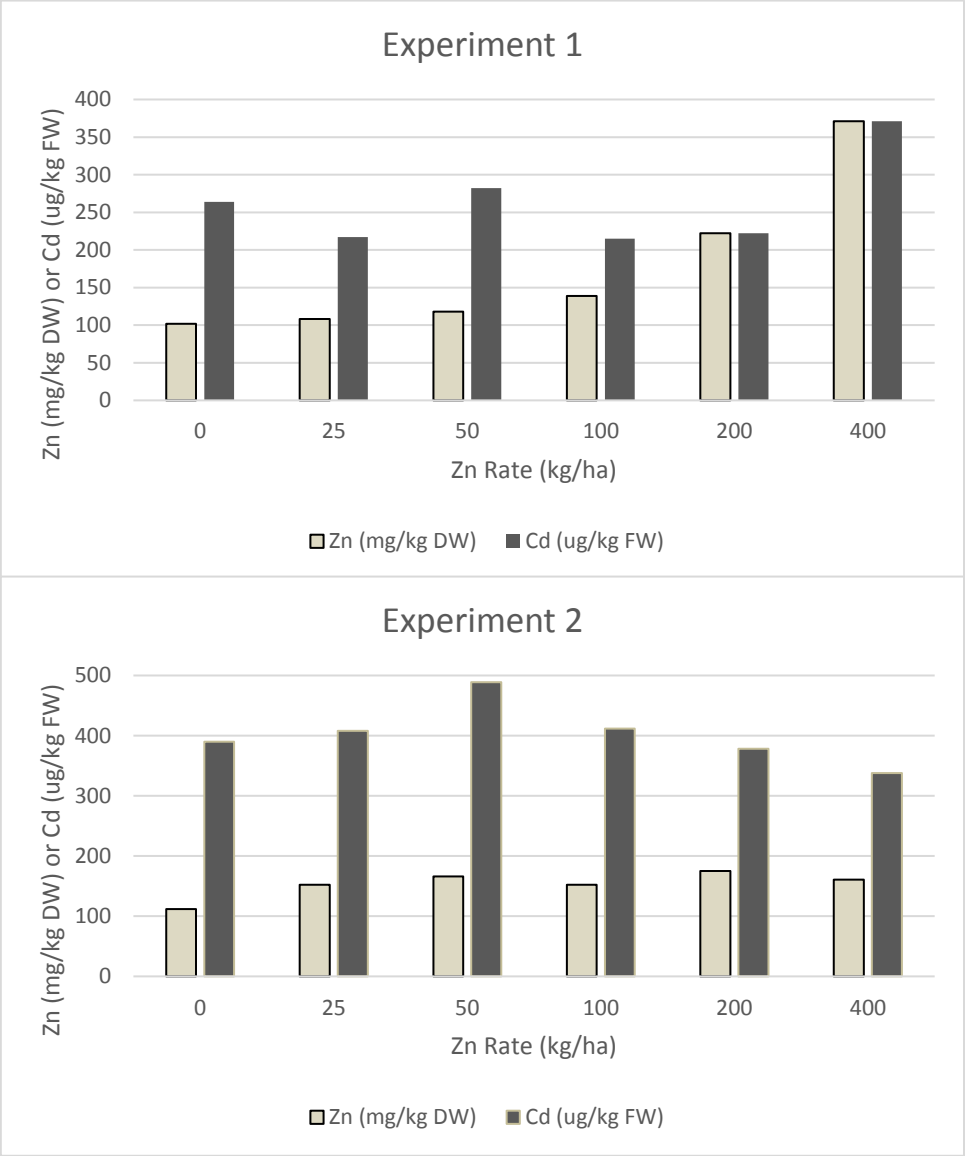


Figure 7. Spinach tissue Zn (mg/kg DW) and Cd (ug/kg FW) to Zn fertilization in two experiments. In both experiments tissue Zn increased to Zn fertilization. In experiment 1, tissue cadmium increased and in experiment two the effect was quadratic (increased then decreased).

THE UNIVERSITY OF ARIZONA

COLLEGE OF AGRICULTURE AND LIFE SCIENCES

COOPERATIVE EXTENSION
School of Plant Sciences

Appendix D
referenced on page 130

Pecan Weed Management Programs

Dr. Bill McCloskey,
Extension Weed Specialist
School of Plant Sciences

Why Control Weeds in Pecans?

- Weeds compete with young trees for resources:
  - Stunt growth
  - Delay nut yield

Why Control Weeds in Pecans?

- Weeds compete with young trees for resources:
  - Stunt growth
  - Delay nut yield
- Weeds produce
  - seeds,
  - rhizomes,
  - tubers, etc.

Objective for HR weeds: Zero Tolerance – stop seed rain on land you manage

Herbicides
Tillage, Mowing
Drought
Competition
Insects, diseases

Germinate and die

Non-dormant Seed bank

Most seeds are dormant

Most seeds are short lived

Dormant seedbank

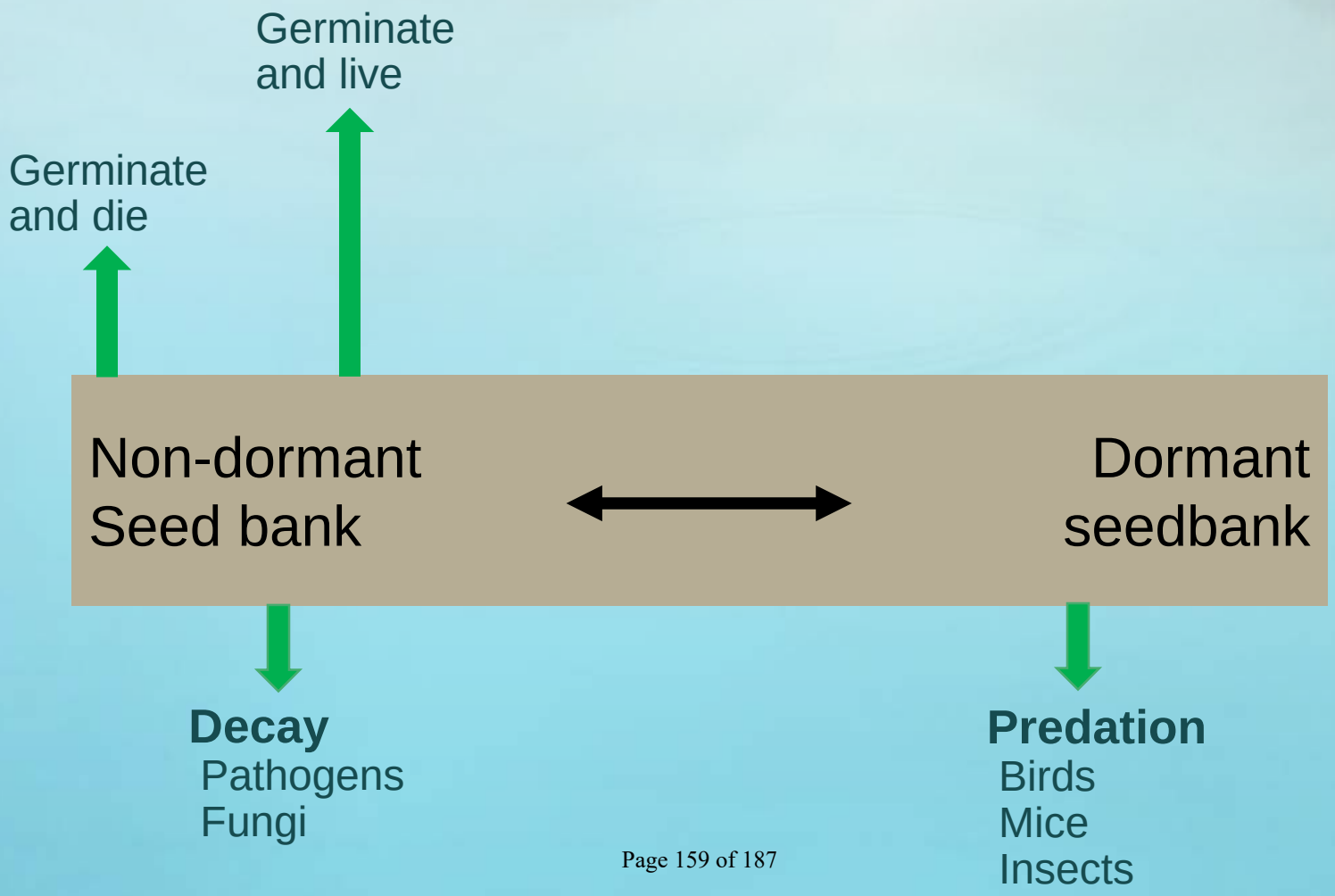
Decay
Pathogens
Fungi

Predation
Birds
Mice
Insects

Fate of weed seeds.

Inputs to seedbank

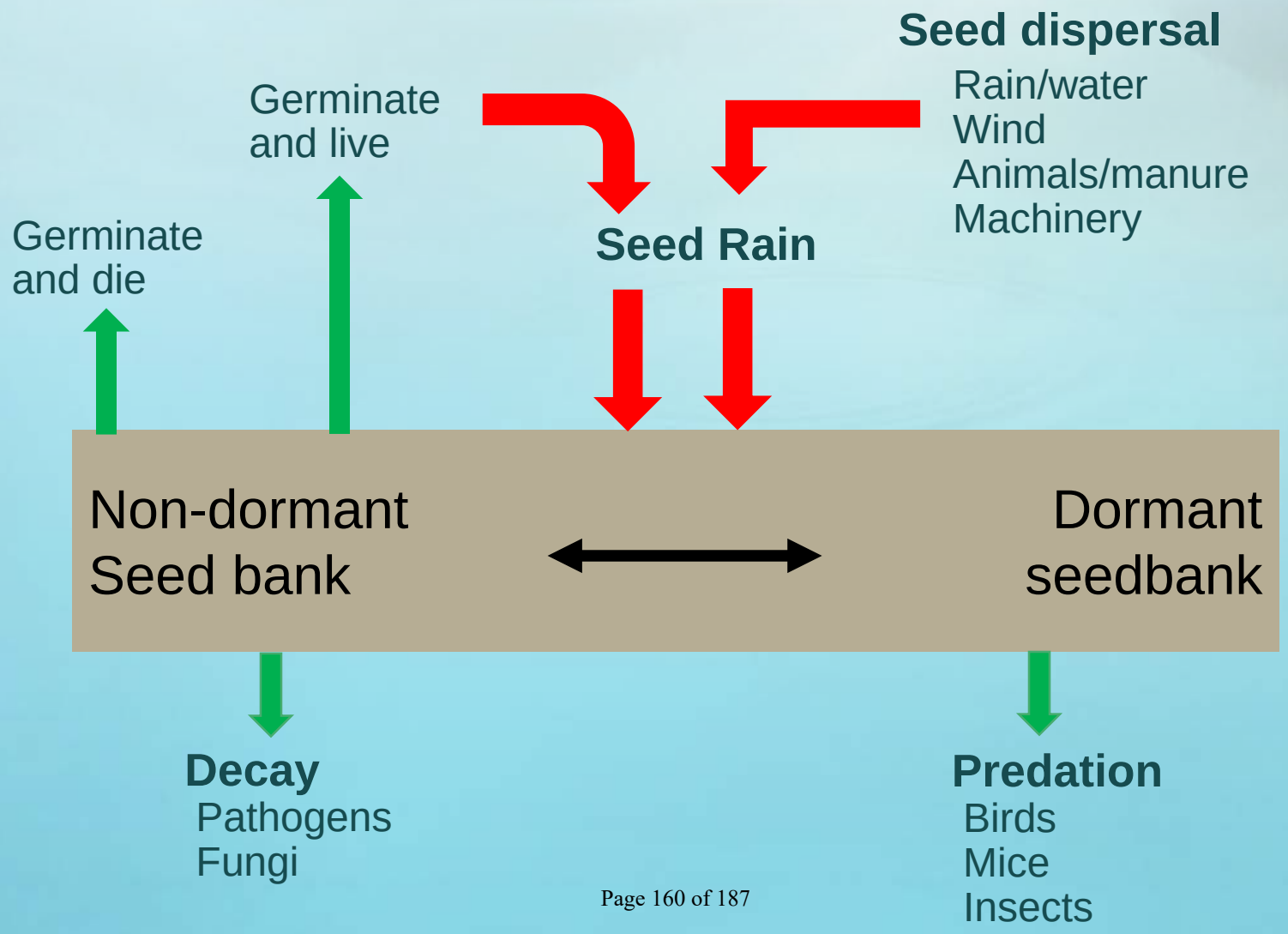
Losses from seedbank



Fate of weed seeds.

Inputs to seedbank

Losses from seedbank



Why Control Weeds in Pecans?

- In older trees, weeds use resources that could be used by trees.
  - Difficult to document yield losses
- Weeds produce biomass that can interfere with harvest

Above: Monsoon rains prevented timely spraying of weeds with postemergence herbicides

Southwestern Tree Nuts

- Course textured soils
- Irrigation – Flood, sprinklers and drip (young)
- Weed control tactics:
  - Tillage
  - Mowing resident weeds
  - Cover crops (young trees)
  - Herbicides
    - Preemergence
    - Postemergence
      - Over reliance on glyphosate

Pros & Cons of Tillage

- Disturbs soil profile which
  - Breaks seed dormancy - weed flushes following irrigation
  - Can damage tree roots, limbs and trunks
  - Must be done frequently to avoid weed competition
  - Can spread perennial weeds
- Can provide
  - Clean start
  - Good surface for application of PREE herbicides

Mix PREE & POST herbicides to control weed seedlings

Mowed resident vegetation

- Advantages:
  - Equipment access during monsoon
  - Dust control
  - Increased water infiltration
- Disadvantages:
  - Insect habitat
  - Resource use
  - Weed seed production
  - Cost
  - Species shift

Pindar GT @ 3 pt/A
(8-24-2011)

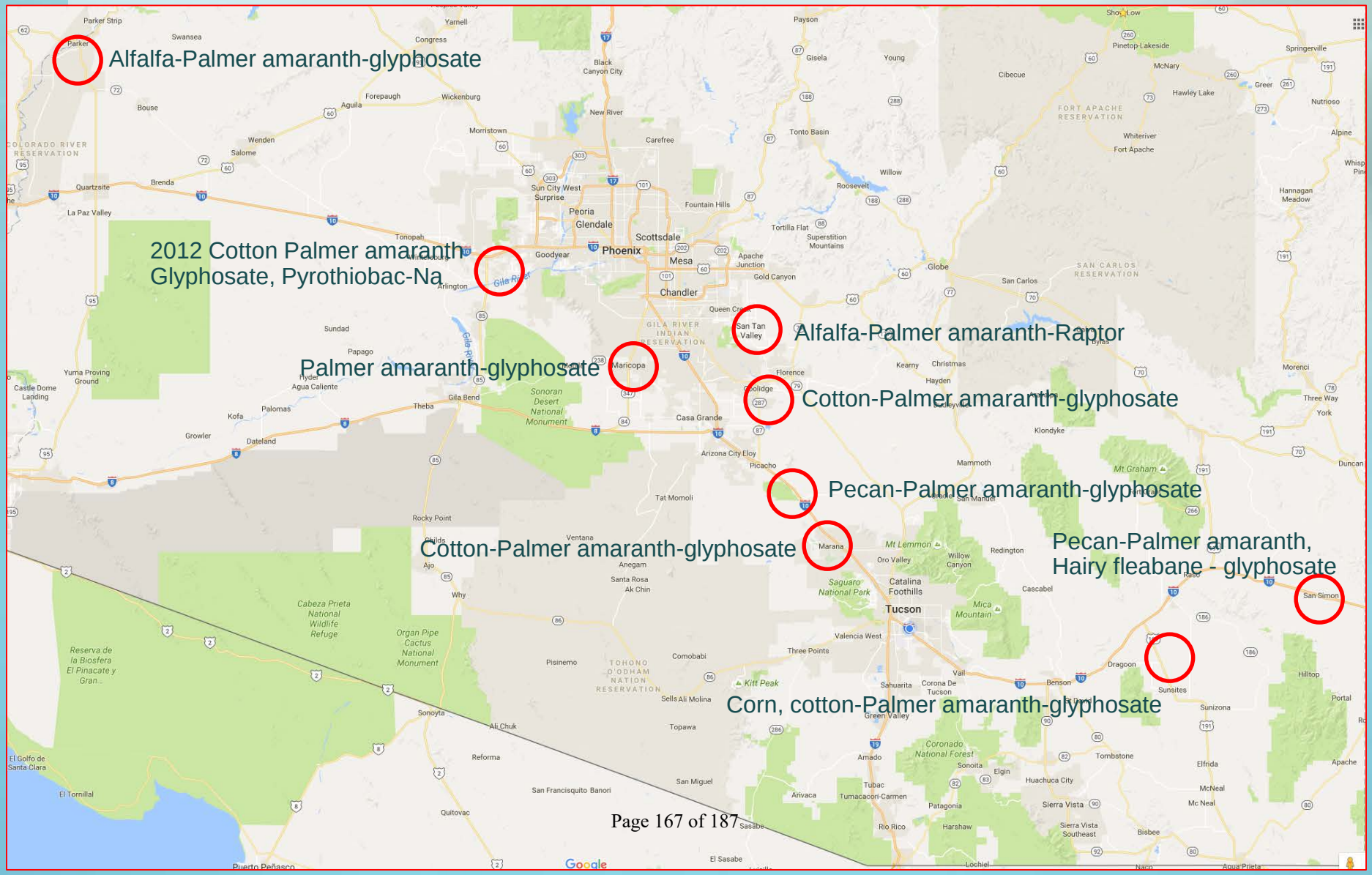
Chemical Weed Control

- Preemergence herbicides reduce problem of access during monsoon
- Reduce weed resource use & competition
- Weed Shifts
- Herbicide resistance
- Spray drift

Chemical Weed Control – reduce weed resource use and competition with trees

- <u>Postemergence only:</u>
  - Numerous applications
  - Herbicide resistance (glyphosate)
  - Weed population shifts
  - Problem of spray drift & injury

Problem of Herbicide Resistant Weeds
Glyphosate resistant Palmer amaranth & Hairy fleabane



Problem of glyphosate drift

Drift from an aerial application of Roundup to adjacent cotton field

Chemical Weed Control – reduce weed resource use and competition with trees

Pindar GT @ 3 pt/A - (8-24-2011)

- <u>Postemergence only:</u>
  - Numerous applications
  - Herbicide resistance (glyphosate)
  - Weed population shifts
  - Problem of spray drift & injury
- <u>Preemergence Herbicides:</u>
  - Reduce POST applications
  - Greater herbicide diversity – reduced risk of resistance
  - Problem of root uptake & injury

Weed free strip in tree row is common
Optimum vegetation free strip : 3 m or 10 feet

No interference of weeds/vegetation with sprinklers

Weed Management Programs

- Weed free strip – tree line
- Mow middles
- Winter tillage
  - Ripping, fertilization
  - Pruning, shredding, disking
  - Leveling for flood irrigation
- Preemergence (PREE) Herbicide

Preemergence Pecan Herbicides (X = bearing, NB = nonbearing)

Trade name	Common name	Pecans/ Pistachios	Weeds controlled
Pindar GT	penoxsulam oxyflurofen	X / X	Broadleaves and grasses
Goal Tender	Oxyfluorfen	X / X	
Surflan	Oryzalin	X / X	Grasses & small seeded broadleaves, suppression of large seeded broadleaves.
Prowl H_2O	Pendimethalin	X / X	
Matrix FNV	Rimsulfuron	X / X	Broadleaves, grasses, yellow nutsedge – also POST activity
Chateau	flumioxazin	X / X	Broadleaves, some grasses
Trellis	isoxaben	X / -	Broadleaves and grasses – also POST activity
Karmex, Diuron	Diuron	X / -	Broadleaves & grasses; has leaching potential
Solicam	Norflurazon	X / X	Grasses, broadleaves, nutsedges
Broadworks	Mesotrione	X / X	Annual broadleaves

Weed Management Programs

- Weed free strip – tree line
- Mow middles
- Preemergence (PREE) Herbicide
  - “Foundation” PREE
    - Pindar or GoalTender
    - Prowl H2O or Surflan
    - Chateau+GoalTender
  - “Supplemental” PREE – Increase weed control (species & numbers)
    - Matrix
    - Trellis
    - Broadworks

Preemergence Pecan Herbicides (MOA = mechanism of action, POST = postemergence)

Trade name	MOA	POST Activity	Product Rate	Annual maximum	Max. time to incorporate
Pindar GT	2+14	Contact	1.5 – 3 pt/A	4.5 pt/A	21 days
GoalTender	14	Contact	2.5 – 3 pt/A (4 pt/A banded)	3 pt/A (4 pt/A banded)	3 to 4 weeks
Surflan	3	No	2 – 6 qt/A	12 qt/A	1 week
Prowl H_2O	3	No	2 – 6.3 qt/A	6.3 qt/A	1 week
Matrix FNV	2	Translocated	4 oz/A	4 oz/A, if ≤50% band, 8 oz/A	2 to 3 weeks
Chateau	14	Contact	6 – 12 oz/A	24 oz/A	Extended period
Trellis	21	No	0.66 – 1.33 lb/A	1.33 lb/A	21 days
Solicam	12	Translocated	2.5 lb/A coarse 3.75 lb/A medium	Same as rate	4 weeks
Broadworks	27	Translocated	3 – 6 fl oz/A	12 fl oz/A	7 to 10 days

Weed Management Programs

- Preemergence (PREE) Herbicide
  - "Foundation" PREE
    - Pindar or GoalTender – better under drip than dinitroanilines
    - Prowl H2O or Surflan – loses activity in anaerobic or water saturated soils.
    - Chateau+GoalTender
  - "Supplemental" PREE – Increase weed control (suppresses difficult species & reduces numbers)
    - Matrix – hairy fleabane
    - Trellis
    - Broadworks

Weed Management Programs

- Weed free strip – tree line
- Mow middles
- Winter tillage
  - Ripping, fertilization
  - Pruning, shredding, disking
  - Leveling for flood irrigation
- Preemergence (PREE) Herbicide
- Postemergence (POST) Herbicide

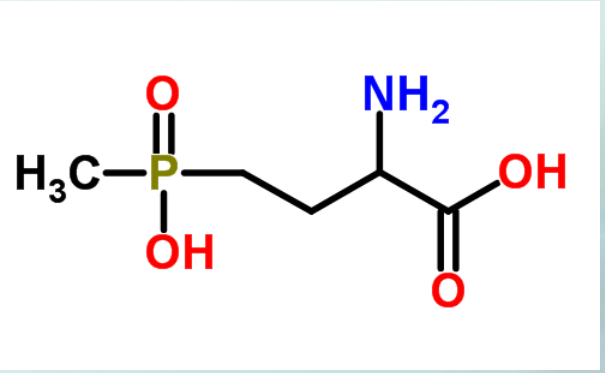
Systemic Postemergence Pecan Herbicides (X = bearing, NB = nonbearing)

Trade name	Common name	Pecans/ Pistachios	Herbicide type, weeds controlled
Select	Clethodim	NB / NB	Systemic, selective; controls only grass weeds
Fusilade DX	Fluazifop-p-butyl	X / NB	
Poast	Sethoxydim	X / X	
Sandea	halosulfuron	X / X	Systemic, selective; controls nutsedge species and some broadleaf weeds
Roundup, Touchdown, etc.	glyphosate	X / X	Systemic, non-selective; Controls green herbaceous plants

Contact Postemergence Pecan Herbicides (X = bearing, NB = nonbearing)

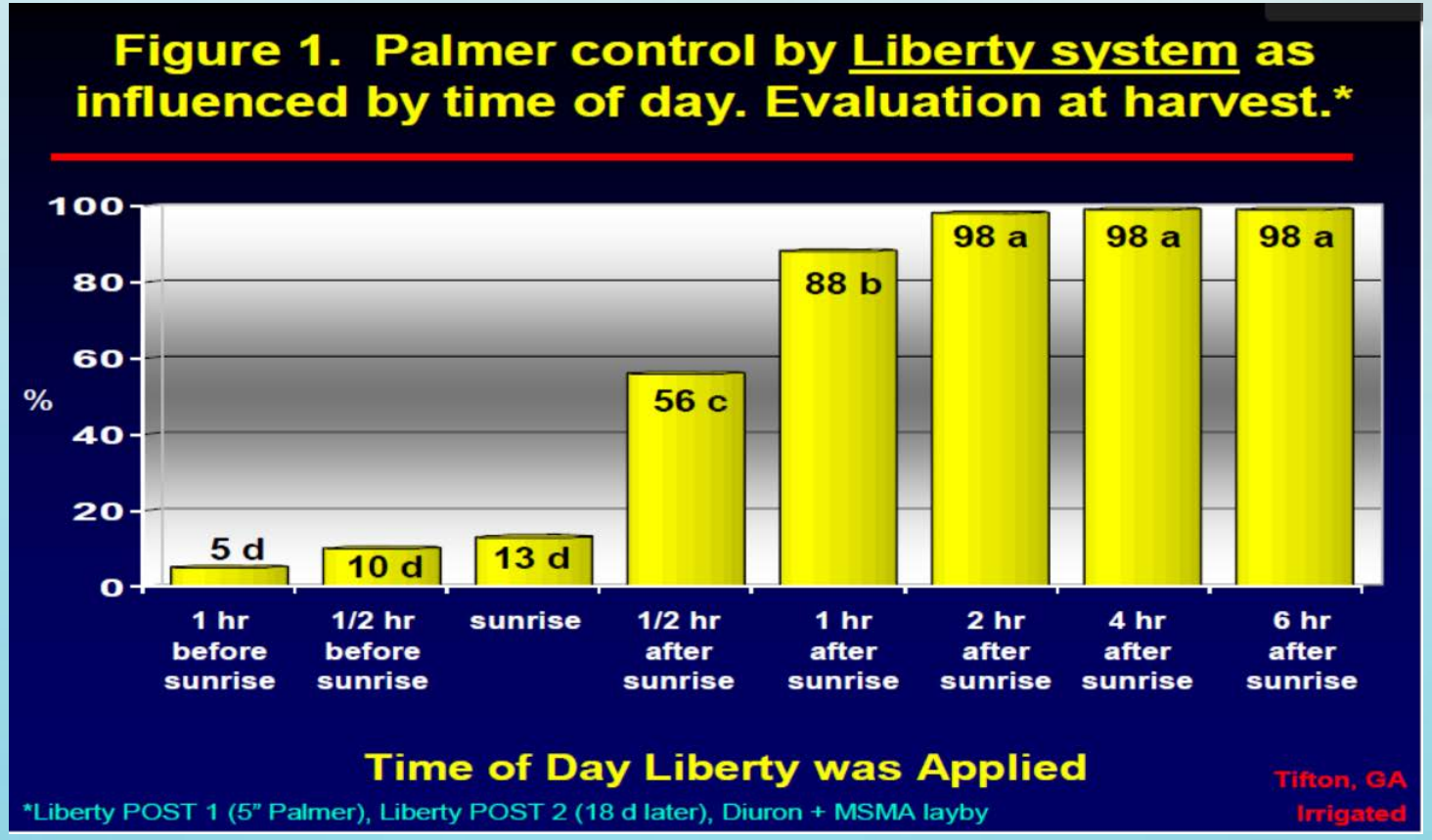
Trade name	Common name	Pecans/ Pistachios	Herbicide type, weeds controlled
Rely, Lifeline	Glufosinate-ammonium	X / X	Contact, non-selective; controls green herbaceous plants Medium to coarse droplets Add surfactant, COC, MeOH
Gramoxone Paraquat	Paraquat (restricted use)	X / X	
Aim	Carfentrazone	X / X	Contact, selective; controls broadleaf weeds; both Chateau and Goal have soil residual activity at higher rates.
Venue	Pyraflufen ethyl	X / X	
Chateau	flumioxazin	X / X	
Goal Tender, Goal	Oxyfluorfen	X / X	

Glufosinate



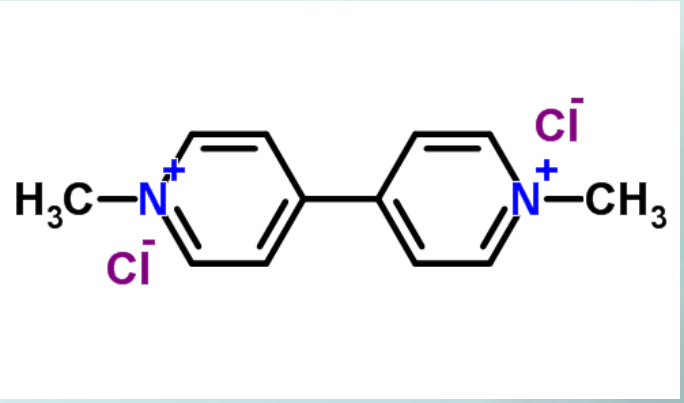
- Broad spectrum control
- Contact herbicide
  - Better on broadleaves
  - 3.5 to 5 pt/A; 15.4 pt/A per year
  - Surfactant included in formulation
  - Add AMS
  - Not mobile after spray droplet lands on leaf
  - Necrotic spots if droplets drift – no crop injury
- Some mobility in soil
  - 7 day soil residual half-life
- Requires sunlight for herbicidal activity

Time of Day Effect on Glufosinate (Liberty/Rely) Activity



Data from Stanley Culpepper, University of Georgia

Paraquat (Gramoxone)



- Broad spectrum control
  - Better on broadleaves than grasses
- Contact herbicide
- Add nonionic surfactant (or crop oil or methylated seed oil)
- 2.5 to 4 pt/A; Up to 5 applications/year
- Sequential treatments needed to control hairy fleabane and other difficult to control weeds
- Not mobile after spray droplet lands on leaf
- Necrotic spots if droplets drift – no crop injury
- Not mobile in soil – strong binding to soil
- Requires sunlight for herbicidal activity

Contact Postemergence Pecan Herbicides (X = bearing, NB = nonbearing)

Trade name	Common name	Pecans/ Pistachios	Herbicide type, weeds controlled
Rely, Lifeline	Glufosinate-ammonium	X / X	Contact, non-selective; controls green herbaceous plants. Medium to coarse droplets Add surfactant, COC, MeOH
Gramoxone Paraquat	Paraquat (restricted use)	X / X	
Aim	Carfentrazone	X / X	Contact, selective; controls broadleaf weeds; both Chateau and Goal have soil residual activity at higher rates.
Venue	Pyraflufen ethyl	X / X	
Chateau	flumioxazin	X / X	
Goal Tender, Goal	Oxyfluorfen	X / X	

Spray Quality Categories

2009

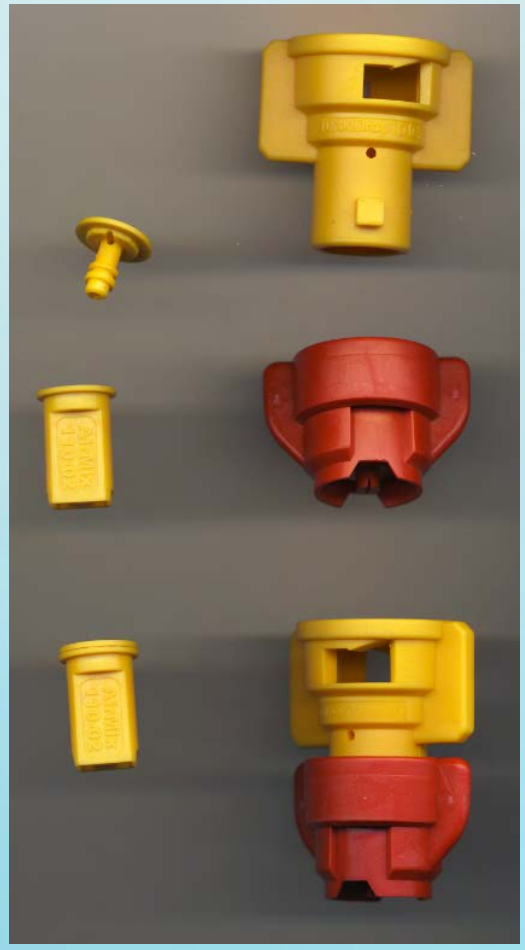
ASABE Standard S-572.1

Category (symbol)	*Color Code*	*VMD Range*
Extra Fine (XF)	Purple	< 60
Very Fine (VF)	Red	61 – 144
Fine (F)	Orange	145 – 235
Medium (M)	Yellow	236 – 340
Coarse (C)	Blue	341 – 403
Very Coarse (VC)	Green	404 – 502
Extra Coarse (XC)	White	503 – 665
Ultra Coarse (UC)	Black	> 665

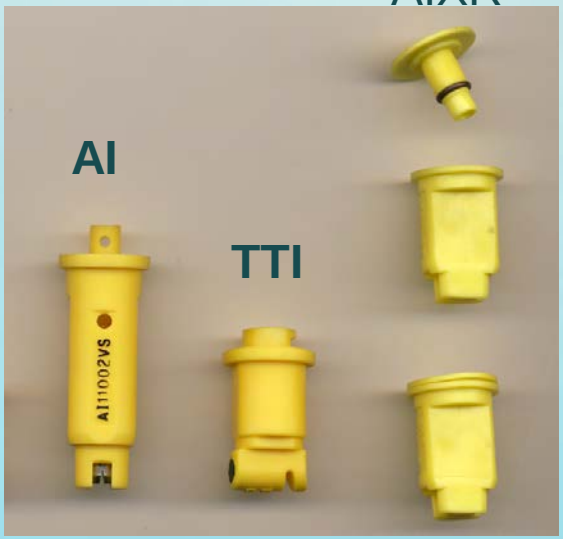
NEW

S572

NEW



- Air induction nozzles at moderate pressure (e.g., 40 PSI) produce very large spray droplets



AI – Air Induction

TTI Turbo Teejet Induction

AIXR – Air Induction Extended Range

AirMix, TDXL (GreenLeaf)

TeeJet Induction nozzles

Air induction nozzles can generate large spray droplets!

TTI TwinJet

Spray Quality Categories

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NEW

S572

NEW

Tree nut weed management tactics

- Need a diversity of tactics to delay development of herbicide resistant weeds
  - Sanitation – minimize weed seed production
  - Tillage/mowing
  - Preemergence herbicide
    - Additional herbicide mechanism of action (MOA)
    - Reduce postemergence herbicide sprays
  - Postemergence herbicides
    - Tank-mix herbicides
    - Rotate herbicides & MOA