SAES-422 Multistate Research Activity Accomplishments Report

Project No. and Title: W-3128 Scaling Microirrigation Technologies to Address the Global Water Challenge
Period Covered: 10-2015 to 09-2016
Date of Report: 02-05-2017
Annual Meeting Dates: 11-05-2016 to 11-06-2016

Participants:

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Brief Summary of Minutes of Annual Meeting:

The annual meeting was held on Saturday, November 5, 2016 in the Ellis Room of the Hyatt Regency in Phoenix, Arizona. Committee Chair, Dr. Kelly Morgan, called the meeting to order at 8:30 am and reviewed the agenda. No changes to the agenda were made and introductions were individually made by each attendee. Dr. Freddie Lamm (Kansas State University) gave a brief report of the webinar that had been previously planned at the Long Beach meeting (2015). The webinar failed to be initiated and the funds to be used for it were returned. There are no immediate plans to organize an educational program by the central committee; however, Dr. Lamm indicated that he would contact some individuals to pursue means of conducting a webinar during the upcoming year on water quality and clogging. Some of the committee members have been engaged in extension education activities to promote the topic areas of water quality, water use efficiency, and advancements in subsurface micro-irrigation. Dr. Lamm introduced the possibility of having voluntary webinars or related types of programs each year developed by committee members. Dr. Pete Jacoby (Washington State University) introduced another potential area for education programming around the issue of gopher damage to buried driplines. Committee members offered examples of efforts being used around the nation. This issue could be a topic for future webinar and the committee may confer by tele-conference about developing a webinar.

The business meeting commenced at 9:00 am. The subject of selecting the next site for the committee meeting was undecided after some discussion of potential locations. This item will pass to the 2017 committee chair, Pete Jacoby, for soliciting further input and final decision on the site and time for the 2017 committee meeting. Past meetings have been planned in conjunction of professional meetings, including the Irrigation Association (2015) and the Tri-Society (ASA, CSSA, and SSSA) meeting (2016). Both of these annual profession society meetings typically call in late fall and both will be held in central Florida during 2017.

Dr. Bradley Rein (NIFA – USDA) reported to the committee regarding issues and opportunities at the federal agency levels that could be considered by committee members. Dr. Rein informed the committee about some new hires within NIFA, one of which has Ag Engineering background and training and one who is a social scientist who will work on translating research findings for more rapid adoption by end users. The majority of Dr. Rein's report addressed new grant opportunities related to the committee's research interests. A walk-through demonstration of the NIFA website was helpful in guiding committee members to sources of new grant opportunities and RFA's.

We also heard from Dr. Steve Loring (New Mexico State University) and ended our business meeting portion at mid-morning.

Provide information with a focus on the decisions made. As an alternative, provide an attachment of your meeting minutes.

Accomplishments:

This section focuses on intended activities, outputs, and short-term outcomes. Committees should build information built around the activity's milestones, as identified in the original proposal. Please indicate significant evidence of linkages both internal to the project/committee and to external peer groups, stakeholders, clientele, and other multistate activities. The report should also reflect on the items that stakeholders want to know, or want to see. The committee should describe plans for the coming year in no more than one or two short paragraphs. If the committee is filing an annual report, the accomplishments will cover only the current year of the project; for termination reports, list accomplishments from the entire span of the project.

- **Short-term Outcomes**: Quantitative, measurable benefits of the research outputs as experienced by those who receive them. Examples include the adoption of a technology, the creation of jobs, reduced cost to the consumer, less pesticide exposure to farmers, or access to more nutritious food.

- **Outputs**: Defined products (tangible or intangible) that are delivered by a research project. Examples of outputs are reports, data, information, observations, publications, and patents.

Florida – Turf App
Irrigation depths applied resulted in significant water savings with the smartphone app and ET controller treatments; irrigation water savings ranged from 42% to 57% compared to the time based schedule. The turf smartphone app irrigation schedule was similar to the ET controllers with savings always significantly greater than the time-based treatment with varying similarities to the two ET controllers. One difference observed between the app and ET controller schedules was found in the seasonal comparisons where both ET controllers had a greater irrigation rate during the dry season while the app had a greater irrigation rate during the wet season. The irrigation depths applied were not significantly different for the app and ET controller for all data and dry season data. However, differences in irrigation depths for the app and ET controller were observed during wet season and may be due to the different methods of integrating rainfall into the irrigation schedule for these two treatments. Overall the smartphone app performed similar to that of the ET controllers and provides an alternative for users where an ET controller is not a viable option. The seasonal water conservation option on the app would provide some incorporation of rainfall into the schedule. For our study, using this feature would have resulted in a reduction in irrigation to 989 mm from 1086 mm with seasonal totals of 568 mm for wet season and 421 mm for dry season. Thus, the lack of on-site rainfall data can be minimized by using the seasonal water conservation mode in the smartphone app.

Florida - Cotton app
The Cotton app was validated results in five commercial cotton fields in southern Georgia. Validation was done with the model using the 2013 calibrated Kc curve. 2013 and 2015 were wetter than normal years while 2014 was a drier than normal year. The Cotton App outperformed the Checkbook Method in terms of mean yield regardless of tillage treatment and did this most effectively during the two wet years. However the differences were statistically significantly different only in 2013 and 2014 because of large intra-treatment variability in yield during 2015. The Cotton App also outperformed the Checkbook Method in irrigation water applied and water use efficiency. This is because the Checkbook Method does not take into account periods with low ET which occur frequently in wet years. The Cotton App outperformed the UGA SSA method in 2014 but in 2015, the UGA SSA conservation tillage treatment outperformed the Cotton App conservation tillage plots. By comparing the soil water tension data from all the treatments and replicated plots, it is clear that in 2015, the treatments that maintained a drier soil profile produced the highest yields. The UGA SSA conservation tillage treatment did have a drier soil profile than the Cotton App. We hypothesize that because the Cotton App does not currently discriminate between conventional and conservation tillage, in 2015 the conservation tillage plots were over-irrigated by the Cotton App.

Florida - Citrus app
The Citrus App requires information on tree spacing (in row and between rows), soil water holding capacity, irrigation system output, and ET source. Water balance estimated using day of year and phenology-based Kc to estimate irrigation quantity and frequency requirements. Evaluation was conducted at three commercial citrus orchards in central and south Florida. The experiment was arranged in a randomized complete block design with four replications at each location. Three irrigation scheduling treatments for conventional irrigation were as follows: 1) Citrus App, 2) Grower determined irrigation, 3) Current University of Florida (UF/IFAS) recommended scheduling. Use of the citrus app consistently resulted in lower water use. Note, citrus trees in Florida have become affected by Citrus Greening disease since 2005 and all trees at the three

locations in this study was determined to be infected by the pathogen. Water applications were significantly lower using the citrus app (3 out of 3 locations) and UF/IFAS recommendations (1 out of 3 locations) compared with grower schedules. Thus the citrus app used an average of 24% less water than the other two irrigation schedules. Citrus tree sap flow measurements were significantly greater and stem water potential lower for trees irrigated based on schedules produced by the citrus app and current UF/IFAS recommendations compared with trees irrigated using grower's experience. As a result of lower water stress, yields were significantly greater for the citrus app (3 out of 3 locations) than the UF/IFAS recommendations and grower applications. Average increase in yield during the three years of the study was 18%. Yields in Florida citrus orchards have declined by 33% to 50% or more during the past 10 years making the results of this study more noteworthy.

Florida - Peanut app

The peanut crop season started on 19 May (planting day) and ended on 16 October 2015 (digging day). During the crop season, cumulative rainfall and calculated ET_c summed up to 26.9 and 20.4 inches, respectively. The first irrigation event occurred on 10 July (52 DAP), when irrigation treatments started. Cumulative irrigation applied per treatment was: 5.2,for grower irrigation schedule, 0.5 for the app schedule, and 1.0 for the soil moisture sensor treatment. Therefore, irrigation treatments applied about 90%, 81% less water than the peanut grower's irrigation practices. Due to the consistent rainfall patterns, peanut required relatively little irrigation throughout the season.

- **Activities**: Organized and specific functions or duties carried out by individuals or teams using scientific methods to reveal new knowledge and develop new understanding.

Alabama – Use of field soil tension measurement in soybeans has been investigated over the past two years on three sites in Alabama. The goal of the research is to develop crop coefficients for soybeans using field tension monitoring and accessible for smart irrigation scheduling. Currently supervising replicated SDI fertigation plots (cotton) in northern Alabama with capability to manually adjust timing of nutrient injection throughout the season. Nine years of subsurface drip irrigation with corresponding cotton yield and daily weather data collection has been completed with replicated research plot study. Results planned for publication 2017.

California (UC Davis) - The evapotranspiration (ET) of an almond tree planted in 2015 was measured lysimetrically, and compared to the ET predicted from a recently published young peach tree model. Measured values were substantially higher (about double) than predicted by the model, but this will be confirmed with further study. The soil and tree components of the model were separated by periodically covering the soil surface, and most of the discrepancy between the measured and modeled values was due to an underestimate of the tree component. Micrometeorological methods to measure ET over a mature commercial almond orchard canopy indicated that canopy ET is not reduced during stress, despite reductions in stomatal conductance. This result was unexpected, and may indicate that a decline in water use efficiency occurs during stress in almonds. A multi-year almond water production function experiment was continued, and thus far the yield effects of reduced irrigation have been minimal (reductions of from 5 - 25%, depending on location), despite imposing a relatively wide range of irrigation amounts (from 40-60"). A multi-year study was initiated to document the long term effects on tree and root health of winter flood irrigations in almond orchards for the purpose of groundwater recharge. Thus far, no negative effects have been observed by applying an additional 24" of water during the dormant season (December/January). The second year of an ongoing walnut irrigation test was performed and demonstrated that plant-based measurements (stem water potential, SWP) could be used to delay the first irrigation in the spring by about 1 month, with no detrimental effects on yield, and evidence was obtained that this practice may improve root health over the long term (years).

California (UC Riverside) - In 2016 we offered short (three-day) courses on how to use HYDRUS models at a) Colorado School of Mines, Golden, CO, b) Czech University of Life Sciences, Prague, Czech Republic, and c) the Research Center for Eco-Environmental Sciences, Chinese Academy of Science, Beijing, Peoples Republic of China. About 100 students participated in these short courses.

Florida - We initiated micro-irrigation projects in Ghana, Burkina Faso and Mali on water- and labor saving drip and sprinkler irrigation technologies for production of onion, tomato and potato. Water savings were in the range of 20 to 40% over traditional irrigation practices. In Florida, micro-irrigation technologies have led to reduction in nutrient leaching, increased water and nutrient uptake in citrus.

Idaho - A web-based water-budget irrigation scheduling program developed by Dr. Troy Peters, WSU, and a soil sensor based approach were compared in several Eastern Idaho farm field sites irrigated by center pivot in 2016.

(1) 4 Watermark granular matrix sensors, tipping bucket rain gage and an AgSense data logger with cell phone transmission, and web-based data storage and retrieval were used on each of 3 malting barley sites, and on 2 potato sites.
(2) 4 Decagon EC-10 soil water sensors and an Onset data logger with cell phone transmission and web-based data storage and retrieval equipment were used on 2 alfalfa sites, and
(3) 4 Decagon EC-5 soil water sensors, a tipping bucket rain gage and Decagon data loggers were used on 2 alfalfa sites.

The WSU "Irrigation Scheduler Remote" program used irrigator-selected soil and crop parameters, AgriMet daily estimated crop ET, and rainfall, and irrigator-input irrigation data to evaluate root zone available soil water and depth of irrigation water required to re-fill the root zone on a daily basis.

Soil sensors were installed at 4 depths (12, 18, 24 and 30 inches) on each site to serve as a daily comparison measurement. In the first two sets of equipment, data from the sensors and a tipping bucket rain gage (where available) were transmitted by cell phone link to a website at 30-minute intervals. This information, formatted in a user-defined fashion, was available from any mobile device (cell phone, laptop, desktop,...) that could connect with the website. Pre and post-season soil sampling at 6-inch intervals to 5 feet (or rock) depth along with rain gage data provided directly-measured water budget information. In the third set of equipment, data were downloaded at the field locations for subsequent analysis and use.

Kansas - Obj. 1: Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.
An irrigation scheduling field study concerning usage of crop coefficients based on thermal units was continued at the KSU Northwest Research-Extension Center (NWREC) at Colby, Kansas. The field data for the 2016 season has been collected and will be analyzed during the winter months. A new irrigation scheduling study involving all three scientific based approaches (soil, plant, and weather measurements) was initiated and data was collected in 2016. The data will be analyzed during the winter months. Both studies will be continued in 2016.

Obj. 2: Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.
Two field studies initiated in 2015 at NWREC to evaluate in-season fertigation with macronutrients (N and P) and microelements (primarily Zinc) for field corn production were continued in 2016. In one study, it was shown that spreading the phosphorus application out during the planting through blister kernel period increased corn grain yields by approximately 1.32 Mg/ha. In the other study, there was no advantage of applying phosphorus through SDI fertigation later than blister kernel growth stage in corn. A field study examining precision mobile drip irrigation (PMDI) where driplines are attached to a moving center pivot platform initiated in 2015 at the KSU Southwest Research-Extension Center at Garden City, Kansas was continued in 2016. A study comparing PMDI and SDI for corn production was initiated in 2016 at NWREC. A study at NWREC to evaluate the potential for narrow row spacing of corn when

grown with subsurface drip irrigation (SDI) was continued in 2016. This latter study is laying groundwork for future collaboration with Chinese Agricultural University, Beijing China. The field data for the 2016 season for all these studies has been collected and will be analyzed during the winter months. A review of subsurface drip irrigation for 4 crops (tomato, cotton, corn and onion) was published in a refereed journal. A manuscript concerning simplified equations to size SDI flushlines has been accepted for publication in a refereed journal in 2017.

Obj. 3: Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.

Presentations have been made at a regional irrigation meeting and the SWREC Field Day for irrigators and nationally for scientists and engineers at the technical conference of the Irrigation Association.

Nebraska - In 2016, Dr. Irmak installed another SDI system in eastern Nebraska (5 acres) that has 136 plots/valves that are controlled individually. The system manifold is has three mainlines with triple-stack orientation. The research project that was conducted by Dr. Irmak on SDI frequency has been published in Irrigation Science. The objectives of this research were to: (i) to evaluate the effects of subsurface drip irrigation (SDI) amount and frequency on maize production and water use efficiency, (ii) develop production functions and quantify water use efficiency, and (iii) develop and analyze crop yield response factors (Ky) for field maize (*Zea mays* L.). Five irrigation treatments were imposed: fully-irrigated treatment (FIT), 25% FIT, 50% FIT, 75% FIT, rainfed and an over-irrigation treatment (125% FIT). There was no significant ($P > 0.05$) difference between irrigation frequencies regarding the maximum grain yield; however, at lower deficit irrigation regime, medium irrigation frequency resulted in lower grain yield. There was a decrease in grain yield with the 125% FIT as compared to the FIT, which had statistically similar yield as 75% FIT. Irrigation rate significantly impacted grain yield in 2005, 2006 and 2007, while irrigation frequency was only significant during the 2005 and 2006 growing seasons (two dry years) and the interacting effect was only significant in the driest year of 2005 ($P = 0.006$). For the pooled data from 2005 to 2008, irrigation rate was significant ($P = 0.001$) and irrigation frequency was also significant ($P = 0.015$), but their interaction was not significant ($P = 0.207$). Overall, there were no significant differences between irrigation frequencies in terms of grain yield. Ky had interannual variation and average seasonal Ky values were 1.65, 0.91, 0.91 and 0.83 in 2005, 2006, 2007 and 2008, respectively, and the pooled data (2005-2008) Ky value was 1.14.

New Mexico - Objective 1: Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.

Development and Evaluation of Soil-Based Irrigation Scheduling: We continued to calibrate the soil moisture content sensor to measure the moisture content, soil temperature, and soil salinity for water, solute and energy transport through soil. The Hydra probe are used to schedule irrigation for the growing chile using irrigation with brackish groundwater and RO concentrate in the greenhouse. During 2015, more experiments were conducted using saline water and sensor calibration and irrigation scheduling was done using Hydra sensors.

Objective 2: Develop micro-irrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.

Greenhouse experiment was conducted to test three chile pepper cultivars growth, physiology and yield irrigated under a water salinity gradient using drip irrigation system. All chile pepper cultivars were salt sensitive and can be irrigated up to 3 dS/m of water.

New York - In 2016 we conducted an irrigation management trial on 3 apple farms (one each in Ulster and Orleans, and Clinton Counties) and 1 at the experimental station in Geneva by using the Cornell Apple irrigation model. Geneva was an Empire/B9 orchard planted in 2011 at 1,156 trees/acre. Hudson (Ulster) was a Gala/M9 orchard, planted in 2011 at 1,117 trees per acre. In 2015, a Plumac/B9 orchard was planted in Orleans, at 1,980 trees/acre. In Champlain valley (Clinton) a NY1/B9 orchard was planted in 2010 at 1,037 trees/acre.

At each site we managed soil water level according to the irrigation model (Cornell) to minimize water stress while other trees were left unirrigated. We assessed tree growth and tree stress, and crop yield, fruit size and fruit quality (flesh firmness and sugars) with irrigation and no irrigation.

Accumulating the water balance values from bud break gives cumulative water supply and water demand. In 2016 both in Geneva and Hudson, the cumulative graph showed that water requirement exceeded supply from rain from June through October, indicating the need to irrigate the trees during the whole summer (Figure 1).

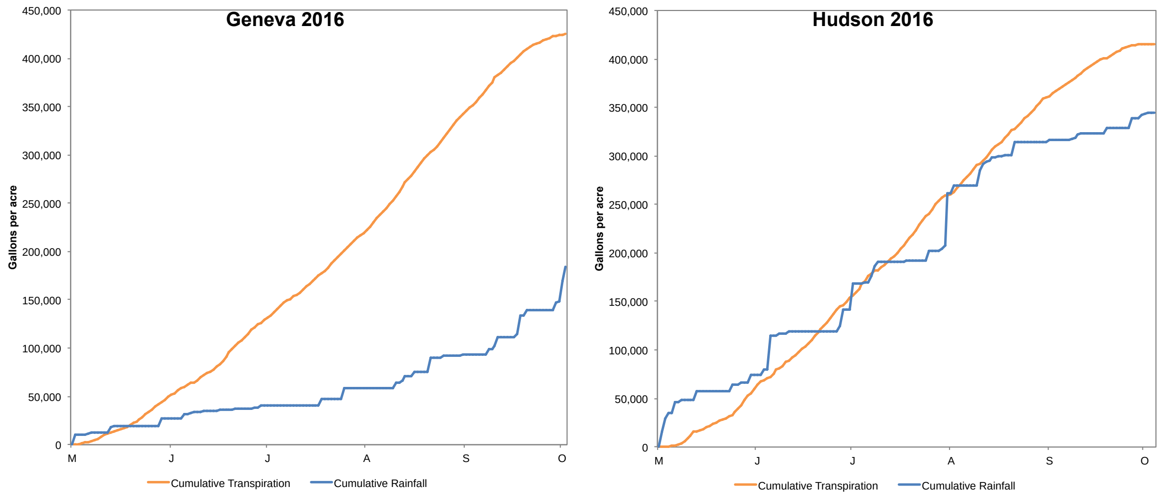

Figure 1. Cumulative tree transpiration and rainfall from May through October in Geneva and Hudson Valley, NY in 2016.

The growth, function, productivity, and water use of trees are closely tied to tree water status. By the use of a pressure chamber, we can measure the suction force that is being exerted by the tree to get the water. The more negative that value is, the more the tension the tree needs to exert, thus, the more stressed it gets. We can consider that tree stress starts with values below about -1.6 MPa. No tree stress was observed in Geneva in 2015, where no differences were observed between irrigated and non-irrigated trees (Figure 2). On the other hand, even though significant differences were observed in 2016 for Geneva, non-irrigated trees barely reached stress (Figure 2). Significant water stress was observed during all three-summer measurements in 2015 in Hudson for non-irrigated trees, with values lower than -1.6 MPa (Figure 2). In 2016 in Hudson Valley, significant differences were observed between irrigated and non-irrigated trees, but stress was not as important as the previous year (Figure 2).

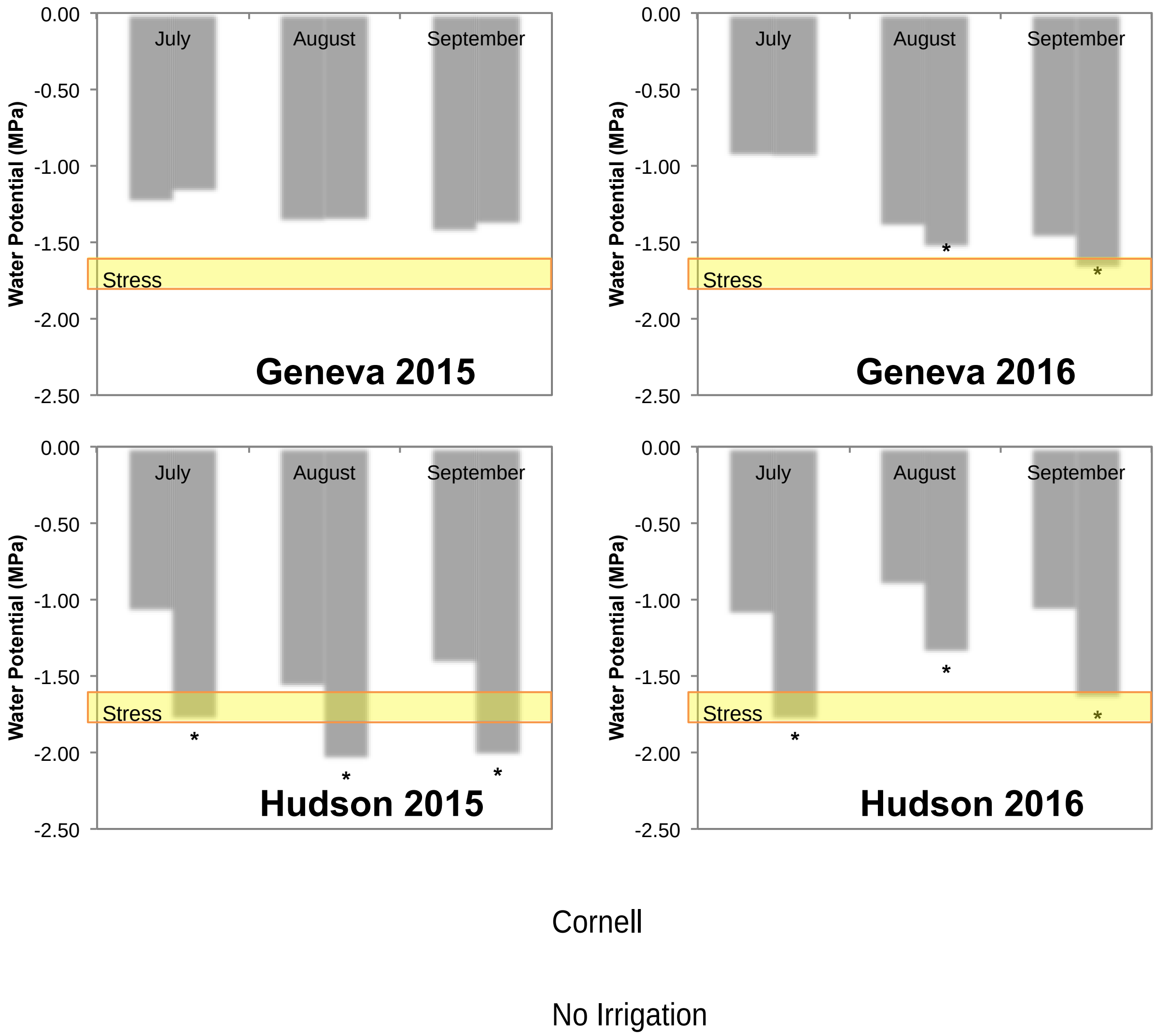

Figure 2. Tree stress during summer in Geneva and Hudson Valley in 2015 and 2016. Asterisks indicate significant differences.

Regarding yield and fruit size, no differences were observed in Geneva for both years (Figure 3), where not much tree stress was observed (Figure 2). Conversely, yield and fruit size in Hudson were significantly much smaller for those non-irrigated trees (Figure 3). Irrigated trees had an average of 1.5 kg more per tree, with bigger apples about 140 g vs 110 g (irrigated – non irrigated respectively) (Figure 3).

Considering the results from the Hudson orchard on its 5th leaf, we can estimate a loss of 235 bu/ha (1,117 trees/acre) or 414 bu/ha in case we had a high density orchard as in Orleans (1,980 trees/acre). In terms of crop value, lack of irrigation will infer a loss of 3,859 $/ha – 6,809 $/ha depending on the tree density. Usually, when the crop is light, there can be some stress with little effect, but when the crop is heavy any stress has a stronger effect. Losses due to water stress could even be worst for full productive orchards and late varieties with a longer growing season such as Fuji.

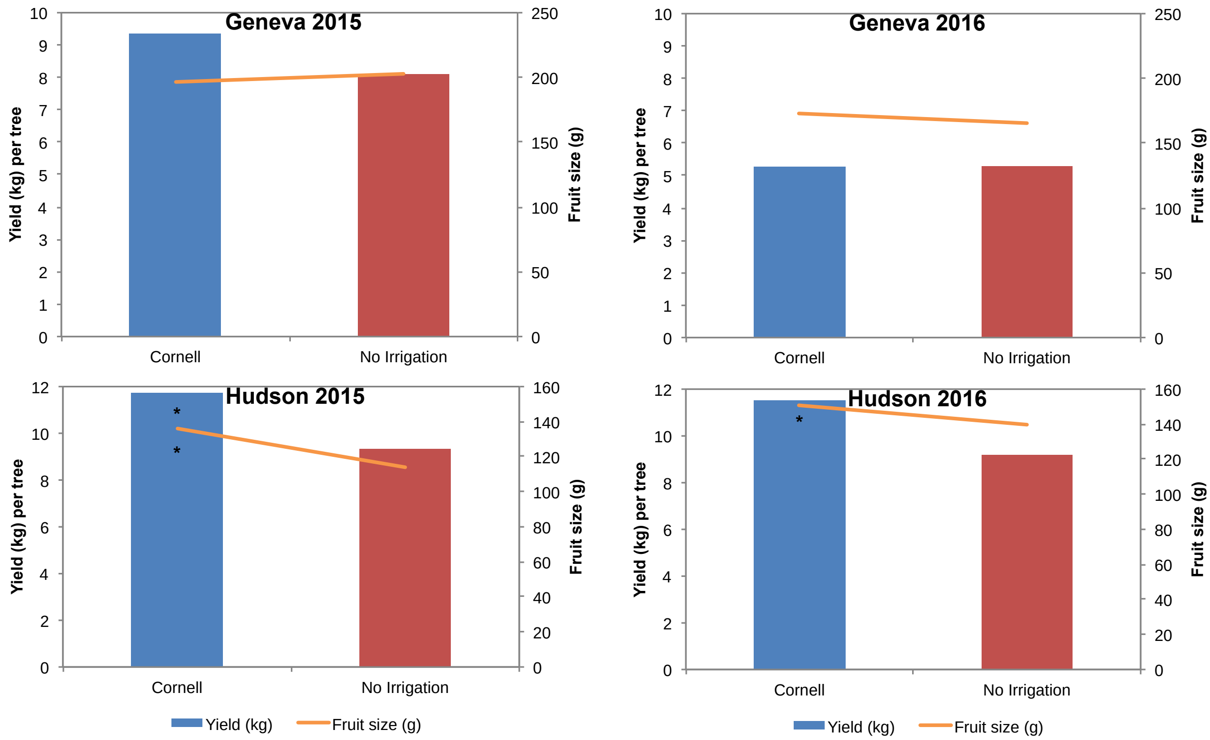

Figure 3. Yield and fruit size in Geneva and Hudson orchards in 2015 and 2016. Asterisks indicate significant differences.

Summary. Good water status is essential to maximize fruit size at any given crop load. In our trials, it was seen that in some locations irrigation was not necessary, but at the Hudson location irrigation led to better fruit size and economic value. With more precise water management growers will be able to limit plant water stress and more consistently achieve the optimum economic fruit size and calcium content for each variety. By the use of the updated Apple Irrigation website, growers can easily improve the yield of their orchards by weekly applying the right water amount.

Oklahoma - <u>Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.</u>

Numerous research and extension activities have been conducted at Oklahoma State University during the report period to promote effective irrigation scheduling methods. A recent multi-state (OK, TX, KS) project was initiated on promoting sensor-based technologies to improve irrigation scheduling, using funds provided by the NRCS Conservation Innovation Grant. As part of this project, canopy temperature and soil moisture sensors were installed at two research stations and three demonstration sites under different types of soil, crop, and irrigation systems. Two of these sites had cotton, corn, and sorghum under SDI systems. In addition, two graduate students have been recruited to work on this project, with results expected to be disseminated within the next three years.

<u>Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.</u>

A research project initiated in 2014 at the OSU Panhandle Research and Extension Center near Goodwell, OK on "Developing Management Strategies for Subsurface Drip Irrigation in the Oklahoma Panhandle" was continued during the 2016 growing season. The objective of this project was to evaluate how crop row placement will influence corn and grain sorghum yield response at irrigation regimes of 50, 75, and 100% of full irrigation. The results from the three years of this project have been disseminated at field days, meetings, and conferences and will be also published in peer-reviewed journals.

Another project evaluated the performance of a SDI system that has been used for disposing swine effluent for the past eight years. Several graduate students received hands-on training on evaluating the performance of drip systems and the results were presented at three conferences. A YouTube video was also produced and uploaded on the same topic.

A third major project was conducted on modeling salt dynamics and accumulation under SDI systems and different treatments of irrigation water quality. HYDRUS 2D/3D model has been used for modeling. Efforts have been made to improve the accuracy of input data by taking numerous samples for soil salinity and root density from southwest Oklahoma. The results will help producers better manage their SDI systems when marginal-quality water resources are used to meet full or partial crop demand.

Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.

Dissemination of information on adoption of microirrigation systems was accomplished by presenting at numerous field days, meetings, workshops, and in-service trainings.

Oklahoma - Output: Presentations were given on topics related to the project objectives at 16 conferences, workshops, and field days, reaching a total of 361 contact hours. A YouTube video was produced on evaluating the performance of SDI systems: https://youtu.be/CqGp5Eug9eg

Oregon - Objective One: Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.

A. Vineyards

In OR, WA, and CA soil-based drip irrigation scheduling is being combined with weather-based drip irrigation scheduling to optimize the yield and quality of vineyard production and financial return in cooperation with SmartVineyards. Ground truth of plant water potential is also being measured. Early during the growing season there are risks of wasting water and nutrients from over irrigation when the flush of early annual vine growth can be favored by minimal or very low levels of water stress. Later in the season, the relative amount of water stress that is most beneficial for the final product increases with the grape development stage. The ideal amount and timing (trajectory) of water stress (as measured by soil, plant, or weather data) will vary with cultivar, weather, and site. In Oregon we are trying to understand the optimal trajectory of stress over time as measured in the soil, the environment, or plant. We seek to measure the trajectory of stress. Modification of the stress trajectory holds the promise of better water use efficiency, protection of water quality, optimization of product quality, and the realization of providing a better return on vineyard investment. The approach is to collect and evaluate automated data that is interpreted and provided in real time to growers.

B. Automation of data collection and delivery

The approach taken for vineyards (above) is being tested on a smaller scale with several other crops.

C. Seed production of native plants

In Oregon fixed irrigation schedules are being compared to soil- and weather-based scheduling for seed production from native plants. Plant species required 0 to 200 mm of supplemental irrigation per year to maximize seed yield. For a given species, yield responses to irrigation varied substantially by year. We have determined that accounting for rainfall during and prior to seed production improves the accuracy of estimating the amount of irrigation required. Species differ in the preceding time interval where precipitation needs to be counted against the irrigation requirement.

D. Stevia

Although drip irrigation has been used for the production of *Stevia rebaudiana*, few people have determined the best irrigation criteria in terms of soil water tension or crop evapotranspiration. Stevia leaf production was tested using irrigation onset criteria to trigger irrigation at different levels of soil water tension. Equivalent levels of crop evapotranspiration were calculated and they were compared to reference evapotranspiration. Leaf yield and steviol glycoside content were greatest with irrigation onset criteria at very low levels of soil water tension (10-20 kPa). When correcting for crop canopy cover, leaf yield and steviol glycoside content were greatest when water application was similar to reference evapotranspiration.

Objective Two: Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.

A. Protection of fresh produce from human pathogens in irrigation water

Many fresh fruit and vegetables grown with drip irrigation are commonly consumed raw; therefore, they are subject to the FDA's provisions of the Food Safety Modernization Act. A major portion of the Produce Rule focuses on the microbiological quality of irrigation water used in the production of raw vegetable products. We conducted multi-year studies on the effect of contaminated irrigation water applied via furrow or drip irrigation on the relative fate of generic *E. coli* in water, in soil, and on onions during growth, curing, harvesting, and storage.

It is very important to have in irrigation practices to this food safety modernization act in order to use your vacation effectively for the production of fresh vegetables for the production of fresh produce. We study actual movement and the soil from water that exited drip tape. The water source is highly contaminated with *E.* ***coli***. We found that the actually bacteria stated in the soil to the water entered soil did not move appreciably towards the onion bulbs. Furthermore the back trio did survive long in the soil bacteria did not survive long in the soil or on the surface the bulbs.

Irrigation with contaminated irrigation water. We tested traces of chlorine dioxide as a possible means to lower the bacterial contamination of water used for the production of fresh produce.

1. Current subsurface drip or furrow irrigation practices do not appear to pose a significant risk for *E. coli* contamination of dry bulb onion grown on silt loam in the Treasure Valley, in part because most of the *E. coli* load in contaminated water remained close to where water entered into the soil (i.e., edges of furrows or drip tape).

2. *E. coli* had rapid die-off both in the soil and on onion exteriors in the field.

3. Onions from these drip and furrow irrigation trials that were stored in sterilized plastic containers or old wooden bins largely had no detectable *E. coli* on the bulb exteriors at the time of pack-out. There were isolated cases of *E. coli* detection on bulb exteriors but these few cases were not correlated with storage container type or irrigation water source. No *E. coli* was detected in the interior of any onion bulbs. Therefore, plastic containers do not provide added food safety value compared with wooden boxes for the storage of dry bulb onions.

4. The use of chlorine dioxide in drip irrigation systems shows promise as a means to remediate microbial contamination of irrigation water, if needed for compliance with water quality standards. The use of 1 and 3 ppm chlorine dioxide resulted in substantial reductions in *E. coli* in irrigation water clear to the end of the drip tape.

B. Fertigation

Nutrient application strategies for drip-irrigated onion was studied. Phosphorus can be a limiting factor in production. High soil pH, and cold soil complicate phosphorus availability. Supplemental phosphorus through the drip system was compared with phosphorus applied for planning. Various plant and soil sampling strategies were compared for fertigation guidelines.

C. Delivery of herbicides

Herbicides were applied through the drip irrigation system in the hopes of achieving better control of yellow nutsedge. Outlook herbicide applied through drip irrigation was successful in helping to control yellow nutsedge.

D. Delivery of fungicides

Fungicides were applied through the drip system in order to try to obtain better control of root fungi. Pink root and plate rot were not significant problems in the onion fields used for the trials and the products tested were not beneficial.

E. Adaptation of drip irrigation for potato production

Potato production is generally conducted with sprinkler irrigation. In the US drip irrigation has not been cost effective in comparison to sprinkler irrigation. We sought to change the drip irrigation configuration so that the drip irrigation system could be more efficiently utilized. Rows of potato plants were moved so that two rows of plants could be irrigated with a single drip tape. In this way only half the length of tape would be needed to grow a potato crop. Currently sprinkler irrigation is used in part to cool the environment. In order to try to cool the environment of the developing potato tubers, we tested production with potatoes planted into flat beds. Double rows of plants with drip tapes 72 inches apart used less drip tape and water in 2016 while retaining acceptable yield.

Objective 3: Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.

In objective 1 above, the automatic collection, evaluation, and deliver of soil and weather data is described. The goal is to interpret and deliver results, predictions, and projections in real time to growers' smart phones and laptops based on growers' demands. Growers are gaining real time access to information from their fields for water management decision making. These emerging tools and technology for growers have the potential to simultaneously optimize economic outcomes and minimize the losses of water and nutrients.

Oregon - Outcomes or Projected Impacts (from the project proposal)

- Soil-, weather-, and plant-based or combined microirrigation scheduling approaches will provide valuable choices for a diverse clientele of growers to improve their crop production and profitability while reducing irrigation withdrawals.
- Increased adoption and proficient management of microirrigation scheduling by growers will improve water productivity and promote improved water quality over a wider range of end-user characteristics and constraints.
- Risks of negative impacts to environment, soil, and water quality that affect all of society will be minimized through reduced leaching or other off-site /non-target chemical movement possibly opening up previously non-productive lands to microirrigation.
- Benefits of microirrigation to growers will be more fully realized through application of improved fertigation practices that will better match fertilizer applications (rates, timing, placement and formulations) to crop requirements.
- Conceptualization and generalization of microirrigation design and management procedures and tools will allow for growers, technical service providers, dealers, and industry to communicate more easily the requirements and preferences for new system installations.
- Improved design and management procedures for SDI will allow broader penetration of microirrigation into regions of the country where adoption has been limited.

- Comparisons of alternative irrigation systems will allow growers to make the best system choice for their operations and will allow them to optimize performance of existing systems.
- Internet-based decision tools and apps (for smartphones, tablets, etc.) will provide convenient, easily updated, and audience-tailored content to help end-users improve irrigation scheduling, water and nutrient management, and system design.
- Expansion of existing websites and accessibility of publications will allow for increased regional, national and international adoption of microirrigation technology.
- Educational events tailored to the audience abilities and needs will increase adoption and correct usage of microirrigation.
- Technical sessions and/or conferences will bring together experts representing different approaches to microirrigation; expand the knowledge base; improve networking of scientists and contribute to a more integrated approach to this field of research and education.
- Increased collaboration between public and private entities will help to increase adoption of microirrigation on a much broader scale and will improve the correct implementation of this technology.

Texas - Objective 1: Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.

Accomplishments: Grain sorghum and corn were produced with subsurface drip irrigation (SDI) at the USDA-ARS laboratory in Bushland, Texas in 2015 and 2016, respectively, in two 4.7-ha fields containing large weighing lysimeters. Two additional 4.7-ha fields containing large weighing lysimeters were located adjacent to the SDI fields; these were planted and managed in nearly the same way as the SDI fields (crops, agronomy, and tillage) except irrigation was by sprinkler. For the two SDI fields and one sprinkler field, irrigations were scheduled to replace full crop evapotranspiration (ET) in 20-mm increments; in the second sprinkler field, irrigations were applied at 75% crop ET. Crop ET was measured by the lysimeters and estimated by neutron probe using a soil water balance (where probe access tubes were located both in the lysimeters and in the surrounding fields. In-situ soil temperature, in-situ soil heat flux, radiometric soil and canopy temperature, and micrometeorological variables were measured at each lysimeter. Although irrigations were scheduled by soil-based methods, the additional radiometric temperature and micrometeorological measurements will be used to further develop mass and energy balance models for crops grown under sprinkler and SDI; these models will have direct application in plant- and weather-based irrigation scheduling methods.

Objective 2: Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.

Accomplishments: The two SDI fields described in Objective 1 were based on designs and management practices developed from previous research at USDA-ARS, Bushland, Texas and partners at Texas A&M AgriLife Research and Extension. The SDI lateral depths were buried and maintained at ~0.22 m below the soil surface and spaced at 1.52 m. Crops were flat-planted in rows spaced 0.76 m, resulting in SDI laterals being located in alternate interrows. Furrow dikes were installed in each interrow following crop establishment to control run on and run off of surface water. Following crop harvest in 2015, crop residue was left on the surface during the winter, but shredded and incorporated into the soil in time for planting in 2016. However, crop residue left on the soil surface results in more favorable rodent habitat; the SDI laterals suffered extensive rodent damage, requiring an inordinate amount of labor for repairs. Therefore, crop residue will be incorporated into the soil earlier to discourage rodents, but recognizing that this carries a significant caveat. The Pullman clay loam and other soils prevalent in our region are prone to crusting following even light wetting events, and crusting of bare soil results in much greater wind erosion potential, which is a very serious concern during high wind periods typical in the spring season. For bare soil, diligence is then required to roughen the soil surface following crusting, which is effective in reducing wind erosion at our location.

Objective 3: Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.

Accomplishments: Early season soil water evaporation losses (i.e., during sparse canopy cover) were up to 40% less for SDI compared with sprinkler, as measured by the weighing lysimeters. More detailed measurements of soil water evaporation using microlysimeters are currently under analysis. Although crop ET was sometimes larger for SDI compared with sprinkler later in the season when plants were fully developed, SDI resulted in greater seasonal crop water productivity. These results will be disseminated to university partners to develop extension publications, and presented at producer-oriented conferences, workshops, seminars, and field days.

Virgin Islands - Greenhouse production of slicing cucumbers in the U.S. Virgin Islands (1st crop cycle)

Cucumber is one of the major vegetables in greenhouse production. Little information is available regarding the cultivation of cucumbers in closed environment in the U.S. Virgin Islands. Our study evaluated the production of slicing cucumbers in greenhouse under different substrate volumetric water contents (VWC) applied using low-cost open-source microcontrollers. We tested four cucumber varieties (‘Boa’, ‘Bomber, ‘Corinto’ and ‘Summer Dance’) and three substrate VWCs to trigger irrigation (0.24, 0.36 and 0.48 m^3/m^3), on a split-plot CRD and three replications. Plants were transplanted into 9.45-L pots with Pro-Mix BX Mycorrhizae: perlite substrate (70%: 30%), trained on a vertical plastic line, and fertigated with calcium nitrate (150 and 140 mg/L Ca and N) and 10-30-20 peat-lite plant starter fertilizer (30 mg/L N). We assembled two independent and fully automated irrigation systems using a Mega 2560 board (Arduino), a logging shield (Adafruit), eighteen 10HS soil moisture sensors (Decagon), three 5-VDC 8-module relay drivers (SainSmart) and eighteen 24-VAC 2.54-cm solenoid valves (RainBird) connected to a 12/24-VDC 500-VA 31EJ02 transformer (Dayton). The power line was protected with a 3400-J 51110-SRG surge protector (Leviton). The system was powered using a 20-W Infinium solar panel (ML Solar) connected to a 12/24-VDC 10-A 1210RN solar charge controller (EPSolar) and two 12-VDC 7.2-Ah rechargeable batteries (Yuasa). Irrigation was installed using a manifold built with 2.54-cm PVC pipes, one solenoid valve and 1.9-cm polyethylene tubing with 4-L/h drip emitters connected to one O-ring tubing per plant. When the soil VWC dropped below the thresholds, irrigation was turned on for 1 min. The soil moisture sensors malfunctioned due to a defective internal part, not controlling the irrigation properly. Irrigation was controlled manually every other day. The three VWC treatments were averaged, resulting in nine replications per variety. ‘Corinto’ (22,436) and ‘Boa’ (20,000 kg/ha) total yield were higher than ‘Summer Dance’ (10,604) and ‘Mountie’ (10,435 kg/ha) ($p=0.0001$). Marketable yield was respectively 85%, 91%, 63% and 40% of the total yield ($p<0.0001$). Total number of fruits per plant were 9.6 for ‘Corinto’, 7.1 for ’Boa’, 4.7 for ‘Mountie’ and 3.8 for ‘Summer Dance’ ($p<0.0001$). Fruit width, hardness and sugar content were not significantly different ($p>0.05$). Fruits were shorter on ‘Boa’ (18.7) and ‘Corinto’ (19.7 cm) compared to ‘Mountie’ (24.2) and ‘Summer Dance’ (25.7 cm) ($p=0.0180$). Based on our results, fully functional sensors are necessary to control irrigation properly. ‘Corinto’ and ‘Boa’ are the recommended varieties for greenhouse cultivation in the U.S. Virgin Islands.

Mulching strategies using conservation tillage for weed management in tropical organic hot pepper cropping systems

Soil conservation and effective weed management are generally conflicting objectives in tropical organic cropping systems where tillage is the primary means for weed suppression. Cover crops, conservation tillage, and mulching are known practices that provide numerous ecosystem services, but are seldom incorporated together into an integrated cropping system plan. The primary objective of this research is to evaluate a holistic approach to soil conservation that provides weed suppression in tropical organic cropping systems. Experiments were conducted at the Agricultural Experiment Station on St. Croix, USVI in 2015 and 2016 at two independent field sites. Trials began with the establishment of sunn hemp (*Crotalaria juncea* L.) in all experimental areas on October 16, 2015 and terminated on January 11, 2016. Four treatments were arranged in a RCBD split with two weed removal frequencies (1 and 3 weeks), and replicated three times. Treatments included: 1) sunn hemp mulch (SHM), 2) sunn hemp mulch plus hay (SHM+hay), 3) sunn hemp mulch plus black landscape fabric (SHM+fabric) and 4) sunn hemp mowed and incorporated that served as a check plot (SH+none). Sunn hemp mulch was generated using a no-till roller-crimper. Peppers (*Capsicum annum* L.) were transplanted into treatments on January 14, 2016. Following treatment establishment, irrigation was performed using weather-based evapotranspiration calculations and fertigation was used in accordance with best management practice recommendations. Above-ground biomass of sunn hemp at termination did not differ between fields; and measured 3,717 kg ha^{-1} in field 1 and 4,367 kg ha^{-1} in field 2. In-bed weed suppression at three weeks after pepper transplant (WAT) was greatest for SHM+fabric, followed by SHM+hay, and lowest for SHM and SH+none treatments. At six WAT, SHM+fabric provided the greatest weed suppression with similar results for the remaining three treatments in field 1. In Field 2, SHM+fabric suppressed weeds as well as SH+none and SHM+hay. A similar trend was observed at nine WAT for both fields as described for field 1. Low frequency weeding at three-week intervals was generally as effective as weekly weed removal resulting in similar pepper yields. Overall, the SHM+fabric and SHM+hay treatments had the greatest Jalapeno yields with no differences between the SHM and SH+none treatments. Serrano pepper yields were greatest in the SHM+fabric, SHM+hay, and SH+none treatments; with the lowest yields recorded in the SHM treatment. Results indicate that soil conservation need not be compromised at the expense of weed suppression through the implementation of integrated mulching strategies.

Washington State - Obj. 1: Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.

Three field research locations are being used to collect data from treatments intended to quantify potential to sustain fruit production in vineyards during future periods of low water availability in the Yakima Valley of Washington State. This area is primarily, if not wholly dependent, on irrigation water released from winter snowpack in the Cascade Mountain range. Two of these field locations are cited in commercial wine grape vineyards with grower/producer cooperators and activities are guided by an industry advisory committee that meets quarterly with the research team conducting these experiments. Treatments involve the application of season-long deficit irrigation by deep subsurface micro-irrigation and at rates equivalent to 60, 30, and 15 percent of the commercial irrigation rate. Plant water stress was measured a selected dates during the 2016 growing season using on-plant measurements by the pressure bomb technique and compared with remote sensing images using near-IR and multi-spectral cameras. Another experiment is using similar treatments and methods to determine impacts of these techniques in a Concord grape vineyard located at the WSU Irrigated Agriculture Research and Extension Center near Prosser. The fourth field experiment is located within a commercial wine grape vineyard near Benton City and is contrasting water loss from a vineyard using an Eddy Covariance flux station with the estimated ET loss and recommended water replacement using the FAO P-M method. These data are currently being reduced and analyzed after completion of the 2016 growing season. Additionally, both fruit quantity and quality measurements are being analyzed to determine water: fruit production efficiency for future recommendations to growers in this region.

Obj. 2: Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.

Our hypothesis is that subsurface irrigation applied directly into the vine's lower root-zone can result in both greater water use efficiency and improved fruit quality over surface applied drip irrigation. A randomized complete block design with three replications of each treatment and a split plot design to compare pulse and continuous irrigation schedules were used with season-long deficit irrigation treatments at Kiona Vineyards in the Red Mountain AVA of Washington. During 2015-2016, over 800 vines received subsurface drip irrigation applied by direct root-zone (DRZ) delivery at depths of 1, 2 or 3 feet below ground via vertically installed hard plastic tubes. Subsurface irrigation was delivered as either continuous or pulsed application and compared to surface drip irrigation application on an additional 180 vines managed to meet commercial production and quality goals.

Obj. 3: Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.

Our lab group is developing a web-site https://labs.wsu.edu/jacoby/ inform our grower audience about our most current research activities and findings. Additionally, we participate in field days to engage growers with on-site applied research each growing season, present posters and oral reports of our research at annual grower meetings such as the Washington Winegrowers and the Washington Grape Society, as well as national meetings such as the Irrigation Association and American Society of Enology and Viticulture. We also prepare new articles for the popular press and work closely with reporters with local and area media outlets. The project PI and a colleague presented a webinar sponsored by Decagon Devices on the topic *Growing Wine Grapes with Less Water* which featured subsurface micro-irrigation technology developed through our applied research program.

- **Milestones**: Key intermediate targets necessary for achieving and/or delivering the outputs of a project, within an agreed timeframe. Milestones are useful for managing complex projects. For example, a milestone for a biotechnology project might be "To reduce our genetic transformation procedures to practice by December 2004."

Impacts:

This section focuses on actual or intended potential long-term outcomes and impacts. Committees should build information around the activity's milestones, as identified in the original proposal. The report should also reflect on the items that stakeholders want to know, or want to see. List any grants, contracts, and/or other resources obtained by one or more project members as a result of the project's activities. Include the recipients, funding source, amount awarded and term if applicable. If the committee is filing an annual report, the impacts will cover only the current year of the project; for termination reports, list impacts from the entire span of the project.

Additional Definitions of "Impact": *The economic, social, health or environmental consequences derived as benefits for the intended users. These are usually quantitatively measured either directly or indirectly as indicators of benefits. (An example of an impact would be improved human nutrition for so many individuals through genetically engineering rice to contain the precursors to vitamin A.)*

The quantifiable difference a land-grant program makes in the quality of life for its clients and general citizenry. Supplementing that brief statement is also the definition of an impact statement: A brief document that describes the social, environmental, and/or economic difference that your research, teaching, or extension efforts have made on the public. Specifically, it states your accomplishments and the payoff to society.

- **Activities:** Organized and specific functions or duties carried out by individuals or teams using scientific methods to reveal new knowledge and develop new understanding.

Kansas - Usage of subsurface drip irrigation (SDI) continues to grow in the USA with over 310,000 hectares reported in the last USDA-NASS survey. Principal growth has been in three major crops (processing tomato, cotton and corn).

In-season fertigation of phosphorus with SDI has increased corn grain yields by 8% to a yield level of 17.1 Mg/ha.

Conceptual discussions of SDI opportunities and challenges held with Chinese colleagues in 2014 has led to adoption of solutions to corn germination problems when using SDI in the Inner Mongolia region of China. Corn germination increased 18% and corn grain yield increased 17% in a two year study. Examination of the problem led to a “scaled” solution to the particular constraints of this region.

Texas - Continued adoption of SDI in the US Great Plains and other water-limited regions will increase crop water productivity primarily by reducing soil water evaporative losses, and in many cases increasing the quantity and quality of crop produced. Increases in crop water productivity will maintain farm profitability while prolonging water resources, and enhance resiliency to climate change.

- **Milestones:** Key intermediate targets necessary for achieving and/or delivering the outputs of a project, within an agreed timeframe. Milestones are useful for managing complex projects. For example, a milestone for a biotechnology project might be "To reduce our genetic transformation procedures to practice by December 2004."

- **Indicators:** Qualitative surrogate observations or indirect measures of quantitative performance measures which permit monitoring the achievement of outcomes when direct measurement of performance is difficult, too costly, or not possible. An indicator of cultivar adoption might be seed certification records, rather than actual land area planted to that cultivar.

Publications:

Kansas –

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Lamm, F. R. 2016. Cotton, Tomato, Corn, and Onion Production with Subsurface Drip Irrigation - A Review. Trans. ASABE Vol. 59(1):263-278.

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New Mexico –

Baath G. S., M. K. Shukla, P. W. Bosland, R. L. Steiner, and S. J. Walker. 2017. Irrigation Water Salinity Influences at Various Growth Stages of *Capsicum annuum*. Ag Water Management. 179: 246-253.

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Baath G. and M.K. Shukla. 2016. Water Use and Yield Responses of Chile pepper Cultivars Irrigated with Brackish Water and RO Concentrate. Soil Science Society America Annual Meeting, Phoenix, AZ, Nov. 6-9

Baath G. and M.K. Shukla. 2016. Transpiration rate for chile peppers irrigated with brackish groundwater and RO concentrate. AGU, Dec. 12-16, San Francisco, CA.

Shukla M.K. 2016. Irrigation water management for semi-arid areas: opportunities for augmenting water resources and improving water use efficiency. College of Natural Resources and Environment, Northwest A&F University, Yangling, Nov. 8.

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Oregon –

Refereed Journal Articles

Parris, C.A., C.C. Shock, and M. Qian. 2016. Soil water tension irrigation criteria affects *Stevia rebaudiana* leaf yield and leaf steviol glycoside composition. HortSci. In press.

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Shock, C.C. 2016. Optimizing horticultural production using drip irrigation. Conference on Water and Energy Innovation for Food Security and Environmental Sustainability, Chinese Agriculture University, Beijing, China, 2 June.

Shock, C.C. 2016. Pacific Northwest Potato Research. Qinghai Academy of Agricultural and Forestry Sciences, Qinghai University, Xining, China, 12 June.

National presentations

Reitz, S.R. C.C. Shock, H. Kreeft, J.C. Klauzer, and A. Rivera. 2016. Dry bulb onion storage in sterilized plastic crates compared to storage in old wooden boxes. American Society of Horticultural Sciences, Atlanta, GA. 10 August. https://ashs.confex.com/ashs/2016/meetingapp.cgi/Paper/25083.

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Texas –

Publications

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Colaizzi, P.D., S.R. Evett, D.K. Brauer, T.A. Howell, S.A. O’Shaughnessy, and J.A. Tolk. 2015. Water and energy partitioning of a row crop under sprinkler and subsurface drip irrigation. Sino-USA Water Saving Technologies Flagship Program Conference, 9 Nov. 2015, Long Beach, CA.

Evett, S.R., D.K. Brauer, P.D. Colaizzi, J.A. Tolk, and S.A. O’Shaughnessy. 2015. Weighing lysimeter measures of evaporative losses and water use efficiency SDI and sprinkler irrigation systems compared for corn and sorghum. Irrigation Workshop, 15-17 Oct. 2015, Yangling, China.

Evett, S.R., R.C. Schwartz, C. Clewett, S.A. O’Shaughnessy, and P.D. Colaizzi. 2015. Current developments in soil water sensing for climate, environment, hydrology, and agriculture. Seminar at Texas A&M University, 28 Oct. 2015, College Station, TX.

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Washington State –

Symposium and Conference Proceedings

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Zuniga, C.E., L.R. Khot, **P.W. Jacoby**, and S. Sankaran. 2016. Remote sensing based water-use efficiency evaluation in sub-surface irrigated wine grape vines. Proc. SPIE 9866, Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping. http://dx.dpi.org/10.1117/12.2228791/.

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Jan. 9-10, New Orleans, LA

<u>Extension/Outreach Presentations/Posters</u>

Khot, L.R. and **P.W. Jacoby.** 2016. Growing vines with less water: Use of remote sensing and new irrigation methods to increase water conservation in wine grape production. Decagon Webinar Series, October 27. Pullman, WA

Jacoby, P.W. 2016. Direct root-zone irrigation in vineyards. *In*: WSU Viticulture and Enology Extension News, p. 8, spring ed. http://www.wine.wsu.edu/research-extension.

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sub-surface irrigation to regulate wine grape physiology. Ann. Conference, NW Center for Small Fruits Research, Dec. 8. Kennewick, WA

Jacoby, P.W. 2016. Impacts of season-long deficit irrigation on canopy growth and stress physiology of wine grapes. Vit. & Enol. Extension Field Day, Benton City, WA

Thompson, J.R. and **P.W. Jacoby. 2016**. Deep subsurface drip irrigation for vineyard application. SURCA – WSU Showcase Event. Mar. 25, Pullman, WA (Crimson Award Recipient)

York, Z.B., **P.W. Jacoby**, R.T. Peters, S. Sankaran, L.R. Khot, and J.R. Thompson. 2016. Deep subsurface irrigation in Concord vineyards. SURCA – WSU Showcase Event, Mar. 25. Pullman

Jacoby, P.W. 2016. Use of subsurface irrigation to increase water use efficiency and water conservation in specialty crops. Presented to Grape Technology Group organized by Gwen Hoheisel. Feb. 4, Prosser, WA