Oklahoma Water Resources Center

2016 Annual Research Report

Research conducted March 1, 2016 – February 28, 2017

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OWRRI Program

Introduction

The Oklahoma Water Resources Center (OWRC) was under the leadership of Dr. Garey Fox (Director) and Mrs. Leslie Elmore (Program Coordinator) through December 2016. As of December 2016, Interim Director, Dr. Justin Quetone Moss, assumed leadership of the OWRC. Significant progress was made in 2016-2017 to address key priority research areas, extension, outreach and information transfer, and education related to water resources in Oklahoma and the region.

The OWRC successfully administered three USGS 104(b) projects in 2016-2017. These projects included: "Algal Remediation of Waste Water Produced during Hydraulic Fracturing" with Principal Investigator (PI), Dr. Nurhan Dunford; "Western Oklahoma Irrigation Water and Energy Audits: Findings, Recommendations and Educational Materials" with PI, Dr. Scott Frazier; and "Evaluating the Reuse of Swine Lagoon Effluent and Recycled Municipal Water for Agricultural Production" with PI, Dr. Hailin Zhang.

The OWRC initiated a new Water Research Faculty Fellow Program through the Thomas E. Berry Professorship in Integrated Water Research and Management. This program recognizes faculty, Extension educators, and district specialists who are making outstanding contributions in Research, Extension, or Education in Water Resources. The 2015-2017 Berry Fellows and their projects included:

- Dr. Francisco Ochoa-Corona, Associate Professor in Entomology and Plant Pathology “Field Deployable Water Filtration System with Bioinformatics and Pyrosequencing for Effective Monitoring and Survey of Water-Borne Viruses.

- Dr. Glenn Brown, Regents Professor of Biosystems and Agricultural Engineering “The Application of Fly Ash to Treat Storm Water around Poultry Houses.

- Ms. Cheryl Newberry, District Program Specialist-4H, Oklahoma Cooperative Extension Service “Youth Water Education and Water Fairs.

- Dr. Jason Warren, Associate Professor of Plant and Soil Sciences “On-Farm Subsurface Drip Irrigation: How does Soil Type Impact Efficiency and Management

The 2016-2018 Berry fellows and their projects included:

- Dr. Tyson E. Ochsner, Associate Professor of Applied Soil Physics and Sarkeys Distinguished Professor in the Department of Plant and Soil Sciences – Improved seasonal streamflow forecasts to inform surface water management in Oklahoma.

- Dr. Jason R. Vogel, Associate Professor and Stormwater Specialist in the Department of Biosystems and Agricultural Engineering – Using Oklahoma-sourced Biochar for Removal of Pesticides in Runoff.

A short summary of other accomplishments for FY2016 include:

Dr. Garey Fox, previous Director, served as Lead Scientist for the NSF EPSCoR Track I Grant titled “Adapting Socio-Ecological Systems to Increased Climate Variability” ($20 million project) and brought vision, leadership, and organization to the research group.

Lead and managed Oklahoma Water Resources Center (OWRC) staff (Leslie Elmore, Program Coordinator). Dr. Garey Fox also expanded staff and responsibilities through the NSF EPSCoR project with Emma Custer, Program Coordinator and Dr. Ron Miller, Post-doctorate Researcher.

Successfully and efficiently managed and administered the USGS 104b grant program through the USGS and the National Institutes for Water Resources (NIWR), including active participation in the NIWR annual meetings in Washington DC and educating the Oklahoma congressional delegation on the impacts and importance of the program to Oklahoma.

Administered programs for four previously selected fellows and selected two new recipients for the Thomas
E. Berry Faculty Fellows Program which was established with support from Dick and Malinda Fischer.

Generated and disseminated high quality Oklahoma Cooperative Extension Service media (e.g., videos, articles, and fact sheets) including the newly Foundations of Oklahoma Water videos, promotional Water Fair videos and articles.

Organized and hosted the 5th Annual Student Water Conference at the Oklahoma State University Student Union with presentations from 44 students representing 10 universities from across the country and a keynote presentation from Dr. Ty Ferre, Professor, University of Arizona and 2016 Darcy Lecturer.

The OWRC website was a highly successful tool for dissemination of water research and extension information with 42,359 page views (39,869 in 2015) and 12,814 users (16,612 in 2015).

Successfully transitioned leadership from the previous Director, Dr. Garey Fox, to the current Interim Director, Dr. Justin Quetone Moss, in December 2016. This included Dr. Fox and Dr. Moss co-hosting and running the OWRC Winter Water Research Advisory Board Meeting in December 2016.

Research Program Introduction

FY2016 projects:

The Oklahoma Water Resources Center successfully administered three research projects funding in 2016. They were: Algal Remediation of Waste Water Produced during Hydraulic Fracturing with PI: Nurhan Dunford; Western Oklahoma Irrigation Water and Energy Audits: Findings, Recommendations and Educational Materials with PIs: Scott Frazier, Saleh Taghvaeian, Jason Warren, Don Sternitzke, and Cameron Murley; and Evaluating the Reuse of Swine Lagoon Effluent and Recycled Municipal Water for Agricultural Production with PIs: Hailin Zhang, Doug Hamilton, Saleh Taghvaeian, and Scott Carter.

Selection of FY2017 projects:

Research pre-proposals were solicited from any Oklahoma university starting in late April 2016. One-page pre-proposals were due in July 2016. The 25-member Water Research Advisory Board (Board) then reviewed and discussed these pre-proposals at the summer Board meeting.The Board selected projects to submit full proposals. Six full proposals were submitted (one researcher declined to submit two proposals). Each full proposal was externally reviewed by three reviewers solicited by Dr. Garey Fox, Director of the Oklahoma Water Resources Center, with guidance from the PI. Reviewers included at least one reviewer with detailed knowledge of the project objectives as they relate to Oklahoma water and two experts in the broader scientific field outside of Oklahoma. In December 2016 the researchers presented their proposals to the Board in 30-minute presentations in Stillwater, OK. After the presentations, the Board deliberated on the selection of the top proposals. The Oklahoma Water Resources Center provided a ranking/classification scheme that summarized the external reviews. This input assisted the Board in incorporating the feedback from experts in each of the fields. The following projects were selected for funding:

Utilizing native isopods to assess the connectivity and quality of Oklahoma groundwater PI: Ronald Bonnett and Alexander Hess, University of Tulsa Summary: The convoluted karstic drainages of the Oklahoma Ozarks have challenged mapping of hydrological connectivity among its extensive groundwater networks. The geographic distributions of species reflect their habitat associations and dispersal limitations. For aquatic species this information and can be used to understand variations in water chemistry and hydrologic patterns. Freshwater isopods are excellent models for such studies due to their ubiquity in both surface and subterranean systems. Here we use a DNA barcoding approach to determine the distribution and diversity of isopods in aquatic systems of the Oklahoma Ozarks. We will test whether the distributions of these species correspond to watershed boundaries at different geographic scales, and evaluate subterranean and surface connections. We will also examine water chemistry parameters associated with the presence and density of isopod species to assess their utility as bioindicators. Due to their reliance upon watershed connectivity for dispersal and their role in nutrient cycling, groundwater isopods in the Ozarks represent a compelling group for understanding regional hydrologic connectivity and health of the watershed.

Combining remote sensing and in-situ data to estimate soil moisture across mixed land cover types PIs: Tyson Ochsner, Briana Wyatt (Gradaute Student PI), and Chris Zou, Oklahoma State University Summary: Soil moisture is an essential variable which affects climatic, hydrological, agricultural, and ecological systems. Due to the impact of soil moisture on important earth processes, in-situ soil monitoring networks are becoming more prevalent. However, the majority of soil moisture monitoring networks consider only one land cover type, usually grasslands, which limits the use of these data for areas with mixed land cover types. The Oklahoma Mesonet has monitored soil moisture at over 100 grassland sites for nearly two decades, but large areas of forest (12 million acres, or 28% of the state's land area), cropland (~8 million acres, or 18%), and other land cover types have gone largely unmonitored. While the current long-term soil moisture record is useful for a number of applications in many research areas, a major limitation of the current data is that it has been collected exclusively in grassland ecosystems and does not reflect soil moisture conditions under other land covers. However, remote sensing by satellites has led to the availability of high-resolution vegetation indices (VI) data, and we hypothesize that these data, along with in-situ meteorological data from the Mesonet, may be incorporated into a simple water balance model to effectively estimate root-zone soil moisture at sites throughout Oklahoma. These estimates may then be used to train a computational model to estimate soil moisture across the entire state, regardless of land cover. The proposed generalized soil moisture estimation method would provide new, much needed information relevant to a number of disciplines, including hydrology, water resource planning, climatology, and agriculture. The long-term goal for this project is to increase scientific understanding of the variability of soil moisture under the many cover types found throughout Oklahoma and to create a new, general method of large-scale soil moisture estimation and mapping. We will reach this goal by 1) utilizing vegetation indices (e.g., NDVI or ERI) data collected by the MODIS satellite and Mesonet meteorological data to develop an efficient computational model capable of estimating soil moisture under various land cover types found in Oklahoma, and 2) validating estimated soil moisture values using in-situ soil moisture monitoring in multiple vegetation types throughout Oklahoma.

The impact of drought on vegetation water use in different climatic divisions across Oklahoma PIs: Saleh Taghvaeian, Kul Khand (Gradaute Student PI), and Prasanna Gowda, Oklahoma State University Summary: Water consumed by vegetation is a major component of surface water budget, having a significant impact on water availability at variable scales. The state of Oklahoma lies between the eastern humid and western semi-arid climates including nine climatic divisions (CDs) delineated based on precipitation and temperature gradients. The southeast CD 9 is humid with largest average annual rainfall (57 in), whereas the Panhandle CD 1 is the driest with only 17 in of average annual rainfall. The water use of different types of vegetation is impacted by the variation in climatic conditions, with the same vegetation requiring more water in semi-arid regions than in humid environments. At the same time, the water use and its role in plant health and survival is influenced by drought, a phenomenon that occurs frequently in Oklahoma. Understanding the complex and spatially-variable interactions among vegetation water use, climatic factors, and drought can provide decision maker with critical information required to develop and optimize water management plans to conserve available water resources for agricultural and natural ecosystems. The main objective of this study is to investigate the variations in water use responses for different vegetation types in humid and semi-arid regions of Oklahoma under different levels of drought severity. In this study space-borne remote sensing techniques will be combined with ground-based data to conduct the water use analysis. Freely accessible satellite imagery at appropriate spatial resolution will be used to provide information at individual farm level and sub-basins. A surface energy balance model will be identified and used to map water use estimate across different climatic regions for multiple years with and without drought. The meteorological information will be obtained from the Mesonet weather stations located at each CDs. The study will cover multiple drought events specific to each of CDs including the exceptional drought of 2012. The drought indicator products will be obtained from the US Drought Monitor and other appropriate sources. Landcover data from the USDA National Agricultural Statistics Service (CropScape) will be used for identification of different vegetation types. Irrigated and non-irrigated cropland will be differentiated for water use comparisons based on remotely sensed vegetation indices and surface temperature. Multiple samples of varying sizes from each of the landcover type will be extracted and coupled with drought indices for analyzing water use signals at different climatic environments under variable drought levels. The results from this study include the time series plots of ET from different landcovers. ET maps showing the averages and anomalies at multiple time scales such as month, season and year. Results from this study and meteorological observations from Mesonet stations expect to provide the critical information affecting the water balance at two different climatic divisions of Oklahoma. We expect to see varying ET responses during normal and drought years from different landcovers. For example, above or below average ET among irrigated and non-irrigated agriculture and grasslands during normal year versus during the drought year. Drought impact is expected to be severe and last longer in non-irrigated grasslands or croplands and in forests with lower access to groundwater. These inter-comparisons of ET from multiple landcovers at varying time scale and integrating meteorological information from Mesonet stations expect to improve our understanding on relationships between drought and ET in humid and semi-arid CDs of Oklahoma.

Economics of groundwater interaction and competing crops PIs: Arthur Stoecker and Karthik Ramaswamy (Gradaute Student PI), Oklahoma State University Summary: This study seeks to observe the benefits and costs due to interaction in groundwater when distinct groups of producers compete for a common supply of groundwater. Intensive use and low recharge means, producers in the Oklahoma Panhandle overlying Ogallala aquifer face continuous declines in groundwater levels. Recent study and field experiments have shown 145 bushels of grain sorghum can be produced with 10 acre-inches of irrigation while corn requires 22 acre-inches to produce 190 bushels. Research has shown producers can increase total discounted profits by choosing crops that use less water per acre but yield higher profits per unit of groundwater and by irrigating for a longer period of time. However, groundwater is a common pool resource. Part of the groundwater from a conserving producer may flow to a non-conserving neighbor thus reducing incentives for conservation. If several producers form their groundwater control groups, how large a contiguous land they must control to capture the benefits from an optimal long-term use? Two groups of producers are considered. Group one producer's chooses the crop (corn) and irrigation level to maximize annual profits until the aquifer is completed. The second group attempts to maximize the NPV of groundwater reserves. The second group may choose less intensively irrigated sorghum, which requires less water per acre but returns more profit per unit of water than corn. Group two may initially earn lower profits per acre than group one but may ultimately earn greater discounted profits by irrigating for more years. EPIC simulation was used for crops on 640-acre field irrigations for CP and SDI system with well capacities from 100 to 800 gallons per minute and plant water-stress factor from 0.30 to 0.90. The water use, net returns and irrigation investments (system replacement intervals) are then incorporated into a 60-year Mixed Integer Programming (CPLEX) model for a 640-acre field with four existing wells. In our model, the area controlled by producers in group two is surrounded by producers in group one, but two areas are linked by a groundwater model. The size to the area controlled by group two is taken as one, nine, twenty-five square miles. Based on USGS estimates of specific yield and hydraulic conductivity, possible drawdowns and well yields are estimated using the Cooper-Jacob approximation. Two levels of hydraulic conductivity will be considered. The results are expected to illustrate the effect on the size of the conserving district and hydraulic conductivity in the aquifer on the incentives for producers in group two.

The following pages contain the project annual reports for the projects selected for funding in FY2016. These include: Algal Remediation of Waste Water Produced during Hydraulic Fracturing with PI: Nurhan Dunford; Western Oklahoma Irrigation Water and Energy Audits: Findings, Recommendations and Educational Materials with PIs: Scott Frazier, Saleh Taghvaeian, Jason Warren, Don Sternitzke, and Cameron Murley; and Evaluating the Reuse of Swine Lagoon Effluent and Recycled Municipal Water for Agricultural Production with PIs: Hailin Zhang, Doug Hamilton, Saleh Taghvaeian, and Scott Carter.

Information Transfer Project

Basic Information

Title:	Information Transfer Project
Project Number:	2016OK323B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	3
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Justin Quetone Moss

Information Transfer Program Annual Report FY2016

An essential part of the mission of the Oklahoma Water Resources Center is the transfer of knowledge gathered through university research to appropriate research consumers for application to real-world problems in a manner that is readily understood. In 2016, the Oklahoma Water Resources Center engaged in four primary efforts: (1) publication of a newsletter containing previous grant impact statements, (2) meetings with state agency personnel, (3) maintenance of an up-to-date website, and (4) holding of an annual Water Research Symposium and a Student Water Conference.

The following accomplishments were made for the information transfer project in FY2016.

- Developed and hosted OSU Water Week, March 21-26, 2016, in conjunction with UN World Water Day 2016.
    - Activities included:
        - A week-long photo challenge over water and jobs
        - A flash talk series with faculty researchers to give brief updates of the Thomas E. Berry Fellows Program, the DASNR Water Grants Program, and the USGS 104b Grants Program
        - A water waste photo challenge in cooperation with the OSU Sustainability and Energy Management Department
        - A water related movie viewing with the BAE Graduate Student Association
        - A tour of the OSU water treatment plant
        - A “choose water over soda” challenge with the US Green Building Council
        - The Student Water Conference
        - A pledge to “boot the bottle” and to drink water from reusable bottles rather than purchasing bottled water.
        - A stream clean-up in Little Boomer Creek
- OSU Water Expertise Booklet was updated to include the most recent list of water Research and Extension professionals
    - This booklet has helped to identify recent publications, fact sheets, and watershed projects of individual scientists and extension professionals
- Continued distribution and strengthening of the *Aquahoman* newsletter (Volume 12, Issues 1-3).
    - The *Aquahoman* was published and distributed in March, June, and September 2016. It is sent to approximately 850 subscribers, now provides USGS 104b (OWRRI) grant impact statements from awards approximately 6 to 9 years ago to document the importance of the grant program at university, state, and national levels.
- Continued distribution and strengthening of the *Currents* news update.
    - Currently, in the months that the *Aquahoman* is not published, we will publish and distribute a monthly news updated titled *Currents*

    - Like the *Aquahoman*, it is sent to approximately 850 subscribers and was published and distributed in August, October, November, and December 2016
- News and Notices email updates
    - In addition to the *Aquahoman* and *Currents* newsletters, weekly to monthly "News and Notices Updates" were distributed to OWRC affiliated faculty and staff, where an e-mail update is sent on news, events, funding opportunities, new resources, and other important information
- Water seminar series
    - Dr. Bin Wang, University of Oklahoma, "Challenges in Soil Erodibility Research" – February 3, 2016
    - Dr. Garey Fox, Oklahoma State University, "Powering Oklahoma and the Nation – OSU's water research portfolio within the food-energy-water nexus" – February 17, 2016
    - Dr. Justin Quetone Moss, Oklahoma State University "Community-Engaged Research – water conservation in Oklahoma" – February 19, 2016
    - Dr. Mike Treglia, University of Tulsa, "Working Towards LiDAR-based data products for Oklahoma and their Applications in Natural Resources Research – February 19, 2016
    - Dr. Ty Ferre, University of Arizona, "Seeing Things Differently: Rethinking the Relationship Between Data, Models, and Decision-Making" – March 24, 2016
    - Michael Graves, Garver Engineering, "Oklahoma Drivers and Regulation Development for Wastewater Reuse" – May 16, 2016
    - Dr. Doug Shields, Doug Shields Engineering, "Uncertainty and Variability in Stream Restoration Designs" – June 3, 2016
    - Dr. Renee McPherson, University of Oklahoma, "Global Climate Models and Downscaling: What (the heck) are they and why should I care?" – July 12, 2016
- The OWRC website was a highly successful tool for dissemination of water research and extension information with 42,359 page views (39,869 in 2015) and 12,814 users (16,612 in 2015).
- Four Oklahoma Cooperative Extension Service fact sheets were developed, reviewed, and published
    - A OCES fact sheet, WREC-104, titled "Introduction to Groundwater Hydrology and Management" was published by Dr. Garey Fox, Dr. Saleh Taghvaeian, and Dr. Larry Sanders
    - An OCES fact sheet, BAE-1531, titled "The Ogallala Aquifer" was published by Dr. Saleh Taghvaeian, Dr. R. Scott Frazier, Dustin Livingston, and Dr. Garey Fox
    - An OCES fact sheet, HLA-6612, titled "Turf Irrigation Water Quality: A Concise Guide" was published by Dr. Justin Quetone Moss and Michael Kress
    - An OCES fact sheet, HLA-6613, titled "Turf Irrigation Water Quality: A Reference Guide" was published by Dr. Justin Quetone Moss and Michael Kress
- The 5th Annual Student Water Conference was held March 24-25, 2016
    - The event was held at the Oklahoma State University Student Union with presentations from 44 students representing 10 universities from across the country

    - The event included a keynote presentation from Dr. Ty Ferre, Professor, University of Arizona and 2016 Darcy Lecturer
- The Oklahoma Governor's Water Conference and Research Symposium was held October 11-12, 2016
    - The Conference Theme was "Weathering Oklahoma's Extremes"
    - Keynote speaker, Damon Lane, Chief Meteorologist, KOCO 5 First Alert Weather, presented "Why We Don't Understand Drought"
    - Invited speaker, Dr. Robert Glennon, presented "Our Future in a Water-Stressed World"
    - The Water Center hosted Conrad Weaver for a Q&A session following a screening of his documentary, "Thirsty Land"
    - The Cafe-Style Poster Session included 24 student presentations
    - Outstanding Poster Presenters (with prizes) included:
        - Patrick Rydzak/Jon Daniels (Oklahoma State University) for Water as a Vehicle for Waterborne Plant Pathogens and the Global Impact
        - Briana Wyatt (Oklahoma State University) for Estimation of Soil Moisture Using Remotely-sensed Vegetation Indices
        - Alex McLemore (Oklahoma State University) for Hydraulic Analysis of Established Bioretention Cells in Grove, Oklahoma
    - The oral sessions included 20 research presentations from University and Agency presenters
- Planned Conferences for 2017
    - 6th Annual Student Water Conference – Spring 2017, Oklahoma State University
    - Oklahoma Governor's Water Conference and Research Symposium – Fall 2017, Location TBD
    - Oklahoma Grows Green Industry Water Conference in cooperation with the Oklahoma Nursery and Landscape Association and the Oklahoma Turfgrass Research Foundation – November 8-9, 2017 at the Winstar Convention Center, Thackerville, OK.

Water Research Advisory Board: The Board consists of 25 water professionals representing state agencies, federal agencies, tribes, and non-governmental organizations. This advisory board was formed in 2006 to assist by setting funding priorities, recommending proposals for funding, and providing general advice on the direction of the Institute. The Board members have found that they also benefit from their involvement in at least two ways. First, they profit from the opportunity to discuss water issues with other professionals. Second, the semiannual meetings afford them the opportunity to stay informed about water research and water resource planning in Oklahoma. This is accomplished, in part, by having the investigators of the previous year's projects return and present their findings to the Board. Thus, the Board is an important part of the Oklahoma Water Resources Center's efforts to disseminate research findings to state agencies for use in problem-solving.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	5	0	0	0	5
Masters	7	0	0	0	7
Ph.D.	1	0	0	0	1
Post-Doc.	1	0	0	0	1
Total	1	0	0	0	14

Notable Awards and Achievements

None

Publications from Prior Years

1. 2015OK320B ("Threats to the Lugert-Altus Irrigation District: Untangling the Effects of Drought, Land Use Change, and Groundwater Development") - Articles in Refereed Scientific Journals - Krueger, Erik S., Yohannes Tadesse Yimam, Tyson E. Ochsner. 2017. Human factors were dominant drivers of record low streamflow to a surface water irrigation district in the US southern Great Plains. Agricultural Water Management. Volume 185, 1 May 2017, Pages 93–104.
2. 2007OK79B ("Subsurface Transport of Phosphorus to Streams: A Potential Source of Phosphorus not Alleviated by Best Management Practices") - Articles in Refereed Scientific Journals - Penn, C.J., J. Bowen, J.M. McGrath, G. Fox, G. Brown, and R. Nairn, 2016. Evaluation of a universal flow-through model for predicting and designing phosphorus removal structures. Chemosphere, 151: 345-355.
3. 2010OK180B ("Water conservation in Oklahoma urban and suburban watersheds through modification of irrigation practices.") - Articles in Refereed Scientific Journals - Boyer, T. A., Jayasekera, D.H., Justin Q. Moss. 2016. An Assessment of Oklahoma City Commercial Businesses' Willingness to Adopt Irrigation Water Conservation Methods. HortTechnology, Vol. 26(6).

Funding

Funding for the projects reported herein was provided by the U.S. Geological Survey and the Division of Agricultural Sciences and Natural Resources at Oklahoma State University. Additional support was provided by private donations to the Thomas E. Berry Endowed Professorship in Integrated Water Resources and Management and external grant funding from the NSF through a research infrastructure and improvement grant through EPSCoR and a USDA AFRI National Integrated Water Quality Program (NIWQP). Research projects through the USGS 104(b) program included in-kind services made available by the researchers' institutions. The Oklahoma Water Resources Center is grateful for their support.

Title: Algal Remediation of Waste Water Produced during Hydraulic Fracturing

Authors' Names and Affiliations: Nurhan Turgut Dunford, Professor, Oklahoma State University, FAPC Room 103, Stillwater, OK, 74078

Phone: 405-744-7062

E-mail address: Nurhan.Dunford@okstate.edu

Institution, and department: Oklahoma State University, Department of Biosystems and Agricultural Engineering

Start Date: March 01, 2016

End Date: February 28, 2017

Congressional District: Federal Congressional District: 3

Focus Category: WW, WQL, WV, TRT, WU

Descriptors: Wastewater, biological treatment, algae, hydraulic fracturing

Students: (Include number of students supported by the project during the project period in the table below.)

Student Status	Number	Disciplines
Undergraduate		
M.S.		
Ph.D.		
Post Doc	1	Biology
Total		

Principal Investigators: Nurhan Turgut Dunford, Professor, Oklahoma State University, Department of Biosystems and Agricultural Engineering

Publications: (Two manuscripts are in preparation)

1) Nan Zhou; Nurhan Turgut Dunford. ***In Press***. Characteristics of Green Microalgae and Cyanobacteria Isolated from Great Salt Plains. Trans. ASABE.
2) Nurhan Turgut Dunford. Lipid Profile of Oklahoma Native Microalgae Strains and Chemical Composition of the Bio-oil Produced by Pyrolysis of the Algal Biomass. 2017 American Oil Chemists' Society Annual Meeting and Industry Showcases, April 30–May 3, 2017, Rosen Shingle Creek, Orlando, Florida, USA.
3) Nurhan Turgut Dunford; Giovanni Lutzu. Algal Wastewater Remediation. 37th Annual Oklahoma Governor's Water Conference and Research Symposium, Norman, OK. October 22-12, 2016.

4) Nurhan Turgut Dunford. Algal Treatment of Wastewater Generated during Animal and Natural Gas Production. 2. Alg Technology Symposium, Seferihisar, Izmir, Turkey, May 24-27, 2016.
5) Giovanni Antonio Lutzu; Nurhan Turgut Dunford. Growing Oklahoma Native Microalgae Strains in Waste Water Generated during Hydraulic Fracturing for Natural Gas Production. Oklahoma Clean Lakes and Watersheds Conference, Stillwater, OK, March 29-30, 2016.

Problem and Research Objectives:

Problem statement: Oklahoma is one of the largest natural gas and oil producing states in the country. The oil and gas industry utilizes fracking technology widely and generate large volumes of wastewater (frac water). Frac water contains high concentration of inorganic salts and other organic and inorganic pollutant. The current wastewater disposal methods are costly and adversely affect underground water sources. Development of new technologies for frac water remediation and reuse is critical for the long-term sustainability of this industry and most importantly for protection of the environment, safety of the citizens and conservation of diminishing water resources.

Microalgae are ubiquitous photosynthetic microorganisms that are found both in marine and freshwater environments. They have a great potential to produce not only biomass as feedstock for renewable fuels, high-value products, food, and feed applications but also to provide a viable solution to the problem of environmental pollution. Microalgae can grow in wastewater and absorb contaminants, hence, produce biomass while cleaning of wastewater.

Objectives: The main objective of this project was to answer the following question: Can microalgae cultivation be used to treat wastewater produced during hydraulic fracturing (frac water)? The ultimate goal is to use frac water for algal biomass production while removing contaminants. The target is to clean up the water to a level that it can be re-used for irrigation or in industrial operations. The specific objectives of the proposal are as follows: 1) determine the types and concentrations of the contaminants and micro and macro nutrients present in water collected from fracking facilities operating in different regions of OK; 2) identify Oklahoma native algae strains that are capable of growing in frac water; 3) examine the contaminant removal in monocultures of microalgae; 4) examine the chemical composition of the algal biomass produced in frac water.

Methodology:

Objective 1: Both flow back and produced water samples were obtained from fracking sites operating in OK (see Table 1).

TABLE 1: Types and location of wastewater samples examined in the study.

SITE	COUNTY	WASTE TYPE
ElReno	Canadian	Flow back
Cumberland	Marshall	produced
Okarche – JR Burton	Kingfisher	produced
Okarche – Alig	Kingfisher	produced
Okarche – Santana	Kingfisher	produced
Okarche - Carol	Kingfisher	Flow back
Okarche – Judy	Kingfisher	Flow back
Okarche - Dorothy	Kingfisher	Flow back
Okarche – Judy	Kingfisher	produced

Good Laboratory Practices (GLP) for safe handling, storage and disposal practices were followed and students and employees working on the project were trained on GLP. Standard Operating Procedures (SOP) were prepared and followed throughout the project execution. The water samples were analyzed for their chemical composition using standard/official analytical protocols. The samples were analyzed for conductivity, TDS (total dissolve solids), pH, iron, aluminum, copper, boron and other heavy metals, COD (chemical oxygen demand), BOD (Biological oxygen demand).

Objective 2) The following microalgae strains were examined in this project: SP19, SP20, *Nannochloropsis oculata*, *Botryococcus brunii*, *Duneliella Tertiolacta*, *Picochlorum oklahomensis*, SP38, SP44, SP46, SP47, SP48, SP50, SP1, SP11, SP22, SP23, SP27, SP28, SP29, SP30, SP31, SP33, SP25. The screening study was carried out in 1 L sterile flasks placed in an environment controlled growth chamber which were maintained at 20^{o}C, 85 µmol/m^2/sec illumination, 12 h light-12 h dark period, 20 mL/min gas bubbling with 5% CO_2-95 % air (v/v) mixture. The growth performance of the strains were monitored through the analysis of biomass concentration in the medium and optical density measurement at 780 nm. Algae growth tests were carried out in microfiltred and autoclaved wastewater to maintain monocultures.

Objective 3) The most productive algae strain identified in objective 2 were cultivated in flow back and produced water samples. The produced biomass was separated from the growth medium (wastewater) by centrifugation after cells reached stationary growth phase. Supernatant (residual waste water after biomass removal) was analyzed for the compounds/parameters listed in objective 1. Contaminant removal efficiency was calculated for each compound/parameter as follows: Contaminant removal efficiency = [(Concentration of the contaminant in wastewater prior to algae cultivation - Concentration of the contaminant in wastewater after algae cultivation and biomass removal)/ Concentration of the contaminant in wastewater prior to algae cultivation]*100.

Objective 4) The biomass produced in objective 2 and 3 were characterized for its chemical composition. Ash, mineral and heavy metal composition and content, volatile matter, fixed carbon, high heating value of the biomass samples were determined by using standard analytical methods and Thermogravimetric Analysis (TGA).

Principal Findings and Significance:

Selected Results

Data in Table 2 clearly demonstrates the effect of culture growth medium and strain type on microalgae growth parameters and biomass production efficiency. In general, maximum biomass concentration obtained in flow back water was lower than (< 1 g dry biomass/L culture medium) that is obtained in standard media. Standard growth media are optimized for cell survival and contain all the essential nutrients for algae growth. The culture banks, UTEX and CCMP, from which the algae strains examined in this study were purchased, use standard media to maintain their culture collection.

A few strains performed similar in flow back water and standard medium, i.e. SP22. Microalgae utilizes nitrogen and phosphorous as nutrients for growth. Frac water is poor in nutrients (Table 3). To test our hypothesis that ***low biomass concentration in frac water is due to the limited nutrient availability to the cells***, a series of experiments were carried out using growth media enriched in nutrients. The experimental results support our hypothesis. Biomass concentrations in nutrient supplemented growth medium were 6.6 (SP50) and 21 (UTEX 2164) times higher than those obtained in frac water without supplementation (Table 2).

Biomass produced by *diatoms*, SP1 and CCMP2525, grown in flow back water had significantly ($p < 0.05$) higher ash content than that of filamentous, SP31, and unicellular, SP22, green microalgae (Table 4). As expected, strains with high ash content had low HHV (Higher Heating Value). The highest HHV, 21 MJ/kg, was measured in biomass produced by SP31. Biomass from the latter strain also had the highest VM (volatile matter), 79.9%, and lowest fixed carbon, 1.7%. Low ash, high VM and HHV are desirable in biomass to be used as feedstock for bioproduct manufacturing.

This study also examined chemical composition of the frac water samples collected from several wells operating in Oklahoma (Table 1). Most of the produced water samples had a dark oil layer (2% of the total sample weight) which was removed prior to microalgae growth experiments (Picture 1). Significant differences were observed in chemical composition of the samples. Table 3 shows examples of the water quality test results for flow back and produced water. Alkalinity and pH of the flow back water were slightly higher than those of the produced water, 1712 mg/L and 9 and 839 mg/L and 8.5, respectively. Boron, total dissolved solids (TDS) and chlorine contents of the produced water (114, 25000 and 13492, respectively) were significantly higher than those for the flow back water (30, 16,000 and 7065 mg/L, respectively).

Algae growth in frac water and subsequent biomass removal resulted in a significant decrease in the concentrations of many of the wastewater contaminants (Table 5). The drop in pH of the wastewater during algae growth is partly due to the CO_2 bubbling through the growth medium and carbonic acid formation. Nitrogen present in the wastewater samples was taken up and used as nutrient by algae cells resulting in 100% removal. About 65-70% reduction in TDS, over 90% reduction in alkalinity and boron content and 60-70% reduction in chlorine and sodium contents in wastewater were also achieved.

One of the long term goals of this project is to clean up frac water to a level that can be used for irrigation. Hence, our finding that some microalgae strains remove boron very efficiently, is particularly interesting. Boron is used with calcium in plant cell wall synthesis and is essential for cell division. Boron requirements are much higher for reproductive growth. However, the range between an optimum and a toxic application rate is very narrow. Boron levels above 0.5 ppm are considered high for plant growth. Most of the frac water samples tested in this study contains much higher boron concentrations, 30-150 ppm, than needed by plants. Hence, boron removal is critical for potential use of frac water for irrigation.

Although it is not part of this project, one of the PI's PhD students has been able to convert algal biomass produced in wastewater to bio-oil, bio-char and gas which can be further processed to obtain higher value products to be used in industrial applications.

Significance of the findings and conclusions

- This study demonstrated that frac water can be used for microalgae growth.
- Several Oklahoma native microalgae strains (i.e. CCMP 2329, SP28, SP33, SP46 etc.) were identified as high biomass producers in frac water.
- It appears that diatoms accumulate high amount of salt in their cells, consequently, lowering the energy content and value of the biomass for bioproduct development.
- Significant differences were found in chemical composition of flow back and produced water samples collected from wells operating in different regions of Oklahoma.
- Frac water samples had very high total dissolved solids, alkalinity and chlorine contents.
- Although concentrations of nitrogen and phosphorous which are nutrients needed for algae cell growth were low in frac water, several strains performed similar or better in frac water as compared to standard growth media optimized for cell growth. *This could be due to the utilization of hydrocarbons present in frac water by some algae strains. However, this hypothesis needs to be further examined and supported by experimental data.*
- About 60-100% reduction in the concentration of sodium, TDS, alkalinity, chlorine, nitrogen, iron, copper and boron in frac water could be achieved after microalgae growth and biomass removal, supporting the potential of algal remediation of frac water.

- Further research on optimization of the algae growth conditions to maximize biomass productivity and contaminant removal is needed for enhancing technical and economic feasibility of this technology for large scale wastewater remediation.
- A better understanding of kinetics and mechanism of algal contaminant removal from frac water is critical for further exploration of the potential commercial applications of this technology.

PICTURE 1: Oil layer separated from produced water samples.

Table 2: Effect of growth media on the growth characteristics of selected microalgae strains *.

Species	SP1[1]	SP19[1]	SP22[1]	SP22[2]	SP31[1]	SP50[1]	SP50[2]	SP50[3]	2164[1]	2164[2]	2164[3]	2605[1]	2525[1]
μ (day^{-1})	0.11	0.03	0.08	0.48	0.17	0.05	0.38	0.13	0.10	0.3	0.13	0.12	0.44
t_d (day)	6.1	29.3	8.5	1.44	4.8	12.6	1.84	5.2	7.0	2.2	5.3	8.1	3.5
X_{max} (g L^{-1})	0.37	0.43	0.39	0.38	0.67	0.33	0.72	2.2	0.30	1.2	6.3	0.29	0.48
ΔX (mg L^{-1} day^{-1})	12.9	45.0	11.0	25.3	54.0	11.0	51.2	123	26.5	80	424	36.0	43.3

*μ: specific growth rate, t_d: doubling time, X_{max}: maximum biomass concentration, ΔX: average biomass productivity.

Means with the same superscripts in a row are not significantly different (Tukey's HSD test, P > 0.05).

[1]Grown in flowback water

[2]Grown in UTEX/CCMP recommended media

[3]Grown in nutrient supplemented media

TABLE 3: Physical-chemical composition of flow back (FB-from El Reno, OK) and produced water (PW-from Cumberland, OK)

	FB	PW
Cations ($mg\ L^{-1}$)		
Na	5111	8596
Ca	8	101
Mg	50	37
K	48	179
Anions ($mg\ L^{-1}$)		
NO_3-N	39	0.2
Cl^-	7065	13492
SO_4^{2-}	21	18
B	30	114
HCO_3^-	1396	868
CO_3^{2-}	341	77
Trace elements ($mg\ L^{-1}$)		
Zn	0.06	< DL
Cu	0.03	< DL
Mn	< DL	< DL
Fe	0.17	< DL
NH_4^+	NA	86
ICAP_P	NA	0.01
Derived values		
TDS ($mg\ L^{-1}$)	16104	25014
SAR (%)	149	186
PAR (%)	0.8	2.3
RC ($meq\ L^{-1}$)	30	9
SP (%)	98	98
HD ($mg\ L^{-1}$)	224	403
ALK ($mg\ L^{-1}$ as $CaCO_3$)	1712	839
pH	9	9
EC ($\mu mhos\ cm^{-1}$)	24400	37900
COD ($mg\ O_2\ L^{-1}$)	1874	1764

Note: TDS = Total Dissolved Solids, SAR = Sodium Adsorption Ratio, PAR = Potassium Adsorption Ratio, RC = Residual Carbonates, SP = Sodium Percentage, HD = Hardness, ALK = Alkalinity, ICAP_P = Phosphorous by Inductively Coupled Argon Plasma, < DL = under detection limit, NA = not available

TABLE 4: Chemical composition of biomass produced water by selected microalgae strains grown in flowback water [determined by thermogravimetric analysis (TGA)]*.

STRAINS	***M***	***VM***	***FC***	***ASH***	***HHV***
SP1	7.8 ± 0.9	53.0 ± 0.7	3.7 ± 2.0	35.4 ± 3.6	10.1
CCMP2525	4.5 ± 1.6	39.1 ± 1.9	17 .0 ± 0.2	39.4 ± 0.1	12.4
SP31	6.9 ± 0.0	79.9 ± 0.7	1.7 ± 1.5	11.8 ± 0.8	21.0
SP22	10.9 ± 0.7	70.6 ± 4.4	6 .0 ± 6.2	12.5 ± 1.0	14.6

*M: Moisture (%), VM: Volatile matter (%), FC: Fixed carbon (%), Ash (%) and HHV: Higher heating value (MJ kg^{-1})

TABLE 5: Comparison of two algae strains for their contaminant removal efficiency. Data were collected from tests carried out with produced water. Components with no data indicate no reduction or increase (due to water evaporation during algae growth) in concentration.

	SP31	**UTEX 2525**
	(% reduction)	
Cations (ppm)		
Sodium	68	72
Calcium	-	-
Magnesium	-	46
Potassium	69	83
Anions (ppm)		
Nitrate-N	100	100
Chloride	65	69
Sulfate	-	-
Boron	97	98
Bicarbonate	88	88
pH	16	12
EC (µmhos/cm)	65	68
Trace elements (ppm)		
Zinc	-	-
Copper	33	100
Iron	100	100
Derived values		
TDS (ppm)	65	71
SAR (%)	72	69
PAR (%)	75	75
Sodium percentage (%)	6	2
Hardness (ppm)	-	21
Alkalinity (ppm as $CaCO_3$)	92	92
COD (mg O_2 L^{-1})	26	-

Progress Report FY2016: USGS104b Water Grants Program

Title: Western Oklahoma Irrigation Water and Energy Audits: Findings, Recommendations and Educational Materials

Authors' Names and Affiliations: Dr. Robert Scott Frazier (PI), Associate Professor, Oklahoma State University Department of Biosystems and Agricultural Engineering (BAE), 212 Ag Hall, Stillwater, OK 74078. Dr. Saleh Taghvaeian (BAE), Dr. Jason Warren (PSS), Mr. Cameron Murley (FRSU, Panhandle Research and Extension Center-Goodwell)

Start Date: (03/1/2016)

End Date: (02/28/2018)

Congressional District: (Oklahoma Congressional District 3 for University and all project sites)

Focus Category: IG, WU, AG, GW, ECON, MET

Descriptors: Applied Research, Irrigation Efficiency, Water and Energy Nexus, Water Conservation, Aquifer Management, Life Cycle Assessment, Climate Change, Water Availability, Drought, Producers.

Students: (Include number of students supported by the project during the project period in the table below.)

Student Status	Number	Disciplines
Undergraduate		
M.S.	6	Biosystems and Agricultural Engineering
Ph.D.	1	Biosystems and Agricultural Engineering
Post Doc		
Total	7	

Principal Investigators: Dr. Robert Scott Frazier (PI), Associate Professor, Oklahoma State University Department of Biosystems and Agricultural Engineering (BAE), 212 Ag Hall, Stillwater, OK 74078. Dr. Saleh Taghvaeian (BAE), Dr. Jason Warren (PSS), Mr. Cameron Murley (FRSU, Panhandle Research and Extension Center-Goodwell)

Publications: Presentations and Abstracts (of Project Material):

Frazier, Robert; Taghvaeian, Warren (OSU), Murley (ARS), Don Sternitzski (US NRCS), 2016, Western Oklahoma Irrigation Water and Energy Audits: *Findings, Recommendations and Educational Materials,* Spring Crop Clinic (Oklahoma State University) Stillwater, Oklahoma.

Frazier, Robert; Taghvaeian, Warren (OSU), Murley (ARS), Don Sternitzski (US NRCS), 2016, Western Oklahoma Irrigation Water and Energy Audits: *Findings, Recommendations and Educational Materials,* Winter Crop Clinic (Oklahoma State University) Stillwater, Oklahoma.

Frazier, Robert; Taghvaeian, Warren (OSU), Murley (ARS), Don Sternitzski (US NRCS), 2016, Western Oklahoma Irrigation Water and Energy Audits: *Findings, Recommendations and Educational Materials,* Irrigation Conference (OAES, OCES) (Woodward), Oklahoma.

Frazier, Robert, 2016, Irrigation Efficiency Tests in Oklahoma, 2017, ASABE Annual Meeting, Technical Sessions, Orlando Florida. July 17 – July 20

Frazier, Robert; Taghvaeian, Warren (OSU), Murley (ARS), Don Sternitzski (US NRCS), 2016, Western Oklahoma Irrigation Water and Energy Audits: *Findings, Recommendations and Educational Materials,* Governors Water Conference (Norman), Oklahoma.

Blessing, Masasi. Taghvaeian, Frazier, Performance evaluation of irrigation systems in Western Oklahoma, Ninth International Conference on Irrigation and Drainage October 11-14, 2016, Fort Collins, Colorado.

Frazier, Robert; Taghvaeian, Warren (OSU), Murley (ARS), Don Sternitzski (US NRCS), 2017, Western Oklahoma Irrigation Water and Energy Audits: *Findings, Recommendations and Educational Materials,* Spring Irrigation Conference (Ft. Cobb), Oklahoma.

Problem and Research Objectives:

To build on 2015 DASNR seed-grant ("Ogallala Aquifer Irrigation Sustainability Study") and expand both geography and irrigation systems tested in order to determine the overall efficiency and effectiveness of energy and water usage from western Oklahoma water sources (aquifer, surface, etc.) to application to the soil for irrigation. The project also examines important irrigation areas such as irrigation operations costs and environmental impacts along with recommendations for stakeholders.

Methodology: This project will be conducted on a sample of fifteen (15) different center pivot locations in three regions of western Oklahoma (Central, South-West and Panhandle) reflecting the diversity of existing systems. Ten of the tests have been completed to date. The different types of center pivot irrigation systems in these areas and energy sources (fuel, electrical) will be tested in order to measure the water and energy efficiency. The center pivot irrigation tests employed are well-known, accepted and fairly standardized. The main issues are having the specialized equipment and the expertise (which we do).

The irrigation system will be tested for total energy coming into the system driver (electric-motor, fuel-engine) and the total water delivered by the pump at the discharge. The water effectively delivered via the spans and nozzles at critical soil depths will be measured via water collection and soil sampling.

The Life Cycle Assessment (LCA) will be performed primarily on the well-known LCA software Simapro® V8 and will examine the environmental impacts of the reduced fuel or electrical energy use due to efficiency improvements in the following areas:

- Resource Energy (Fossil Fuel Inputs and Outputs)
- Global Warming GHG (CO2 equiv Kg)
- Human Toxicity (DB equiv Kg)
- Terrestrial Ecotoxicity (DB equiv Kg)
- Acidification (SO2 equiv Kg)
- Eutrophication (PO4 equiv Kg)
- Water Usage
- Fossil Fuel Depletion
- VOC's
- Land Use

Specifically, the efficiency of the system engine/motor will be directly measured via electrical or fuel inputs via wattmeter or fuel flow loggers obtained used by this group for a previous project (MS2203 3-phase power clamp meter and Fuji Portaflow-C®). The pump efficiency will be measured via flow, head and power input measurements. In addition to the TDH, the tests will note the current water table levels and the drawdown due to pumping. This will be reported for assessing the relative capacity of the water system at that location. Finally the water delivery subsystem (pivot) will be tested and observed via water sample collection and soil moisture sensors. Water losses from the pivot point (pump outlet) to the soil at plant level will be measured under variable climatic conditions (wind speed, relative humidity, etc.).

Work to Date: The team has completed most (10ea.) of the energy and water sub-surface audits of the irrigation systems in a variety of locations in western Oklahoma. We still need to test surface water systems as well as several systems in a variety of water shed areas. A mix of electric and natural gas systems have been tested. Due to the very high *operational* cost of diesel, we have not been able to find producers using this fuel to run center pivot systems (we will continue to search). In addition considerable analysis needs to be done on completed audits.

Principal Findings and Significance: Early analysis on tested systems is showing a familiar pattern to the 2015 DASNR seed-grant results. Most tested systems are well below the NPPPC benchmarks of about 65% OPE (see Figure 1). This of course leads to recommendations in both the main report and report given to the producers.

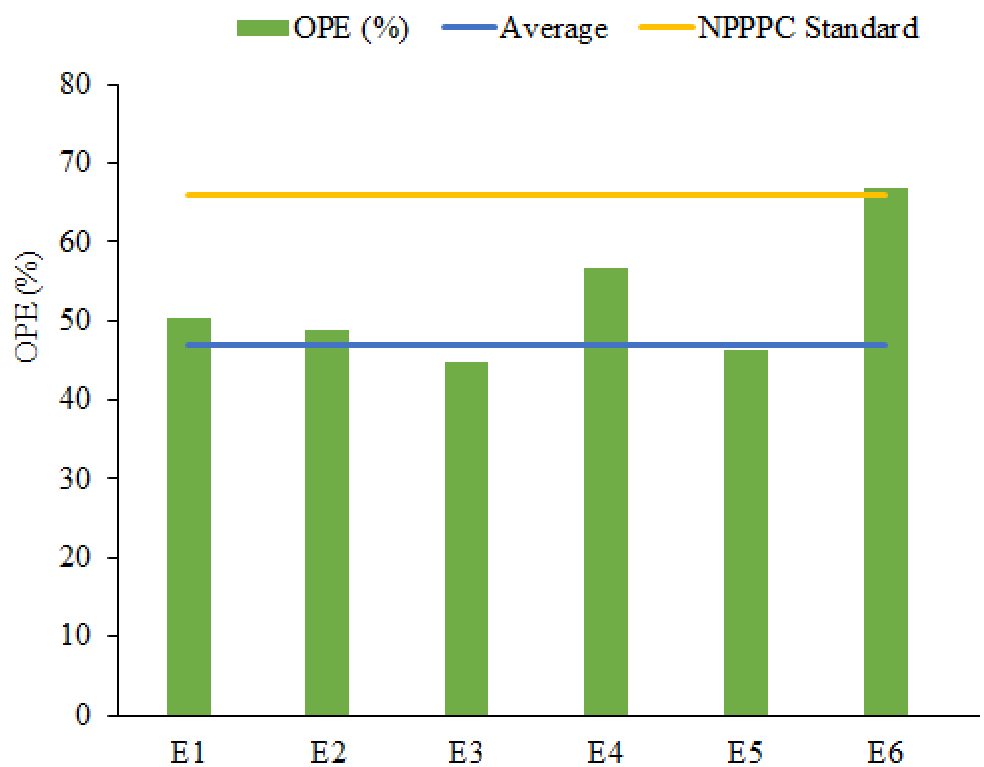


Figure 1. Subset of early testing of electrical irrigation systems
An example of possible economic savings to the (tested) producer systems is demonstrated in Figure 2. below. Again, these are just a subset of the total systems that will be reported in the final report. The saving described below are for every 1,000 hours of system run-time. Many producers will run twice that, or more, in a growing season. Many of the recommendations to achieve the NPPPC OPE benchmark are relatively inexpensive and would result in 1-2 year paybacks and are described in but producer reports and final project report.

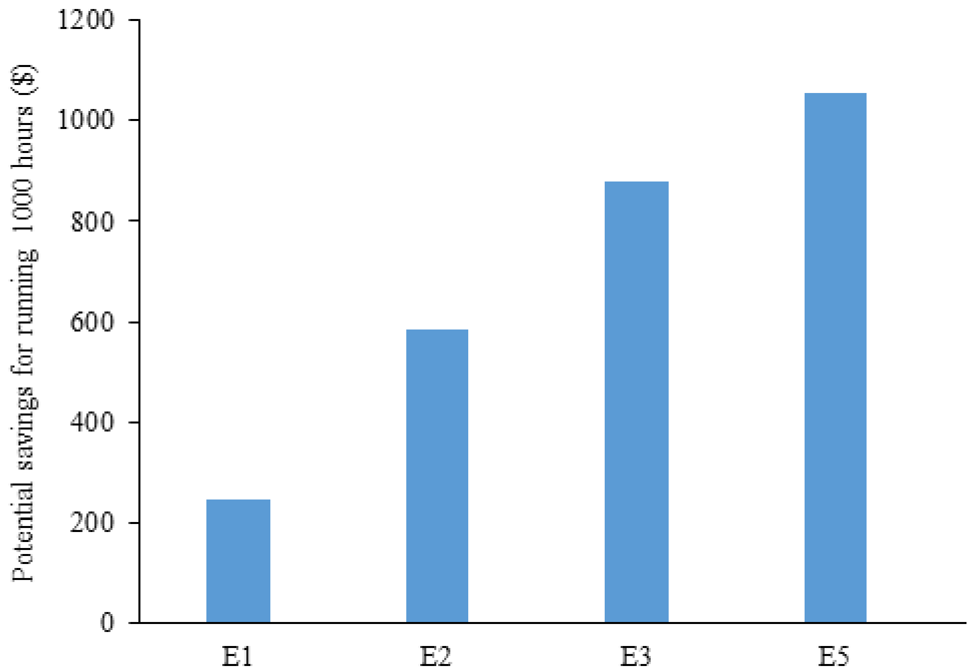


Figure 2. Subset of early techno-economic analysis of electrical irrigation systems

Moving from the energy efficiency to the water efficiency tests for the same systems we see different issues. The ability of the system to deliver all the water output by the pump to the nozzles is shown as “WCE” in Figure 3 below. This metric should be as close to 100% as possible. System #2 below is at approximately 90% - there was pipe leakage noted on this system. The 10% water loss also corresponds to a needless increase in energy usage.

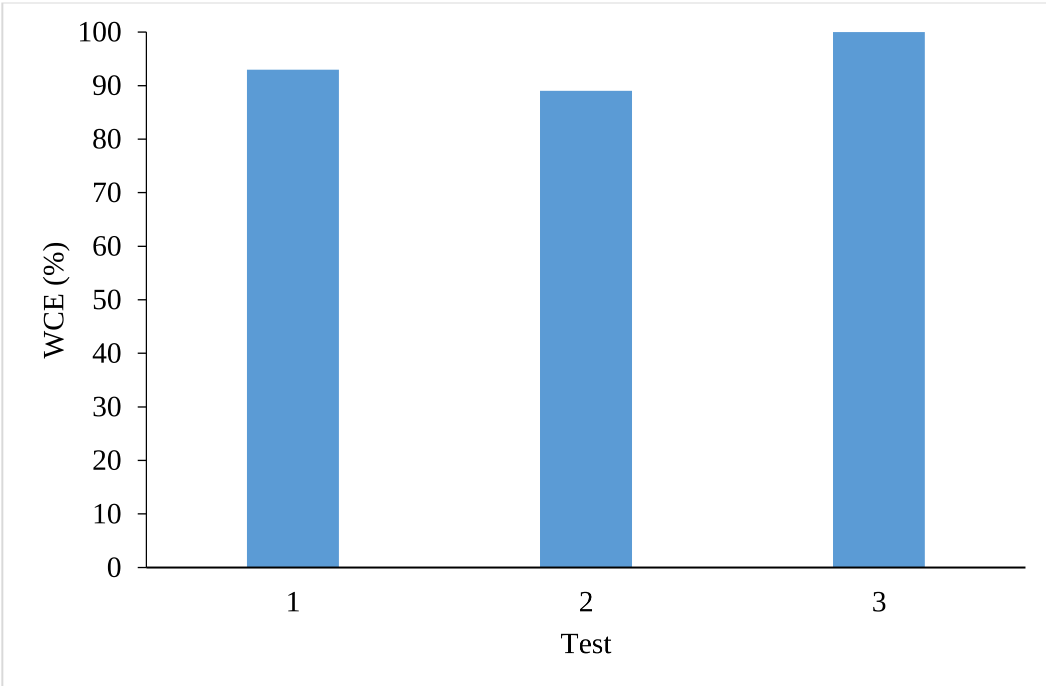


Figure 3. Early Water (Application) Efficiency for three systems tested

The uniformity of the system in delivering water to the irrigated area is described by DU and CU coefficients. A figure of approximately 80% for these two indices is considered acceptable. As can be seen in Figure 4, only system #3 is able to reach this benchmark. System #2 in Figure 4 has severe problems with malfunctioning nozzles. This causes the producer to increase system pressure resulting in a variety of additional problems. All of this is addressed in the producer reports and final program report.

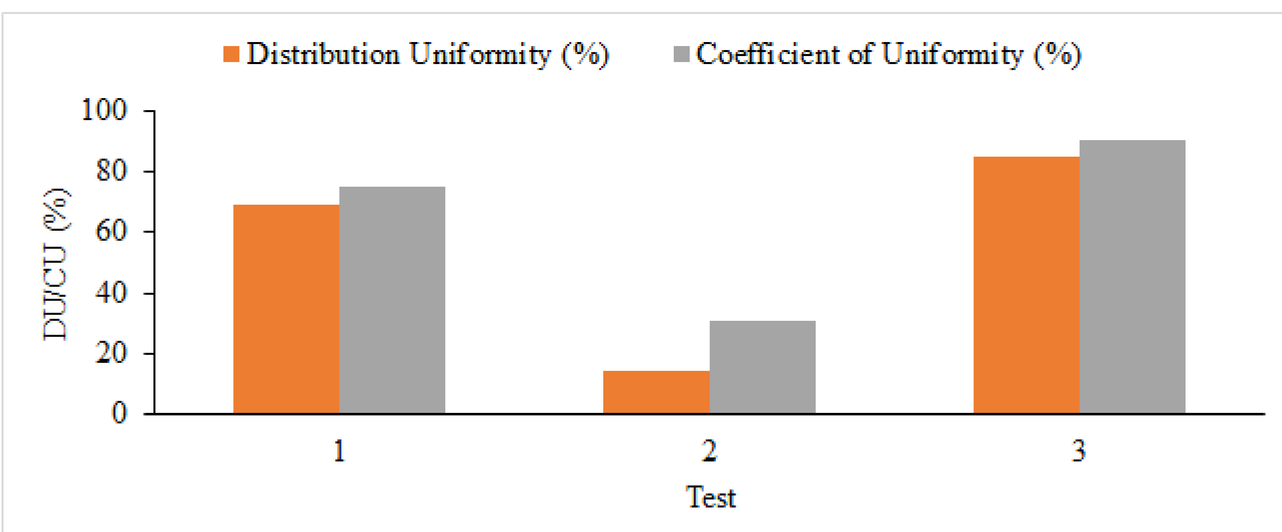


Figure 4. Early Sprinkler Uniformity for three systems tested

To Be Completed: We are continuously testing more systems and completed six natural gas systems in the Oklahoma Panhandle as of March 15 2017. We also need to test several surface water systems and as many others as time permits. The data analysis and Life Cycle Assessment (LCA) needs to be completed for the more recent systems as well. Seven producer reports have been sent out under this grant but there are (and will be) more in the near future. Of course the main project report is due as well.

The primary objectives/deliverables from the project are:

- Comprehensive data sets regarding the energy/water horsepower (driver, pump) efficiency of the various types of irrigation systems in western Oklahoma – ongoing
- Comprehensive data sets regarding the water delivery efficiency of the various types of irrigation systems in western Oklahoma – ongoing
- Recommendations for system improvements based on findings – ongoing
- Detailed Life Cycle Assessment reports for changes in sustainability impacts from improved irrigation systems (GHG, eco and human toxicities, carcinogens, surface water impacts, etc.). – beginning mid-March 2017
- Life Cycle Cost report summarizing economic benefits of recommended improvements – Fall 2017
- Final report summarizing above findings – Fall 2017
- Training and assistance to interested state agency personnel (OSU, NRCS, OWRB, etc.) Education materials associated with the tests and findings (print – fact sheets, online, video, Extension meetings, etc.). Material will discuss lessons learned and recommendations. Material may be provided for state policy makers interested in Oklahoma water resources – Summer and Fall 2017
- Research papers and presentations (Irrigation conferences, ASABE national society meetings) using finding from project – ongoing

Progress Report FY2016

Title: Evaluating the Reuse of Swine Lagoon Effluent and Reclaimed Municipal Water for Agricultural Production

Authors' Names and Affiliations: Hailin Zhang, Oklahoma State University, Department of Plant and Soil Sciences; Saleh Taghvaeian, Oklahoma State University Department of Biosystems and Agricultural Engineering; Doug Hamilton, Oklahoma State University Department of Biosystems and Agricultural Engineering; and Scott Carter, Oklahoma State University Department of Animal Science.

Start Date: (03/1/2016)

End Date: (02/28/2018)

Congressional District: (Oklahoma Congressional District 3 for University and all project sites)

Focus Category: WQL; IG, WS, AG, NU, DROU, NPP

Descriptors: Swine effluent, treated wastewater, irrigation, alternative water sources, nutrient buildup and losses, soil health, water quality, crop production.

Students: (Include number of students supported by the project during the project period in the table below.)

Student Status	Number	Disciplines
Undergraduate	5	Plant and Soil Sciences
M.S.	1	Plant and Soil Sciences
Ph.D.		
Post Doc		
Total	6	

Principal Investigators: Hailin Zhang (PI), Oklahoma State University, Department of Plant and Soil Sciences; Saleh Taghvaeian (CO-PI), Oklahoma State University Department of Biosystems and Agricultural Engineering; Doug Hamilton (CO-PI), Oklahoma State University Department of Biosystems and Agricultural Engineering; and Scott Carter (CO-PI), Oklahoma State University Department of Animal Science.

Publications: Presentations and Abstracts (of Project Material):

None

Problem and Research Objectives:

Significant amount of water in Oklahoma is used for crop irrigation. Water shortage in Oklahoma and the Southern Great Plains has become a major limitation for crop production and other uses, which will have a major impact on local economy. Therefore, alternative sources of irrigation water need to be explored. Treated municipal wastewater (TWW) is one of the most readily available alternative water sources, although infrastructures to use TWW for crop irrigation are lacking in most places and public acceptance is probably low because of the lack of field evaluations in the state. Currently, most TWW in the state is directly discharged to streams and rivers rather than recycled for crop production. Treated swine lagoon effluent is also available in west Oklahoma and other regions. Although swine effluent has been used to irrigate crops, more water use efficient application techniques need to be evaluated and promoted.

In recent years, drought conditions have caused Oklahoma municipalities to rethink the reuse of wastewater through irrigation. OSU and the City of Chickasha have entered into an agreement to test the use of the recyclable municipal water for irrigation at the South Central Research Station near Chickasha. The reclaimed municipal wastewater can be a valuable water source for irrigation, but it contains common salts and other compounds. Baseline of soil salinity needs to be established and continuously monitored in order to sustain the practice. Knowledge gained from this project can be used by the City of Chickasha to expand its use of treated wastewater for other agricultural purposes. It can also guide other communities to safely recycle their treated wastewater.

Oklahoma has over 2-million hogs and generates a great amount of effluent annually. Odor emission and nutrient loss are major challenges face swine producers. Oklahoma State University (OSU) built a state-of-the-art swine facility 10 years ago in order to demonstrate efficient and environmentally friendly management practices for swine production. Subsurface drip irrigation of the lagoon effluent has been used to increase water and nutrient use efficiency, reduce nutrient loss in runoff and to mitigate odor. The effluent from the two-stage anaerobic digestion lagoon has been applied to a 27-acre adjacent field through subsurface drip irrigation at 18-inch depth to produce forage, primarily bermudagrass since the construction of the facility. However, the effluent is continuously applied to the field but the nutrient use efficiency, distribution of N, P and salts in the soil profile, and leaching potential of nitrate have not been evaluated since the facility began operation in 2004. Many hog farmers in the Oklahoma Panhandle are considering installing subsurface drip irrigation system to improve water use efficiency, and lessons learned from this pilot project will ensure their successful transition from center pivot irrigation to subsurface drip system.

This proposal addresses the 2016 Water Research Funding Priorities 5 (Conservation) and 6 (Marginal Quality and Reuse Water) as well as soil health under Priority 8 (Ecosystem Services).

With the thorough evaluation of nutrient, pH and salinity distribution of the field used to land apply swine effluent from OSU Swine Facility and the physical condition of the irrigation tape and pipes, we will have a better understanding of how sustainable subsurface drip irrigation is and what measure needs to be taken to improve its efficiency and longevity. We'll also know the nutrient use efficiency and potential impact of applied nutrients on the environment, such as if N, P and salt have been built-up in the soil and if significant amount of nitrate has moved out of the topsoil towards groundwater. If those potentials exist, recommendations will be made to the facility manager as to what can be done to alleviate the problem. Findings of the study will be disseminated at OSU in-service trainings, NRCS nutrient management training, and other extension programs. A factsheet on sub-surface irrigation with swine effluent will be produced and disseminated widely. Similar findings are expected from the recycled wastewater irrigation site and recommendations on the appropriate amount and timing of irrigation will be developed based on monitoring data and disseminated to other municipalities with potential to recycle wastewater. Through this project we will develop a better understanding of land application of wastewater, by thoroughly examining field conditions at the start of one project and 11 years into the life of another. Lessons learned from the effluent site can be applied to the new site or other locations to avoid any negative agronomic and environmental impacts.

This project is to further evaluate the benefits and negative impacts of 2 alternative irrigation water sources. The first is an ongoing subsurface drip irrigation system using swine effluent and the other is a surface application of treated municipal wastewater. Nutrient and salt distribution and movement in soil profiles will be thoroughly examined. Phosphorus can be built up in the soil if animal manure and municipal wastewater is repeatedly applied to agricultural land and the loss of P in runoff will be escalated. In addition, nitrate can be leached into groundwater and contaminate water resources. Both swine effluent and treated municipal wastewater contain soluble salts and have the potential to buildup to detrimental level under arid and semi-arid climate. The sustainability of both of those systems has not been thoroughly evaluated in Oklahoma, and it is impractical to recommend those water reuse methods to farmers without knowing the fate of nutrients and potential contaminants, and the durability of the subsurface drip irrigation components. Thus, we propose to thoroughly evaluate the swine effluent subsurface drip irrigation system already in use for 11 years near the Swine Research Facility in Stillwater by monitoring nutrient inputs (nutrient concentration and quantity of effluent applied annually and the total amount since the beginning), outputs (forage removal), residual nutrients in the surface and subsurface soils, and nutrient movement in soil profiles; and to begin monitor the proposed municipal wastewater reuse project located at the South Central Research Station in Chickasha by establishing a baseline of nutrients and major contaminants at the beginning of the project, and monitor changes of those parameters every 6-month thereafter. A computer model (HYDRUS) will be used to simulate water and nutrients dynamics in the soil.

Methodology:

We conducted a one-acre grid soil sampling (0-6” only) before the sub-surface irrigation was installed and we have the detailed information of surface soil nutrient status before the effluent was applied to the field. Therefore, we will use those data as the baseline for the evaluation. A new set of grid soil samples up to 1 m deep will be collected from the same acre-grid to assess current nutrient status of the surface and subsurface soils. The profile samples will be separated into 0-6”, 6-12”, 12-24” and 24-36” segments. One of the acre-grids (Grid 15) will be further divided into 25 sub-grids for a higher resolution soil testing (shown on the right side of the field map on Figure 1). Soil samples will be analyzed for pH, plant available N, P, K and electrical conductivity

(EC). Five pairs of lysimeters will be installed at selected locations at 2 and 4 feet deep, and water samples from lysimeters will be collected to monitor nitrate leaching potential to groundwater. Nutrient and EC maps will be generated using GIS software and plotted vertically with soil depth. Forage yield and quality, and effluent application quantity and timing will be determined and closely monitored during the study. Past and present effluent and forage analysis data will be used to calculate the nutrient balance of the entire system. The conditions and effectiveness of the irrigation tape after 11 years in operation will be evaluated as well.

Similar soil and plant health monitoring will also be conducted at the South Central Research Station in Chickasha where the reclaimed municipal wastewater will be used for irrigation. Soil Samples will be collected to 1 m deep at the beginning of the project, and 0-6" soil samples will be collected every 6-month thereafter. Meter deep soil sampling will be repeated 2 to 3 years from the beginning of the study. Lysimeters will be installed at the beginning of the project and water samples will be collected and analyzed monthly if samples are available. This site was recently equipped with two variable-rate sprinkler irrigation systems: a linear move and a center pivot. The fact that these systems allow a variable rate of application enables us to investigate the impact of different wastewater application rates on soil chemical and physical properties. Figure 2 demonstrates an aerial view of this site.

In addition to the field sampling and measurements, the HYDRUS computer model will be used to simulate water and nutrients dynamics in the soil. HYDRUS numerically solves the Richards equation and can model the movement of up to fifteen solutes in the variably-saturated soil medium while accounting for any uptake by crop roots (Šimůnek et al., 2011). Once this model is validated for the specific conditions of the two study sites near Stillwater and Chickasha, it can be run for hypothetical scenarios such as variable precipitation and irrigation (wastewater) application depths.

Work to Date:

Below are the progresses made so far for both the swine effluent subsurface drip irrigation in Stillwater and the treated wastewater reuse in Chickasha.

Principal Findings and Significance:

I. Swine effluent drip irrigation

Oklahoma State University (OSU) built a state-of-the-art swine facility about 13 years ago in order to demonstrate efficient and environmentally friendly management practices for swine production. Subsurface drip irrigation of the lagoon effluent has been used to increase water and nutrient use efficiency, reduce nutrient loss in runoff and to mitigate odor. The effluent from the two-stage anaerobic digestion lagoon has been applied to a 27-acre adjacent field through subsurface drip irrigation at 18-inch depth to produce forage, primarily bermudagrass since the construction of the facility.

1. Amount of effluent and nutrients applied

The amount of effluent and major nutrients applied to the field from 2008 to 2015 is shown in Table 1. We were unable to find the amount of effluent applications and test results of other years. The average amount of effluent applied was 61,902 gallons/acre/year. The amounts of N, P_2O_5 and K_2O applied were 79, 70, 18 lbs/acre/year, respectively. The amount of grass harvested and the nutrient content of the hay need to be found to calculate nutrient balance of the field.

2. Conditions of the drip irrigation tapes

The conditions and effectiveness of the irrigation tape in selected locations were exposed and evaluated by Dr. Saleh Taghvaeian, an Agricultural Engineer and Irrigation Extension Specialist. The drip tapes are in fairly good condition with some clogging emitters and visible root intrusions into the tapes in isolated locations. The drip tapes were installed 36” apart and the pattern of water distribution is visible from the grass growing in the field (Fig. 1). Based on the bermudagrass heights shown in Fig. 1, water did not seem distributed uniformly. It appears the area close to the drip tapes received more effluent, thus more water and nutrients resulting in taller grasses.

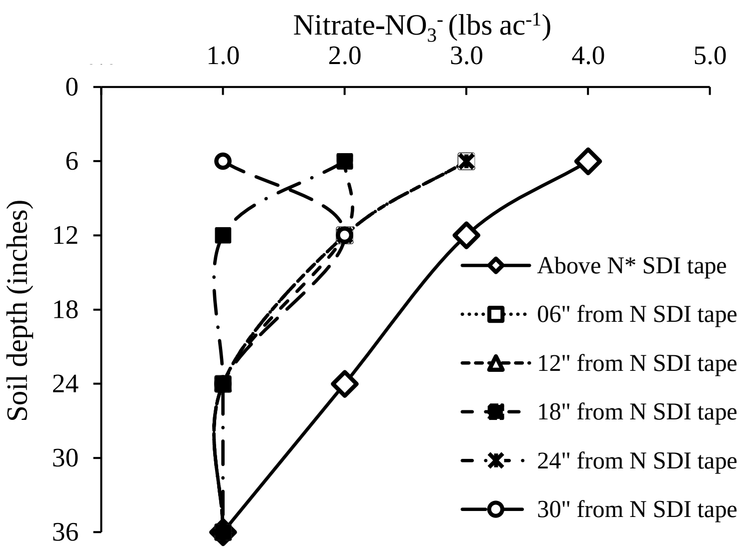
Table 1. The amount of effluent applied through the drip irrigation system to the 27 acres of bermudagrass pasture land from 2008 and 2015 and nitrogen (N), phosphorus (P) and potassium (K) calculated based on the average effluent test results. The amount of effluent applications and test results of other years could not be found.

Year	Effluent	N	P	K
	Gallons	kg		
2008	3202376	1,882	731	345
2009	3430380	2,016	783	370
2010	1936459	1,138	442	209
2011	702696	413	160	76
2012	899008	528	205	97
2013	955000	561	218	103
2014	1494000	878	341	161
2015	751000	441	172	81
Total applied	13,370,919	7,857	3,054	1,443

Figure 1. Bermudagrass in the field with subsurface drip irrigation system to distribute anaerobically digested lagoon effluent. The strips of grass reflect the orientation of drip tapes and un-uniform water distribution.

3. Nutrient distribution in soil profile

Therefore, soil profile samples to 36" deep were collected between 2 drip tapes every 6" apart. Nutrients and soluble salts not accumulated due to the long-term effluent application. However, it does show nutrient and salt contents are higher close to the drip tape (Fig. 2).



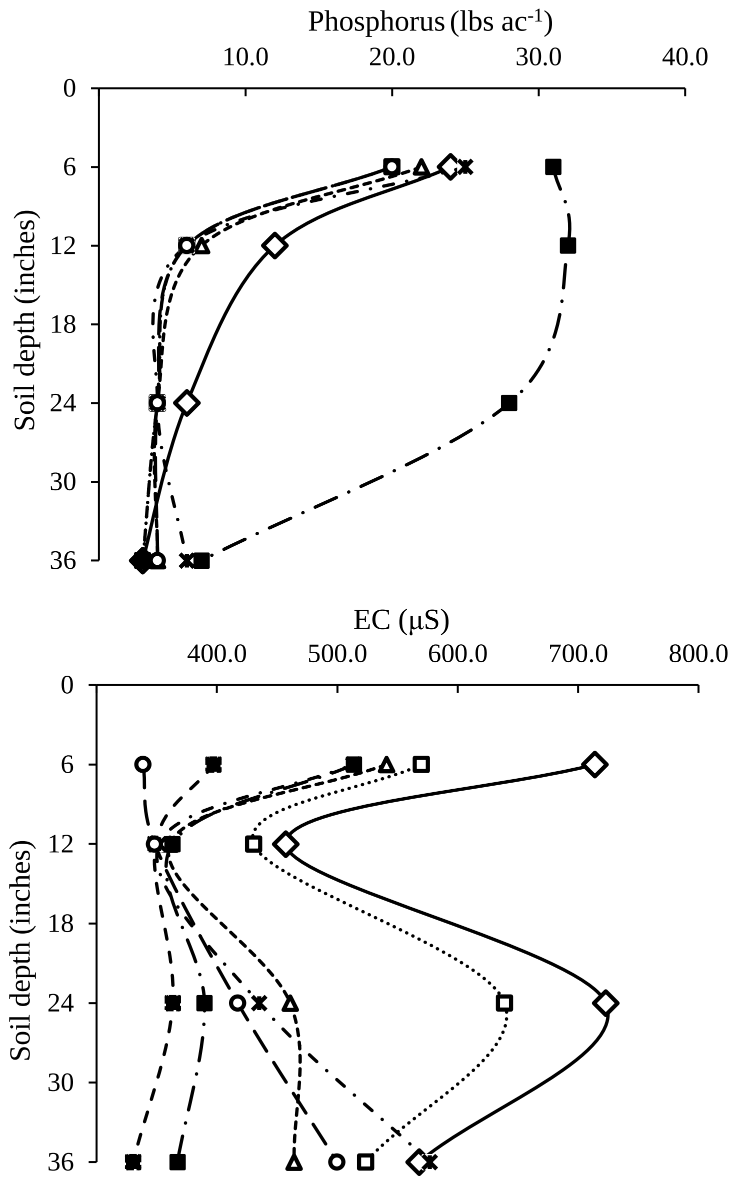


Figure 2. Nitrate-N, soil test P and EC distribution in soil profile between 2 drip tapes.

Grid soil sampling to 36" was also conducted. The results are under analysis.

II. Treated wastewater irrigation using above ground sprinkler

Treated municipal wastewater was used to irrigate 2 fields at the South Central Research Station in Chickasha since 2016. Figure 3 demonstrates an aerial view of the site.

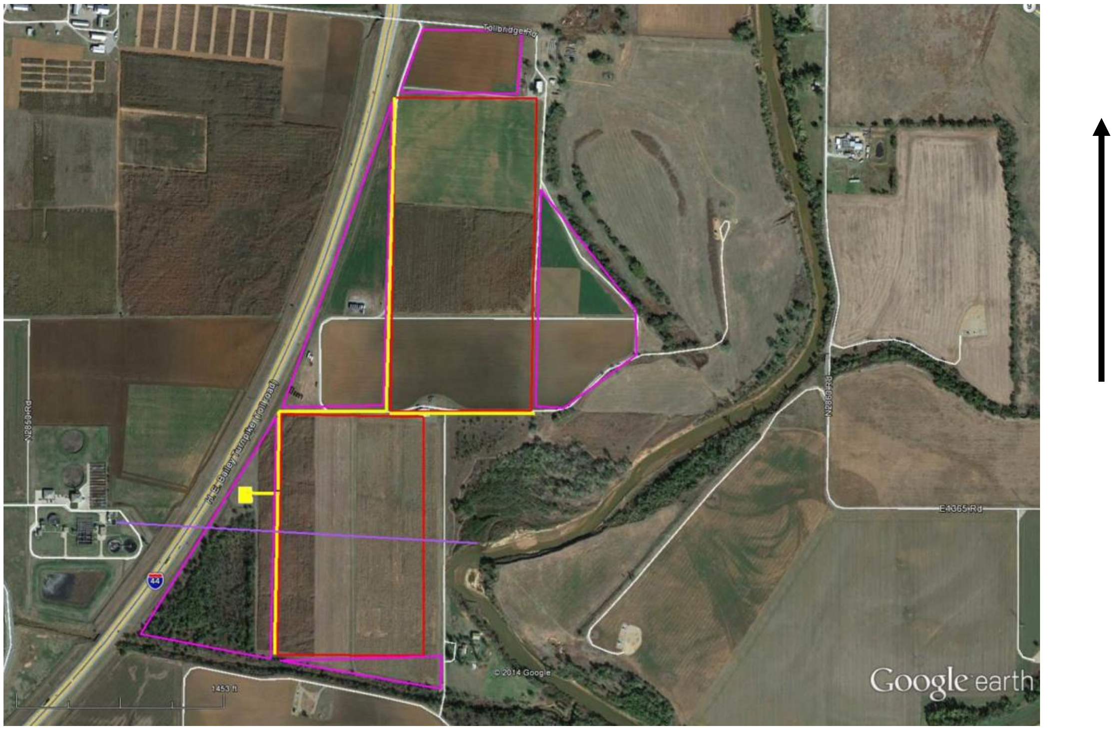


Figure 3. Aerial view of the municipal wastewater reuse site near the city of Chickasha, where two sprinkler irrigation systems were installed. The straight purple line shows the location of current underground pipe that takes the municipal wastewater from the treatment facility and discharges into the Washita River.

About 9 million gallons treated wastewater was used for irrigating those 2 fields already installed with irrigation facilities. The water was tested for irrigation quality and the results of several tests are shown in Table 2. It was considered acceptable irrigation water for most crops based on the analytes tested. It does contain some nitrogen and other nutrients. Therefore, it is recommended to give credit to those nutrients when deciding the amount of fertilizers to be applied.

Table 2. Irrigation quality of the treated wastewater.

Sampling dates	pH	EC	TDS	Nitrate-N	ICP-P	B	Sulfate	SAR	Na%
		uS/cm	---------------------ppm--------------------------						
5/7/2007	7.6	1106	730	11		0.3	181	2.7	44
3/15/2016*	7.8	1218	824	11.6	1.12	0.3	183	1.8	32
5/15/2016	8.0	1210	823	11.3	1.12	0.3	182	1.9	32
3/16/2017	8.4	1113	735	18.1	1.64	0.3	159	2.2	38

*sampled at the pump by the treatment plant. The rest of the samples were collected at the discharge point.

Both fields were divided into about 2-acre grids with a GPS mapping tool. One core sample was pulled from each grid to 36" before wastewater was applied. The profile samples were separated into 0-6", 6-12", 12-24" and 24-36" segments. The surface soil samples (0-6") were analyzed for pH, plant available N, P, K, Ca, Mg, S, micronutrients, and electrical conductivity (EC). The subsurface samples will be analyzed for nitrate-N and EC. Results of the surface samples are shown in Table 3 and 4. There is a huge variability in nutrient contents and EC. Those values will serve as the background levels for future reference as more wastewater is continuously applied.

In collaboration with EPA Robert S. Kerr Environmental Research Center, groundwater monitoring wells were installed for both fields. For each location, one well is located above the hydraulic gradient of the field, one on or near the field, and another one below the hydraulic gradient. The locations of groundwater monitoring wells are shown in Figure 4. Water samples from the wells will be collected and analyzed periodically to monitor nutrients and salt movement.

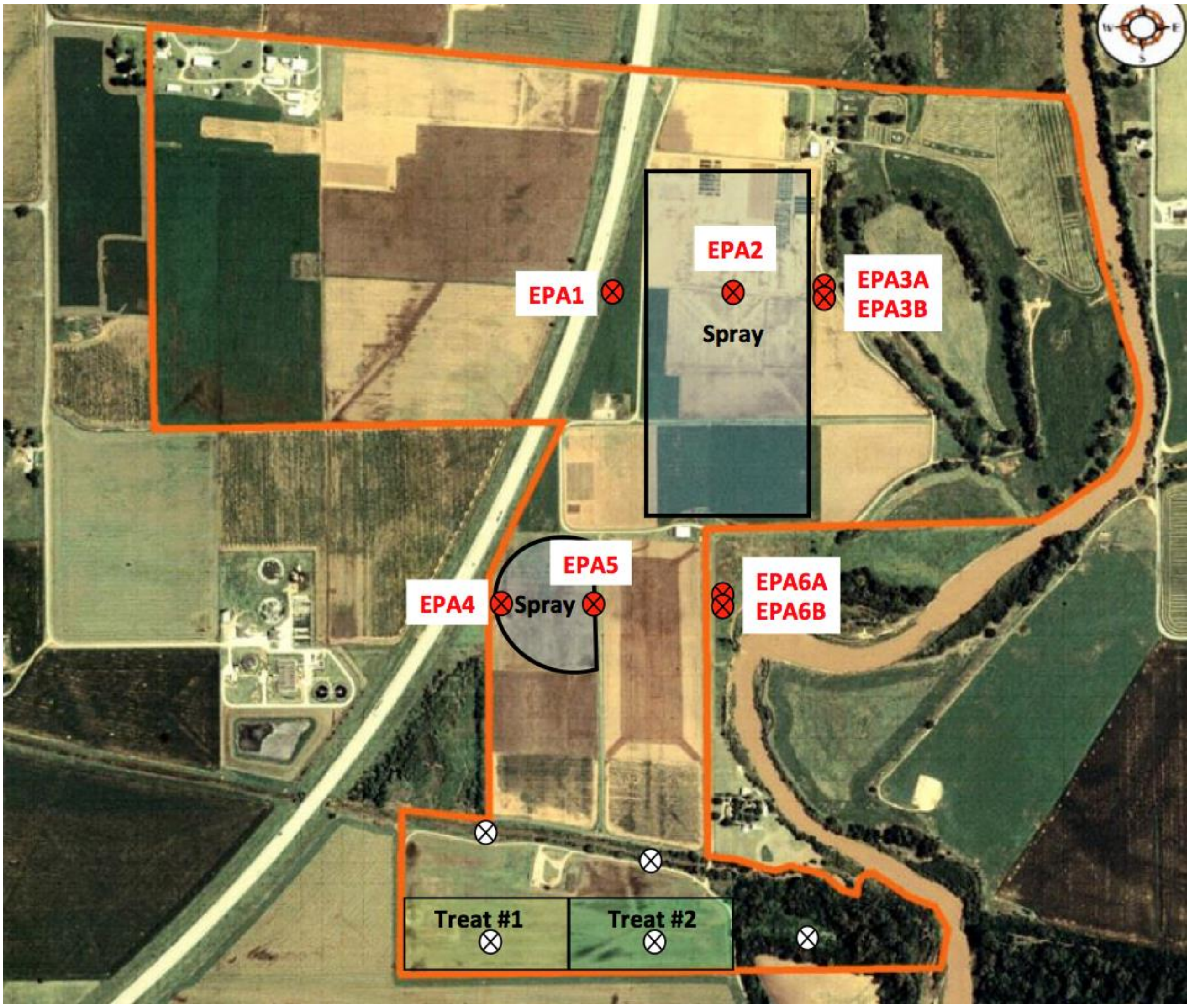


Figure 4. The locations of groundwater monitoring wells.

Table 3. Soil samples (0-6”) from the field with center pivot irrigation systems in Chickasha.

Grid Number	pH	NO_3-N lbs A^{-1}	K	P	Ca	Mg	SO_4-S lbs A^{-1}	Cu	Fe	Zn	B	OM %	EC (µS)
			……….Mehlich-3 (lbs A^{-1})………					…...DTPA-sorbitol (ppm)……..					
1	6.2	50	311	49	3141	1072	11.5	0.6	16.5	0.5	0.15	1.93	1356
2	6.5	23	467	52	3875	1599	12.6	0.8	17.5	0.4	0.19	2.42	1062
3	5.8	14	284	59	2507	1017	11.4	0.7	20	0.3	0.14	1.94	520
4	5.9	54	471	62	3503	1414	10.7	0.9	36.4	0.3	0.16	2.31	1245
5	6.3	20	521	75	4122	1718	8.8	1	34.7	0.4	0.21	2.56	900
6	6.1	36	322	45	2856	1129	10.9	0.7	18.6	0.3	0.17	2.1	924
7	6.2	8	382	28	3875	1205	12.3	0.7	17.3	0.3	0.23	2.64	738
8	6.6	6	606	30	4767	2067	12.9	1.2	29.2	0.4	0.34	2.95	681
9	6.4	3	287	26	3239	1032	9.9	0.5	12.9	0.2	0.16	2.02	513
10	6.1	6	287	26	2968	983	13.3	0.7	19.9	0.3	0.20	1.95	624
11	6.1	17	383	36	3658	1286	16.1	0.8	25.9	0.3	0.22	2.61	801
12	6.5	13	510	40	4165	1587	10.5	0.8	24.6	0.3	0.29	2.72	816

Table 4. Soil samples (0-6”) from the field with lateral irrigation systems in Chickasha.

Grid Number	pH	NO_3-N lbs A^{-1}	K …….Mehlich-3 (lbs A^{-1})…….	P	Ca	Mg	SO_4-S lbs A^{-1}	Cu …...DTPA-sorbitol (ppm)……..	Fe	Zn	B	OM %	EC (µS)
1	6.5	18	496	54	4137	1483	6.2	0.9	22.2	0.4	0.33	2.56	584
2	7.1	23	561	104	4664	1505	5.2	0.8	14.3	0.6	0.42	2.51	867
3	6.8	15	586	71	4113	1622	5.8	0.8	19.7	0.4	0.41	2.8	795
4	6.5	16	410	52	3330	1156	9.0	0.7	14.1	0.3	0.24	2.15	577
5	6.7	22	369	29	3193	1028	6.9	0.5	7.2	0.2	0.21	1.64	654
6	6.5	17	263	35	2366	751	5.7	0.6	10.9	0.2	0.16	0.98	506
7	6.7	12	301	41	2577	744	4.4	0.5	8.4	0.2	0.19	1.02	446
8	6.4	57	506	63	2278	727	12.6	0.6	16.3	0.3	0.21	1.52	1305
9	6.3	25	478	62	2896	1005	9.6	0.5	16.3	0.3	0.18	1.95	699
10	6.4	27	594	125	3654	1309	5.9	0.6	16.2	0.4	0.21	2.44	714
11	6.7	9	661	146	4254	1699	3.7	0.6	19.2	0.3	0.22	2.28	389
12	6.9	27	586	62	4867	1611	6.5	0.6	16	0.3	0.31	2.58	876
14	6.8	13	573	54	4072	1578	9.2	0.6	14.8	0.3	0.24	2.5	639
15	6.7	10	626	150	3660	1327	3.7	0.7	20.4	0.5	0.24	2	467
16	6.7	19	530	135	3045	984	4.7	0.7	17	0.4	0.26	1.56	589
17	6.3	16	356	106	2189	676	6.0	0.7	18.6	0.4	0.15	1.05	564
18	6	30	377	129	2661	725	7.6	0.8	26.4	0.5	0.13	1.99	636

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