Four Years of Maize Farming Experiments in a Semi-Arid Environment

Shannon A. Boomgarden, Duncan Metcalfe, Corinne Springer, Ellyse Simons, and Elizabeth J. Baldwin

THE UNIVERSITY OF UTAH

NATURAL HISTORY MUSEUM OF UTAH

Abstract: We summarize the results of ongoing farming experiments conducted in Range Creek Canyon (RCC) over the last four years. The experiments are designed to collect quantitative data on the economics of simple surface irrigation for maize farming in a semi-arid environment. The focus has been on benefits, measured as variation in weight of kernel yield, as a function of the amount of irrigation water provided. The experiments have built on often unanticipated insights provided by the simple act of performing them, as well as providing a greater understanding of patterning in the number and distribution of archaeological sites in RCC and the decisions faced by the Fremont farmers who lived there between A.D. 900-1200. The experiments have also led to more questions that are being investigated by Field Station staff and students through additional experiments and broader environmental monitoring.

1-Introduction

Location/background:

- RCC is located on the West Tavaputs Plateau in east-central Utah (Figure 1).
- Range Creek is a perennial stream draining 145 sq. miles
- Highest elevation: 10,200 ft (Buin Point). Lowest elevation: 4,200 ft (confluence with the Green River)
- Site of the University of Utah Summer Field School 2003-2013 and 2015-present
- Range Creek Field Station 2009-present
- Recorded nearly 500 prehistoric and historic archaeological sites
- Fremont people A.D. 900-1200
- Two weather stations north at 6,750 ft and central at 5,560 ft.
- Eleven manual rain gauges

Scope of work:

The Range Creek Field Station offers a unique opportunity to conduct long term archaeological research on subsistence strategies in a semi-arid environment. Our focus for the first 12 years was identifying the location and range of variability in archaeological sites within the Range Creek Field Station and surrounding areas.

- Survey and site documentation
- Excavation
- Student instruction
- Subsistence strategies
- Modern and paleoenvironmental reconstruction
- Historic land use

Experiments:

In 2013, our focus expanded to include on-going experiments designed to investigate economic trade-offs of subsistence related behaviors and to gather empirical data on the costs and benefits of performing certain tasks under modern environmental constraints.

- Experiments-farming, irrigation, wild plant collecting and processing, and investments in storage structures

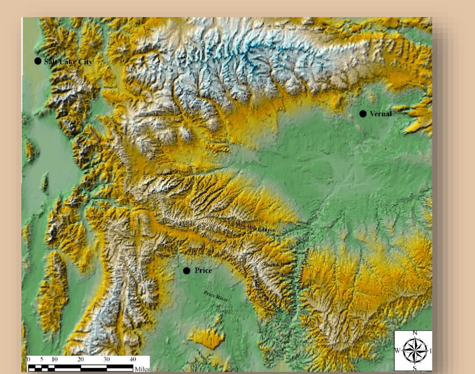
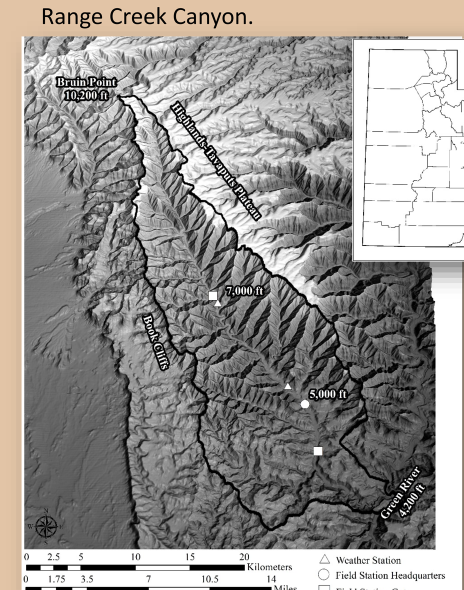


Figure 1. (above) Relief map of the West Tavaputs Plateau. (below) Relief map of Range Creek Canyon.



2-Research Objectives and Questions

There is considerable evidence for a reliance on maize farming in Range Creek Canyon (RCC):

- Maize starch on ground stone tools
- Numerous maize cobs associated with storage features
- Evidence of farm fields from sediment cores-isotope chemistry, charcoal record, and maize pollen (Brunelle 2011, Coltrain 2011, Hart 2011 and 2015, Morss 2010).

There is a long history of interest in prehistoric farming in the Southwest where water is the limiting resource determining farming success. Water availability determines where people located themselves on the landscape, which farming strategies were used to take advantage of locally available moisture, and how much maize could be produced. It is useful to think of water in two ways: available and supplemental.

Available water requires no additional work by the farmer (i.e. soil moisture at the time of planting or direct precipitation). Supplemental water is obtained by moving water to the field by modifying the landscape or capturing and spreading runoff. All of these are irrigation strategies:

- ditches, dams, reservoirs
- floodwater dams
- rock/brush spreaders
- modifying seeps/springs

Irrigation:

An extensive literature exists that summarizes ethnographic observations into broad descriptive summaries of irrigation techniques practiced in the Greater Southwest, with occasional mention of efficiency or time invested (Arbolino 2001, Doolittle 1984, Mabry 2005).

Productivity studies have primarily focused on defining precipitation and temperature thresholds necessary for farming success and then identifying the spatial limits of those thresholds (Benson 2010, Benson et al. 2013, Kohler 2012, Van West 1994, 1996). Little attention has been paid to variability in production, resulting from supplementing water beyond the minimum precipitation threshold required.

With few notable exceptions (Kuehn 2014, Muenchrath 1995, Bellorado 2007), there is currently a paucity of empirical data on the costs and benefits associated with different irrigation techniques; costs in terms of labor and maintenance and benefits in terms of increased harvest yield.

Questions:

- *Under modern environmental constraints, how productive is maize farming in RCC?*
- *What is the relationship between irrigation and harvest yield?*
- *Is it possible to farm using precipitation only (zero cost to farmers)?*

Here we summarize our first four maize growing experiments which have focused on the benefit of adding irrigation water, in varying amounts, using simple surface irrigation to move water from the creek to fields (Figure 2). The costs of the surface irrigation are separate experiments (see Simons et al. 2017).

Experiments designed to investigate additional irrigation options in RCC are in the early stages and are not presented here.

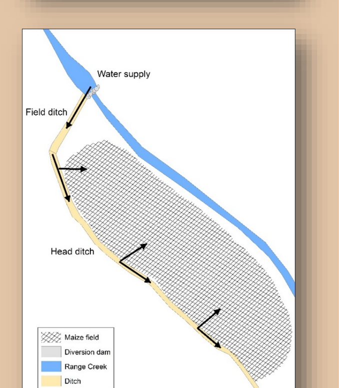


Figure 2. Illustration of simple surface irrigation.

3-Methods

Farming experiments were conducted each year from 2013 to 2016. Table 1 summarizes:

- Heirloom maize varieties chosen for planting each year (from Native Seed Search)
- Planting date
- Layout and number of plots
- Irrigation schedule.

The two experiment locations were chosen for their proximity to modern irrigation systems (Figure 3). Holes were excavated and filled with water to determine the rate of soil percolation. A trench was excavated just outside the field, and its profile mapped and soil samples systematically recovered for soil texture analysis. Only the amount of water added to each plot was varied to understand the relationship between amount of irrigation water and yield. Basins were watered at planting by hand and then the irrigation schedule began once the plants emerged. During irrigation, plots were flooded for 30 minutes each and excess water was diverted away from plots not scheduled for irrigation that day.

Environment and Plant Development:

A weather station located ~4 miles north of the Field Station Headquarters records temperature and precipitation. A manual rain gauge located at the FSH measures direct precipitation falling on the experiments. Each year the plots and basins were numbered and the layout mapped. The following variables were tracked each year:

- Number of plants per basin, height of plants, growth stages, number of cobs, tasseling, pollen dropping, insect/pest damage, wilting, discoloration
- Weather events, description of surface soils, visible surface moisture, and weeding activities
- Overview photographs of the plots were taken weekly and individual basins were photographed toward the end of the season for visual comparison (Figure 4).

Soil Sensors:

Despite controlling the timing of irrigation, the amount of water flowing onto the plots varied significantly throughout the growing season. An independent measure of available soil moisture was needed and soil moisture sensors (tensiometers) provided the solution. Sensors were placed at varying depths below the surface in each maize plot (Figure 5). These sensors record the water tension of soil in centibars (cb) which is proportional to moisture available for plant growth. The higher the centibars, the drier the soil. The ideal soil moisture reading for successful sweet corn farming is 30 cb or below (Irrometer Co). When the soil registers above 30 cb for 24 hours the maize is experiencing moisture stress that can affect yield. Measurements from the sensors were recorded every morning from before planting to harvest after harvest.

Five additional sensors were placed outside of the experimental maize plots in a separate experiment to determine and control for the relationship between the amount of water added by irrigation and its effects on the soil moisture at various depths, as well as the rate of soil drying after irrigation as a function of depth and time. These sensors were in close proximity to the maize farm plots but distant enough not to be affected by irrigation. The control sensors were placed at 4, 6, 12, 24, and 36 inches below ground surface (Figure 6).

Harvest:

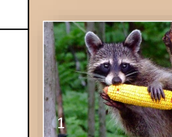
Maize ears were allowed to reach full maturity and begin to dry on the stalk after irrigation was halted at the end of the season. Ears were collected and bagged by basin number (and by plant number in 2013). Ears were individually labeled and continued drying in a large food dehydrator. Dry ears were photographed and analyzed. The following traits were recorded prior to the removal of kernels: ear length (cm), ear weight (g), ear diameter at center (cm), ear length to diameter ratio, number of kernel row, and an estimate of kernel coverage. Descriptions of row irregularity, kernel color, pest damage, and other observations were recorded. Kernels were then removed and weighed separately.

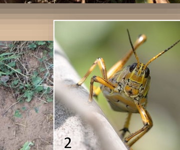
Table 1: Summary of 2013-2016 Maize Farming Experiments

Year	Maize variety	Location	Field/plot layout	Planting date	Growing season (M-S) precipitation rain gauge total	Irrigation schedule	Harvest date	Yield (mean cob weight)	Comments
2013	Onaveno-120 day growing season, popcorn variety traditionally grown in Sonora Mexico.	Located 1 mile north of the Field Station Headquarters	4 plots 9 basins per plot 5 seeds per basin	21-May-13	6.4 inches	Plot 1-not irrigated	16-Oct-13	0.72 g (n=1)	New shoots eaten by rabbits, continued to grow late into October but most ears did not reach full maturity
						Plot 2-irrigated 1 x per week		9.158 g (n=45)	
						Plot 3-irrigated 2 x per week		13.46 g (n=44)	
						Plot 4-irrigated as needed (2 x per week)		12.56 g (n=43)	
2014	Tohono O'odham "60 day"- 80-100 day growing season, flour variety traditionally grown in Southern Arizona and Northern Mexico.	Located at the Field Station Headquarters	4 plots 12 basins per plot 5 seeds per basin	20-May-14	2.9 inches	Plot 1-not irrigated	23-Sep-14	0 (no cobs grown)	Rabbit proof fence used early, shorter growing season, most ears reached full maturity Cobs from 4 basins in plot 4 eaten by horses
						Plot 2-irrigated 1 x every 2 weeks		37.22 g (n=58)	
						Plot 3-irrigated 1 x per week		48.14 g (n=60)	
						Plot 4-irrigated 2 x per week		60.42 (n=38)	
2015	Tohono O'odham "60 day"- 80-100 day growing season, flour variety traditionally grown in Southern Arizona and Northern Mexico.	Located at the Field Station Headquarters	6 plots 12 basins per plot 5 seeds per basin at each planting	5-May-2015 14-June-2015 25-June-2015	8.3 inches	Plot 1-not irrigated	10-Sep-15	13.86 g (n=2)	Early germination issues dueo to heavy spring rain, cold and pests (birds or rodents eating seeds) Raccoons have major impact on yields before harvesting
						Plot 2-irrigated 1 x every 3 weeks		11.28 g (n=19)	
						Plot 3-irrigated 1 x every 2 weeks		31.24 g (n=33)	
						Plot 4-irrigated 1 x per week		21.50 g (n=33)	
						Plot 5-irrigated 2 x per week		29.50 g (n=35)	
						Plot 6- irrigated every day		37.26 g (n=49)	
2016	Tohono O'odham "60 day"- 80-100 day growing season, flour variety traditionally grown in Southern Arizona and Northern Mexico.	Located at the Field Station Headquarters	6 plots 12 basins per plot 5 seeds per basin 1st planting (pulled) 10 seeds per basin 2nd planting	28 May 2016 21-Jun-2016	4.5 inches	Plot 1-not irrigated	No harvest	No harvest	Many early plants did not emerge, we suspect they were planted too deep. So they were pulled up and another 10 seeds per basin were planted again. Grasshoppers decimated crops at early growth stage Not irrigated after July 25th Crop not harvested
						Plot 2-irrigated 1 x every 3 weeks			
						Plot 3-irrigated 1 x every 2 weeks			
						Plot 4-irrigated 1 x per week			
						Plot 5-irrigated 2 x per week			
						Plot 6- irrigated every day			

Onaveño 2013 harvest

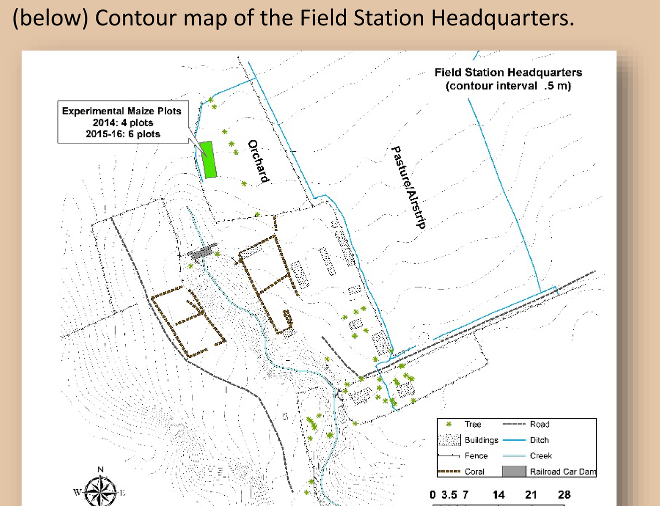
Tohono O'odham 2014 harvest





Internet Photo Sources
1-MiKris Cascade Garden Cooperative
2-A-Z Animals.com

Figure 3. (above) Map of two experimental farming locations. (below) Contour map of the Field Station Headquarters.



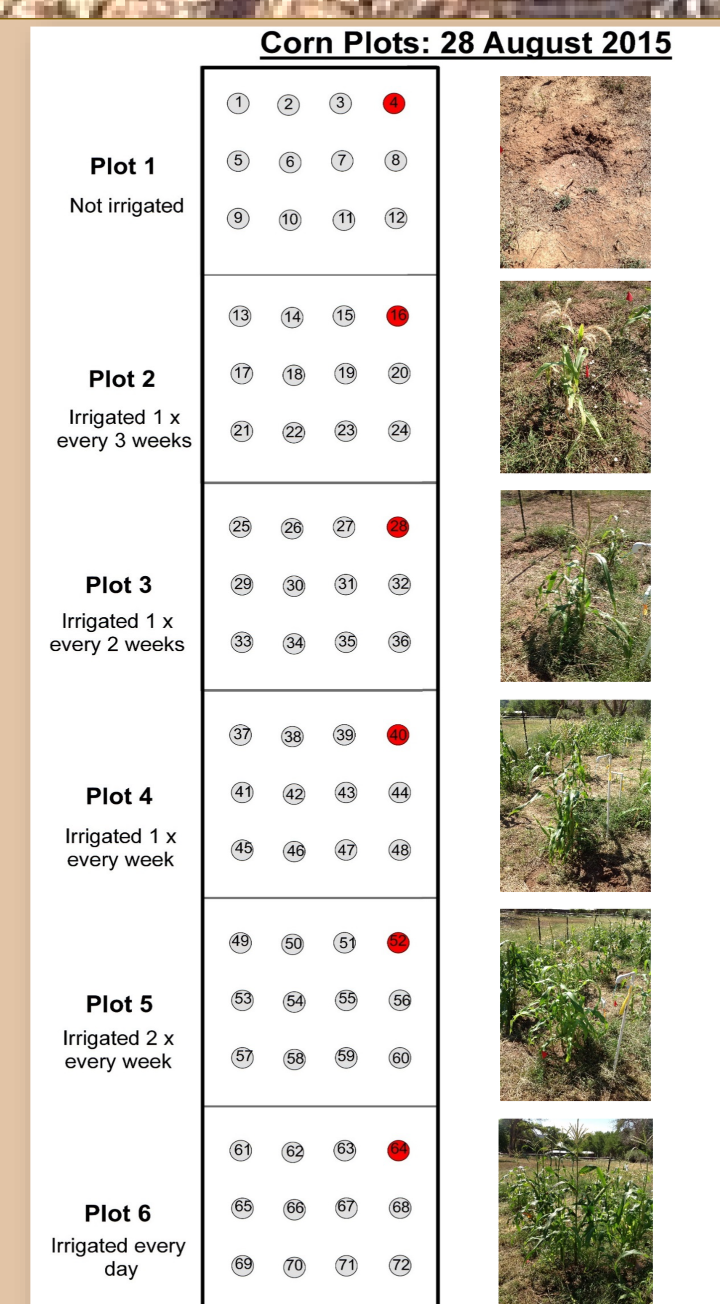


Figure 4. Map showing the layout and irrigation schedule of the 2015 experiment. Red dots indicate the location of basin overview photos taken on 28 August 2015 demonstrating the visible differences in the health of the plants in each plot at the same location relative to the irrigation inlet.

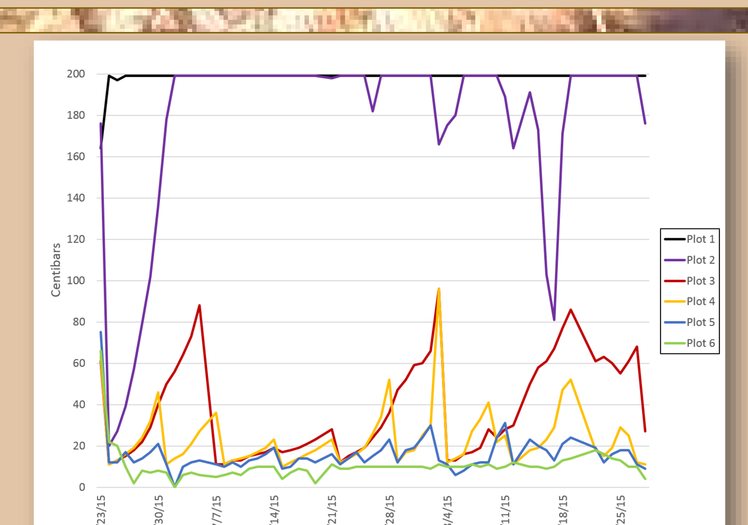


Figure 5. Chart showing the results from the soil moisture sensor readings from the 6 inch depth in all 6 experimental plots during the 2015 growing season. Plots 5 and 6 watered twice per week (Plot 5) and every day (Plot 6) maintained a reading of 30 cb or lower which is ideal for plant growth and higher yields in maize. Once the centibars register above 30 cb for over 24 hours without supplemental water being added, the maize plants will be experiencing stress.

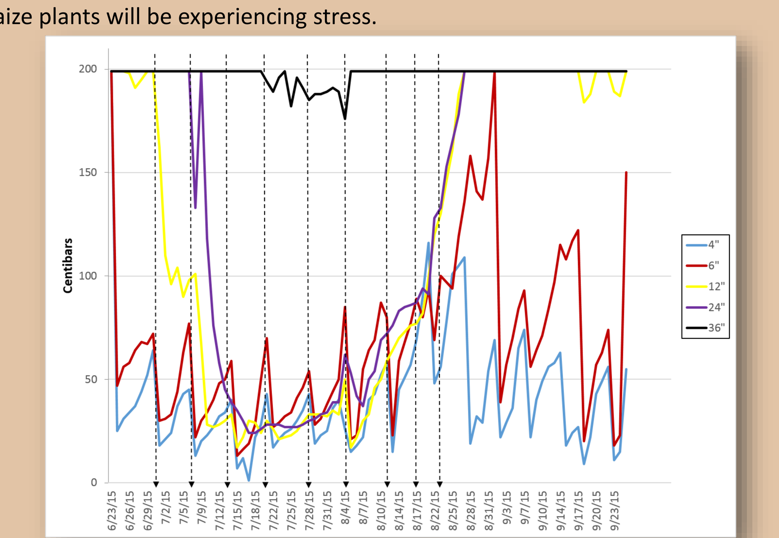


Figure 6. Chart showing the results of from the soil moisture sensors in the sensor control plot. Sensors were placed at 4, 6, 12, 24, and 36 inches below ground surface. The equivalent of 1 inch of water per week was measured and added to the control plot every Tuesday throughout the growing season for a total of nine inches. Sensors at all depths show that maize plants would be stressed receiving only one inch a week despite the total being above the commonly cited 6 inch threshold.

4-Results

Table 1 summarizes the results of each year including harvest date, yield measured in mean cob weight per plot, growing season precipitation, pest damage, poor germination, and other effects on yield.

- *Is it possible to farm using precipitation only (zero irrigation costs to farmers)?*

Our experiments demonstrate that it is impossible to successfully grow maize in Range Creek Canyon using only rainfall to replenish soil moisture lost due to percolation and evapotranspiration. Our experiments show that some form of irrigation method, with its attendant costs, must be used to grow maize in Range Creek Canyon.

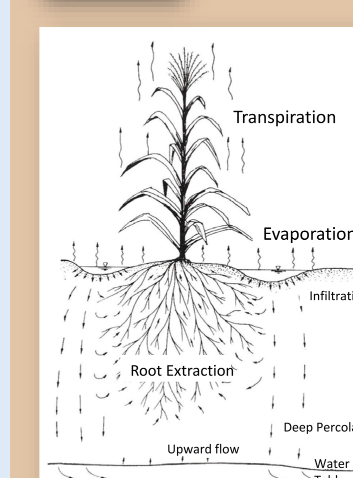
- *Under modern environmental constraints, how productive is maize farming in RCC?*

We were able to produce maize in our experimental plots all four summers using surface irrigation. Each year, yield (measured in mean cob weight) increased as the number of irrigation events increased. The highest yields were recorded in 2014, in the plot watered twice per week (Table 1). In the 2015 and 2016 experiments, some maize grew in plots watered only once every three weeks (albeit a very small harvest) but the greatest yields were associated with irrigating every day. We do not how the raccoon damage might have affected the overall yield.

- *What is the relationship between irrigation and harvest yield?*

If there was no cost and an endless supply of water in the creek for surface irrigation, watering crops every day would be a successful strategy for increasing yield. Unfortunately, irrigation construction and maintenance is not free and the water supply is often limited. Based on the sensor data, it appears that it is possible to maintain soil to below 30 centibars in the root zone by watering two times per week throughout the growing season. While additional water does marginally increase the yield, keeping the soil moisture at this level produced successful harvests each year. The Fremont would have faced daily farming challenges resulting in tradeoffs in deciding how their time would best be spent to increase overall yields. They also would have been competing for the most important resource, water. We will continue to investigate the ultimate balance between amount of water and yield given these constraints and tradeoffs.

Soil Sensors



5-Discussion

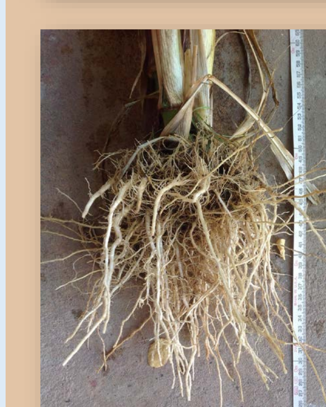
Our sample is small and the results are tentative but these experiments have forced us to learn about and integrate a set of factors that are critical to understanding desert farming in all its manifestations. Our literature review has revealed a significant lack of attention to known physiological demands of heirloom maize varieties in general, driving us to modify and expand our study questions to incorporate:

- Growth stages, rooting depth, root architecture, and phenotypic plasticity
- Pests and farming, growth stages and differential susceptibility
- Wilting point, transient versus permanent
- Pan evaporation values for RCC

Future Experiments:

Our 2017 farming experiment will also add several new components to the study:

- Measuring amount of water applied to plots
- Study of root development under different watering regimes



Tohono O'odham Roots