# Anthropogenic Effects on Soil Properties of the Las Capas Irrigation System of Tucson, Arizona

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## Introduction

A soil study was conducted at the Las Capas archaeological site in order to document and evaluate the soil productivity and hydraulic soil properties of this ancient agricultural irrigation complex in the northern Tucson Basin of southeast Arizona. This site presented an unprecedented opportunity to study the complete configuration and evolution of the oldest irrigation system documented in the United States to date, at more than three millennia old. The Las Capas site is significant archaeologically for a number of reasons, including: (1) the antiquity (~575–1225 B.C.) of the Early Agricultural period irrigation systems represented at the site, (2) the fact that irrigation systems dated to different times are separated stratigraphically within the site, and (3) the fact that extensive and well-preserved gridded irrigation features were identified in the field by mechanical stripping and then sampled. The stratigraphic separation and abundant cultivated irrigation plots facilitated soil sampling so that field, border, and uncultivated control samples could be compared in order to measure the anthropogenic effects of agriculture on soil quality in the irragric soils. Long-term indicators of agricultural soil quality, such as organic carbon, nitrogen content, and hydraulic soil water properties, indicate that anthropogenic changes were favorable for agricultural production and that the Las Capas irrigation system was sustainable. Canals regularly supplied water to the fields, but they also supplied nutrient-rich sediments that continually renewed soil fertility, enough to counter nutrient losses resulting from crop uptake, volatilization, leaching, and oxidation. Fields have significantly elevated organic carbon, nitrogen and available phosphorus levels relative to the borders, at levels that are slightly below but comparable to the control soils. Sodium and sodium adsorption ratios, though elevated in the Las Capas fields, are far below levels that could have had a serious detrimental effect on crop production.

Small white circles mark the locations of conical-shaped planting holes within cultivated fields. The looser fill of these holes promoted water infiltration into the root zone of silty clay loam soils.

## Research Objectives

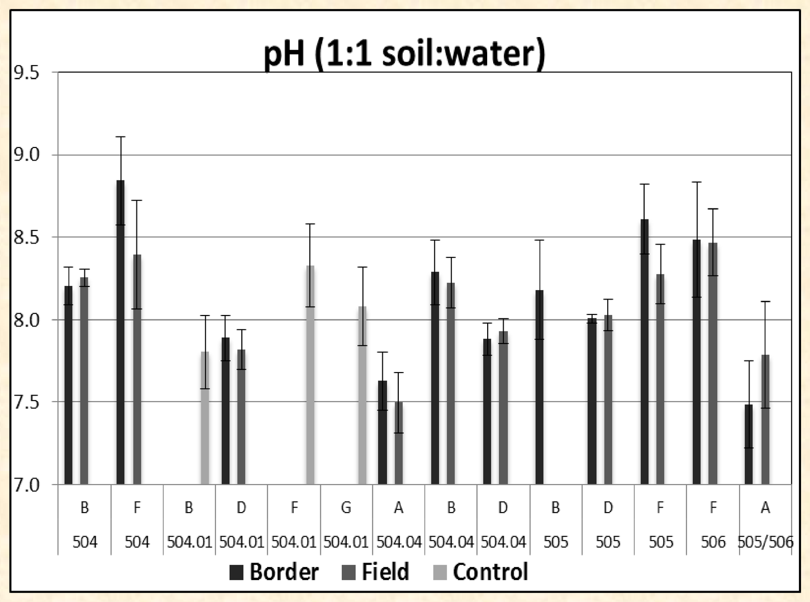
- Measure long-term anthropogenic effects of irrigation on agricultural soil quality
- Model hydraulic soil properties
- Determine if ancient agriculture degraded soil quality
- Assess agricultural sustainability of the Las Capas irrigation system

## Methods

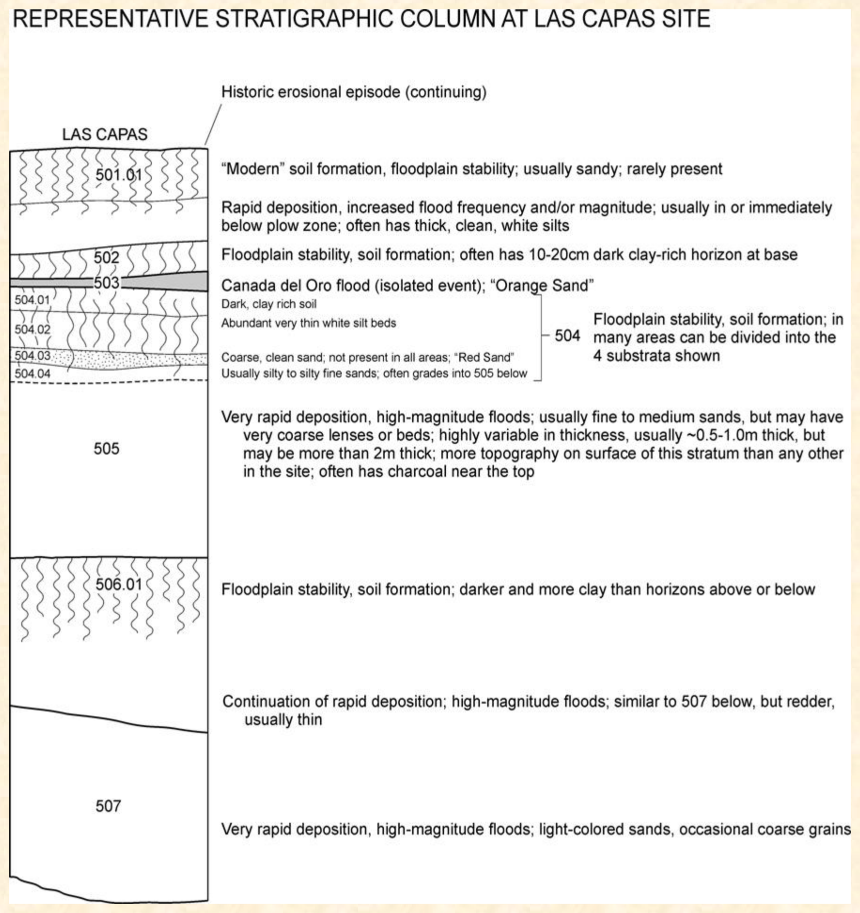
- A total of 238 soil samples were collected and analyzed: 116 soil samples from cultivated fields, 93 from field borders, and 29 from uncultivated controls.
- Samples were collected from all strata where evidence of Early Agricultural period irrigation was identified. These included: (1) Stratum 504 (~800–575 B.C.); (2) Stratum 505 (~ca. 950/925–800 B.C.); and (3) Stratum 506 (~1225–950/925 B.C.).
- pH, total and organic carbon (C), nitrogen (N), C:N ratio, calcium carbonate ($CaCO_3$), available and total phosphorus (P), calcium (Ca), potassium (K), sodium (Na), sodium adsorption ratio (SAR), bulk density, and particle-size analyses were completed.
- *t*-tests were used to evaluate statistical differences between field, border, and uncultivated control soils of different strata and loci.

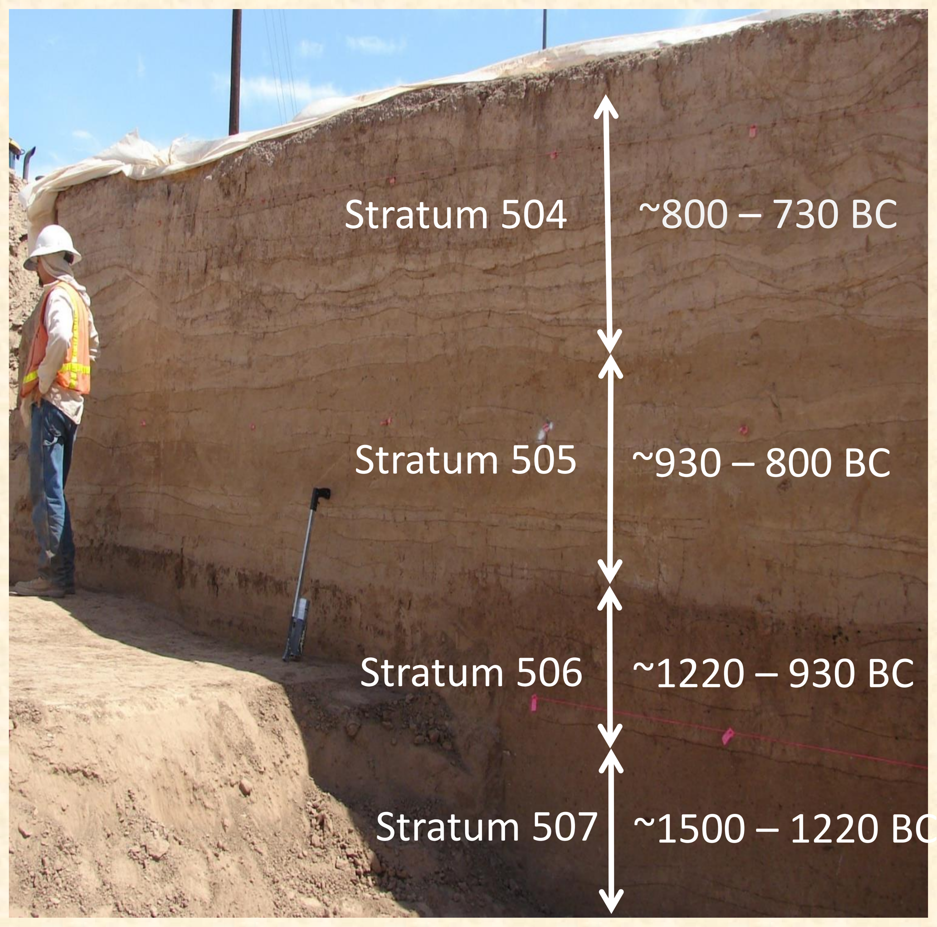
**Soil property means for field, border, and control soils**

| Soil property | Field | Border | Control |
|---|---|---|---|
| pH | 8.02 | 8.10 | 8.08 |
| Total carbon (%) | 1.62 | 1.47 | 1.31 |
| Organic carbon (%) | 0.51 | 0.46 | 0.73 |
| Nitrogen (%) | 0.072 | 0.057 | 0.076 |
| Carbon:nitrogen ratio | 7.9 | 9.0 | 9.8 |
| Calcium carbonate (%) | 14.9 | 12.9 | 10.9 |
| Available phosphorus (mg/kg) | 7.4 | 6.0 | 7.7 |
| Total phosphorus (mg/kg) | 1197 | 1086 | 1526 |
| Calcium (mg/kg) | 1816 | 1762 | 841 |
| Potassium (mg/kg) | 115 | 93 | 29 |
| Sodium (mg/kg) | 2903 | 2668 | 1279 |
| Sodium adsorption | 5.3 | 5.2 | 3.9 |
| Bulk density ($g/cm^3$) | 1.33 | 1.28 | 1.27 |
| Sand (2 mm - 0.05 mm, %) | 11 | 20 | 12 |
| Silt (0.05 mm - 2 µm, %) | 58 | 57 | 53 |
| Clay (<2 µm, %) | 31 | 23 | 35 |
| Average texture | Silty clay loam | Silt loam | Silty clay loam |
| Wilting point ($cm^3$ water/$cm^3$ soil) | 0.17 | 0.13 | 0.19 |
| Field capacity ($cm^3$ water/$cm^3$ soil) | 0.35 | 0.30 | 0.36 |
| Saturation ($cm^3$ water/$cm^3$ soil) | 0.51 | 0.49 | 0.52 |
| Available water ($cm^3$ water/$cm^3$ soil) | 0.18 | 0.17 | 0.17 |
| Saturated hydraulic conductivity (cm/hr) | 0.54 | 0.86 | 0.41 |

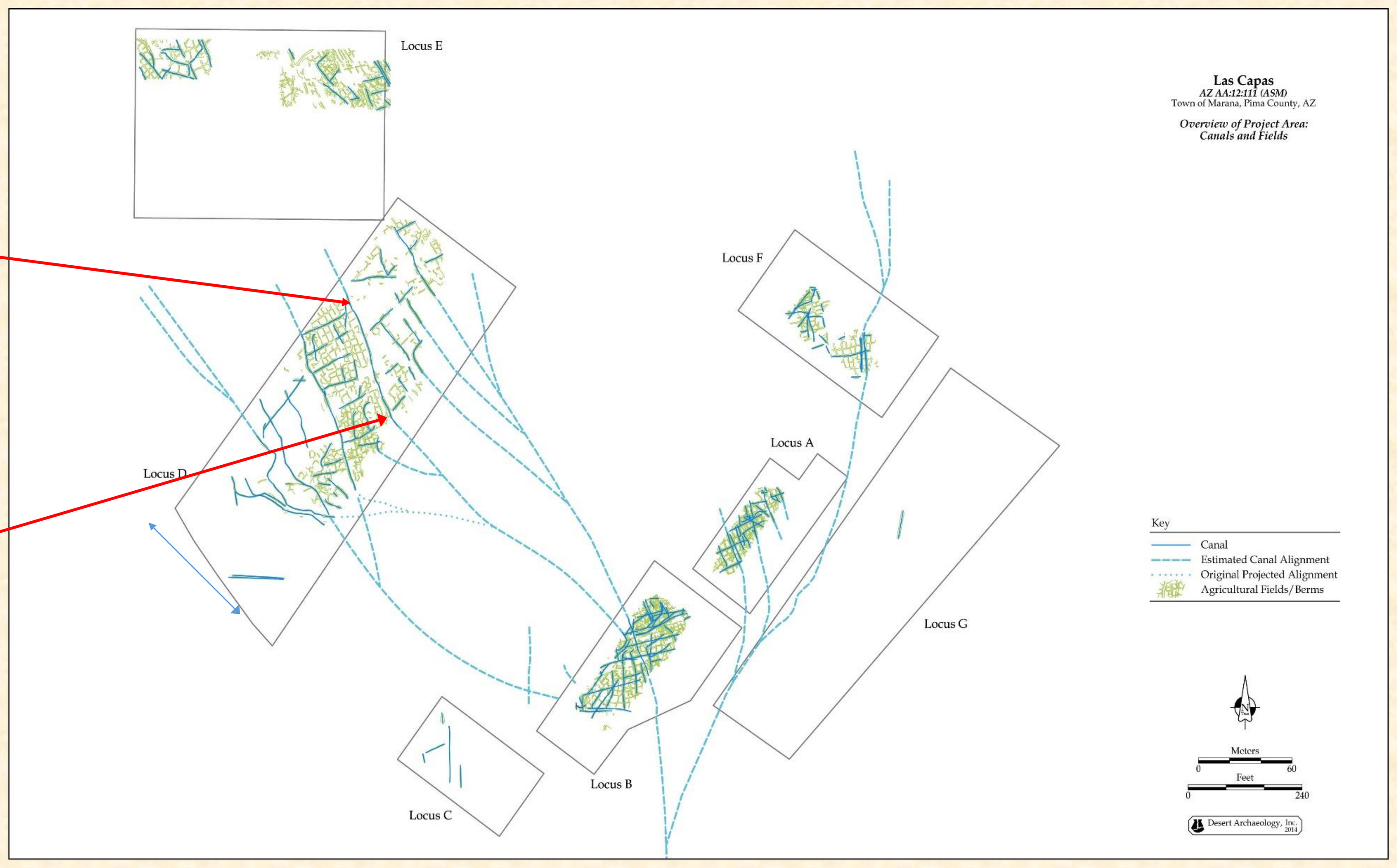



Soil pH in most strata and loci is below 8.5. Cultivating maize in soil with pH 8.5+ would be risky and likely to reduce crop productivity.




The complex alluvial history of Las Capas is documented by cycles of geomorphic stability, soil formation, erosion, and aggradation over seven centuries (see figures above). Below right is a map showing the layout of the irrigation canals and the field grids defined by earthen berms. Below left is an aerial photo showing part of Locus D.



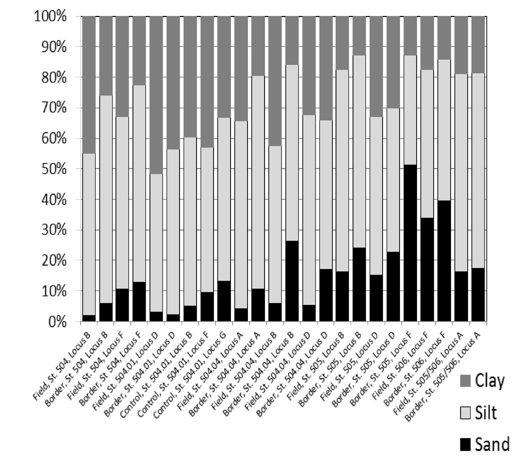

## Conclusions

- Improved soil fertility in the Las Capas irragric soils indicates that the ancient farming system was sustainable.
- Long-term indicators of agricultural soil quality indicate that anthropogenic changes were generally favorable for agricultural production, with fields having significantly elevated organic carbon, nitrogen, and available phosphorus levels relative to the borders, at levels comparable to uncultivated control soils.
- Canals supplied nutrient-rich silt and clay that renewed soil fertility, enough to counter losses caused by crop uptake, volatilization, leaching, and oxidation.
- SAR levels, though elevated in the fields, are far below levels detrimental to crop production. Properly managed irrigation water reduces salinity through leaching.
- Subterranean erosion (piping) was likely a factor in field abandonment. Natural floodplain sediments at the site are highly dispersive and are very prone to piping.

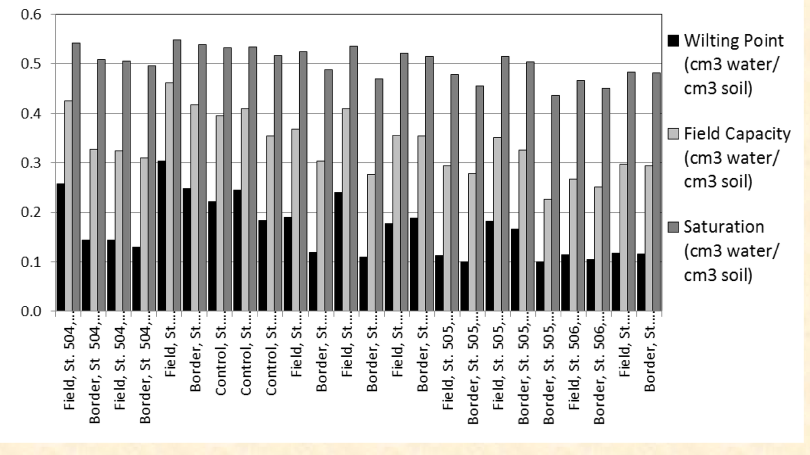
A cross section of an infilled irrigation canal is shown below. Field borders are demarcated by white lines (right). The darker color of the cultivated soils within the borders is caused by the higher clay and organic matter content. The low earthen berm of a field border was reconstructed (bottom right).

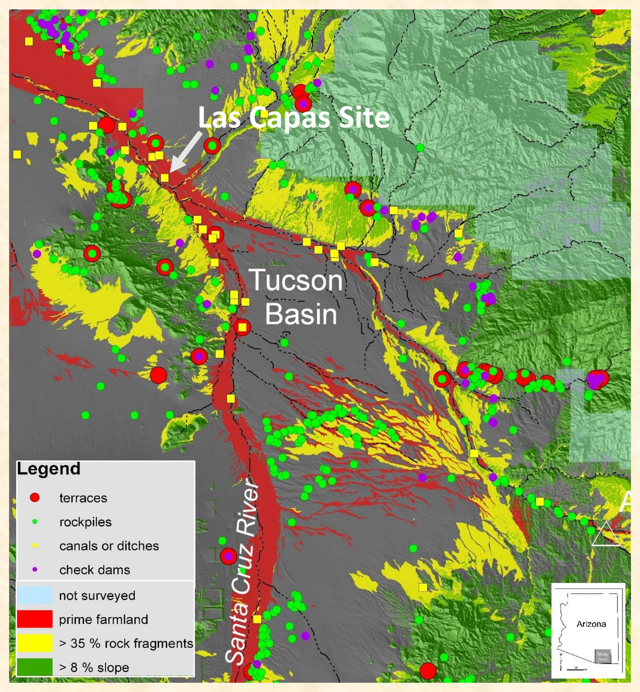
## Results

- Most soils are moderately (pH: 7.9–8.4) or slightly (pH: 7.4–7.8) alkaline, levels suitable for maize cultivation. Soil pH differences between the field, border, and control soils are insignificant.
- Significant differences were identified in the organic C and N levels of the field-border, field-control, and border-control comparisons. Organic C averages 0.51% in the fields, 0.46% in the borders, and 0.73% in the uncultivated controls. N is significantly elevated in the fields (0.072%) relative to the borders (0.057%) and highest for the controls (0.076%).
- C:N ratios are significantly lower in the fields (7.9) and borders (9.0) relative to the controls (9.8), a positive effect of irrigation agriculture for crop productivity. Lower C:N levels are usually favorable for crop production because more N is available to crops.
- Available P is significantly elevated in the fields (7.4 mg/kg) relative to the borders (6.0 mg/kg), and the borders have significantly less available P than the controls (7.7 mg/kg). None of the Las Capas soil samples have available P levels below 2 mg/kg, so there is no evidence of P deficiency.
- Ca, Mg, and Na levels are elevated in the fields and borders relative to the controls, all at levels well above that required by maize. In addition to their importance as nutrients, Ca and Mg serve to moderatie negative effect of high Na levels on crop productivity.
- Sodium adsorption ratios (SAR) and Na levels are elevated in the Las Capas fields, but at levels far too low to affect crop productivity. The highest SAR levels were in the deeper strata, possibly due to capillarity above the water table and/or accumulation of Na leached from above during the later periods of irrigation.
- Sand content is significantly lower in the fields (mean of 11%) and controls (12%) relative to the borders (20%), and clay content is significantly higher in the fields (31%) and controls (29%) relative to the borders (23%). Silt content averaged 58% in the fields and 53% in the borders.
- Bulk densities are about 4–5% higher in the fields (1.33 $g/cm^3$) than the borders (1.28 $g/cm^3$) and controls (1.27 $g/cm^3$). Compaction at such low levels for the silty textures at Las Capas would not have adversely affected crop productivity.




Textures (left) are dominated by silt loams, silty clay loams, and silty clays, all textures with high moisture-and nutrient-holding properties. Hydraulic soil properties modeled at right (based on %clay and %sand) indicate available water capacity is relatively.




This map presents a model of prime farmland in the Tucson Basin area in relation to identified ancient agricultural features (e.g., canals and terraces). Las Capas is in a large expanse of prime farmland along the Santa Cruz River.

## Concluding Thoughts

- It is important for future studies of ancient irrigation systems to search for the agricultural fields, not just the canals.
- The Las Capas study is an important milestone, but much more research is needed on ancient irragric soils of the Southwest. Much less is known about the anthropogenic effects on irragric soils than runoff and rock mulch soils.

## Acknowledgments

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