2015-07-01

Indications of Ancient Maya Soil Resource Management in Northern Belize

Austin Michael Ulmer
Brigham Young University - Provo

Indications of Ancient Maya Soil Resource Management in Northern Belize

Austin Michael Ulmer

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Richard Terry, Chair
Bryan Hopkins
Neil Hansen

Department of Plant and Wildlife Sciences

Brigham Young University

July 2015

ABSTRACT

Indications of Ancient Maya Soil Resource Management in Northern Belize

Austin Michael Ulmer
Department of Plant and Wildlife Sciences, BYU
Master of Science

The objective of this study was to use soil chemical properties, particularly carbon isotopes to describe the agricultural landscape in the Blue Creek region on the Rio Bravo Escarpment in northwestern Belize. The primary question associated with this study focused on the comparative agricultural potential of the soils between the upland karst environment and the lowland coastal plains using the distribution and frequency of ancient Maya maize production. Soil physical features, such as clay concentrations throughout profiles in conjunction with soil chemical properties were used to aid in determining the level of ancient maize production.

Isotopic evidence suggests that anciently, lowland soils were used for maize production more so than upland soils. In addition, profiles at Crocodile Lake indicate the potential for transport of soil δ13C signatures as a result of mass movement events.

Key words: stable carbon isotopes, ancient agriculture, Maya agriculture, soil analysis, geochemistry

ACKNOWLEDGMENTS

The project was made possible by funding from the National Science foundation and Brigham Young University. The faculty and staff of the Department of Plant and Wildlife Sciences have provided irreplaceable support throughout the whole process. This project would not have been completed without them.

I offer a special thanks to Dr. Timothy Beach from the University of Texas for allowing me to come on as a piece of his greater project in the Blue Creek Region. His help in the field and expertise throughout this work is greatly appreciated. I offer additional thanks to Dr. Thomas Guderjan from the Maya Research Program and Dr. Nicholas Dunning from the Programme for Belize for allowing me to work in each of their respective research areas.

I thank my graduate committee: Dr. Richard Terry, Dr. Bryan Hopkins, and Dr. Neil Hansen. Each has provided perspective, motivation, and aid in many ways. I especially thank Dr. Terry for his patience with me. He has provided more opportunities for me to expand my educational experience than any individual at BYU. I am thankful to BYU for giving me the opportunity to study and learn in a wonderful environment.

Lastly, I thank my family, especially my wife. Kristin, thank you for letting me leave on so many research trips. Thank you for your patience. It could not have been done without your love and encouragement.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Ancient Agriculture, Archaeology, and Soil Resources of Northern Belize

The ancient Maya occupied a large geographic portion of Mesoamerica in a diverse environment. This culture was able to support large populations and to thrive even when challenged by excessive precipitation in the rainy season and approximately six months of little to no rainfall in the dry season. An environment that experiences a wide range of precipitation that made the proper management of natural resources, especially soils, key for a civilization's survival (Beach 1998, Dahlin et al 2005, Sweetwood et al 2009, Wilson et al 2008).

Current occupants of this same region experience many similar challenges. While investigations have been conducted on Maya sites, there is much to be learned about the ancient Maya agricultural and land use management practices. In addressing this question, it is important to remember that these practices vary according to temporal and geographic environmental factors. Current challenges mean that individual examinations are required for each of the specific environments (Dunning et al 1996, 2000, Dunning and Beach 2000, 2004, Turner II et al 1985, Fedick 1995). Hydrologic factors are among the most important consideration in the region. Several months of rain (June to October) followed by extended dry season (November to May) mean that to sustain communities in this region requires not only efficient water management practices, but also proper establishment of community sites and agricultural production areas.

By their very nature, agricultural practices leave little physical evidence on the land. In the Maya regions lasting features such as canals and terraces are often obscured by thick jungle vegetation. Recent advances in mapping technology such as Lidar provide some aid in overcoming this challenge. Lidar has been used to discover extensive features such as dams and terraces near the site of Caracol, Belize (Chase et al 2014). Knowledge of Maya paleoecology, subsistence, and agriculture have been interpreted by a number of methods that include: epigraphy (Taube 1992), historical accounts (Tozzer 1941), ethnology (Atran 1993, Cowgill 1962, Dunning and Beach 2004, Jensen et al 2007, Nations and Nigh 1980), pedology (Burnett 2012 et al, Sweetwood et al 2009, Wells et al 2007), palynology (Leyden 2002), paleolimnology (Anselmetti et al 2007, Brenner et al 2002), and interdisciplinary approaches (Beach 1998). Among these methods the use of soil science principles and methods present the opportunity to contribute to a better understanding of the long term physical and chemical influence that comes as a result of human interaction with the surrounding environment. Soil physical and chemical features often contain indications of past agricultural locations, cultivation practices, and crop types. Archaeological applications of these principles allow researchers determine ancient maize distribution over a landscape, distribution and presence of ancient marketplaces near structures, presence of specialty crop production (such as cacao), and overall vegetation changes over a landscape (Stinchcomb et al 2013, 2011 Accoe et al 2002).

Several ancient Maya sites have been identified in Northern Belize. Notable sites include Atun'ha, Blue Creek, and Lamani as well as Xno'ha, La Milpa, and Chan Chich on the Rio Bravo Escarpment. These drastic environmental differences affected the ability to consistently produce food. Various cultivation and resource management systems were required for survival in these environments. Upland Maya relied on terracing systems as a means of resource management and crop production (Beach et al 2002, 1995, 2015). Lowland Maya included wetland field systems as key to their subsistence (Beach et al 2011, 2006, 2009, 2012, Dunning et al 2010, Luzzadder-Beach et al 2009, 2011, 2012). In each case, sustaining agricultural production required and understanding and use of soil and water conservation practices.

Agriculture began in the region around 5000B.C. and deforestation commenced around 2500 B.C. Large scale agricultural intensification began between 2000 and 1000 B.C. The earliest artifactual evidence of the region date around the Middle Preclassic period (900-400 B.C.) (Beach et al 2002). Initial agricultural practices in the region utilized slash and burn agriculture. Large scale urbanization of the region, including the construction of monumental structures, began during the Late Preclassic-Protoclassic period (400 B.C.- A.D. 250). Populations in the region remained dispersed throughout the Protoclassic period (A.D. 150-250). After the Protoclassic period, large dams and reservoirs were constructed during the Early Classic period (A.D. 250-600). Similar agriculture continued for the remainder of the Maya occupation of the region. Post-colonial land uses focused primarily on wood harvesting, especially mahogany (*Swietenia macrophylla*) and cedar (*Cedrelia mexicana*). Wood harvesting continued until the early 1900s (Beach et al 2002).

Early opinions associated (Beach et al 2008) ancient Maya agriculture with swidden cropping systems that utilized crop rotation as the primary means of agricultural sustainability. Current thoughts related to ancient Maya agriculture involve intense human modification on the surrounding environment for management of water resources both groundwater and surface water systems. Water management systems utilized primarily field walls, terraces, and wetland fields. Archaeological identification of these features have provided strong evidence for areas of intensive agriculture (. Geographical features also provide indications of possible ancient agriculture. Lowland bajo margins are known to have been areas of favorable cultivation as well as locations used for water storage (Dunning et al 2003).

Lake sediment cores associated with Preclassic Maya (2000 BCE to 250 AD) typically exhibit thick dense clay mineral layers sandwiched by very thin organic sediments from the earlier Holocene below and the Postclassic from above. These deposition events were caused by erosion and sedimentation resulting from ancient deforestation (Beach et al 2006). The formation of vertisols are common in cleared regions where intensive agriculture was present and are not found under forest in this region. Additional geographic features associated with ancient agriculture in the region include depression soils (especially Rendolls and Vertisols), edges of bajos dominated by footslope terraces, floodplains and alluvial fans (Beach et al 2003). Perennial and seasonal wetlands are present near lowland Maya sites. Pollen evidence of maize indicates initial maize production in the region to be around 4800 to 4420 B.P.

Wetland fields are likely to have been present near the site of Birds of Paradise fields (Luzzadder-Beach et al 2012). Intensive ancient wetland agriculture was present. Additionally, ancient farmers drained wetlands to form canals as a means of water management in the area (Dunning et al 2010). Work near La Milpa indicates large levels of erosion as a result of deforestation in the region. Large scale terraces are also present in the region. Terraces serve at least four likely functions: improve soil moisture conditions, erosion control, water diversion, and provide planting surfaces. The creation of planting surfaces is considered the primary objective associated with terraces in the areas of the Maya. Terraces often exhibit phosphorus enrichment (Beach et al 2002).

1.2 $\delta^{13}C$ as Environmental Proxies

Variations in soil carbon isotopic values (expressed as $\delta^{13}C$) reflect the relative contribution of primary plant species in an ecosystem with varying photosynthetic systems (C_3, C_4, and CAM). Changes in the values of $\delta^{13}C$ with soil depth are used as a record of vegetation change in an environment over time (Boutton et al 1998). Variations in soil organic matter $\delta^{13}C$ values throughout soil depths provide an approximation of changes in dominant vegetation in a landscape over time (Stinchcomb et al 2013, 2011 Accoe et al 2002, Bai et al 2012, Balzotti et al 2013, Beach et al 2009, 2011, 2006, Biedenbender et al 2004, Bostrom et al 2007, Boutton et al 1998, Burnett et al 2012, Feng et al 2003, Freitas et al 2011, Powers et al 2002, Schweizer et al 1999, Werth et al 2008). Natural abundance of ^{13}C serves as a tracer for this transition (Powers et al 2002). Carbon isotope rations act as a type of ecological barometer (Wynn et al 2007) that reflect historical vegetation, climate, and soil conditions in a region. Studies in Brazil, Delaware, and Texas have employed similar principles to describe the vegetative history of the respective regions. These studies focused primarily on transitions between C_3 woody species and C_4 savanna grass species (Pessenda et al 1996, Frietas et al 2011, Bai et al 2012, Biedenbender et al 2004, Stinchcomb et al 2011). These changes in carbon isotope rations have been used as proxies in geoarchaeological, paleoenviromental, and paleaoclimatalogical studies (Stinchcomb et al 2013).

1.3 ^{13}C Accumulation in Plant Function

Variations in plant function allow the differentiation between the isotopic signatures of specific photosynthetic pathways. Three major photosynthetic pathways exist: C_3, C_4, and CAM. The groundwork of this study is based around the physiological differences between C_3 species (the majority of woody species), and C_4 species (many tropical grass species and especially maize). These physiological differences result in varying $\delta^{13}C$ values. Values are expressed as mil discrimination against ^{13}C. C_3 plants have an average value -27‰ and C_4 plants have an average value of -12‰ (Keeley et al 2003).

C_3 plants are known as such because the initial product in carbon fixation is a three-carbon molecule. The primary enzyme responsible for carbon fixation in C_3 plants is ribulose bisphosphate carboxylase (commonly referred to as rubisco). C_4 plants are known as such because the initial product is carbon fixation is the four-carbon molecule malate. The primary enzyme responsible for carbon fixation in C_4 plants is phosphoenolpyrubate carboxylase (commonly referred to as pep carboxylase). The difference in $\delta^{13}C$ values arise due to this physiological variation. C_3 plants (rubisco in particular) strongly discriminate against ^{13}C due to the irregularities introduced into plant cellular structure associated with ^{13}C fixation (Zhang et al 1999). C_4 plants attempt to use every carbon atom that enters stomates in an effort to conserve water resources in plant tissue. This need to fix all carbon that enters the stomates results in little discrimination against ^{13}C, resulting in higher $\delta^{13}C$ values (Siebke et al 1997, von Caemmerer et al 1997).

Several studies of natural abundance ^{13}C in soils have shown that significant changes in $\delta^{13}C$ values can occur over a relatively short period of time (Stinchcomb et al 2013, 2011 Accoe et al 2002, Agren et al 1996, Bai et al 2012, Balesdent et al 1996, Balzotti et al 2013, Beach et al 2009, 2011, 2006, Biedenbender et al 2004, Bostrom et al 2007, Boutton et al 1998, Burnett et al 2012, Feng et al 2003, Freitas et al 2011, Powers et al 2002, Pessenda et al 1996, Schweizer et al 1999, Wedin et al 1995, Werth et al 2008). The C4 grass species Andropogan gerardi was observed to increase δ13C values by 1.6-2.2 ‰ over a four year period under monoculture (Wedin et al 1995). Maize is observed to utilize photosynthate to promote microbial activity in vadose zones in the form of root exudates (Balesdetn et al 1996). ^{13}C enrichment rates are noted to be greater in maize cultivated soils than the soils of C_4 grasses (Accoe et al 2002, Balzotti et al 2013).

1.4 Evidences of Carbon Isotope Fractionation and Isotope Discrimination

There is some debate about the portion of ^{13}C accumulation in the soil is a result of plant discrimination or fractionation that occurs via microbial organic matter diagenesis. Yang et al (2014) demonstrated that soil microbes discriminate against ^{13}C resulting in an increase of 2.5‰ to 3‰ in $\delta^{13}C$ values. Variations in methods of carbon fixation occur as a result of an organism's need to obtain energy in the most efficient manner possible. Similarly, various isotopes of carbon are not equally accessible for microbial decomposers. Decomposers exist in a system where carbon is limited and the ability to survive is based on accessing carbon as efficiently as possible, resulting in microbial discrimination against ^{13}C, which results in a more rapid loss of ^{12}C.

The $\delta^{13}C$ of soil organic matter increase as decomposition advances (Agren et al 1996, Bostrom et al 2007). Soil microbial diagenesis of the soil organic matter leads to ^{13}C enrichment. Fractionalization during microbial processing can lead to a significant shift in $\delta^{13}C$ values. Non-extractable organic carbon was found in decomposition studies to be stable over a six month period. Initial changes were found to be an increase of 2.6‰ (+/- 0.4) in $\delta^{13}C$ over a fifteen day period after which the overall $\delta^{13}C$ changes very little. (Lerch et al 2011).

It is important to understand microbial diagenesis of SOM in carbon isotope studies because microbial discrimination will result in increased $\delta^{13}C$ values through greater depth of soils. This allows deep profiles great change in $\delta^{13}C$ values to serve as controls for each particular environment. Carbon isotope graphs in Balzotti et al 2013, Burnett et al 2009, and Beach et al 2011 all depict $\delta^{13}C$ gradually increasing with depth. Although in most cases there is a gradual increase in $\delta^{13}C$ values to the point where the shift could be considered significant based solely on greatest change, these values increase as a result of microbial discrimination and other factors as noted in previous paragraphs (Yang et al 2014, Agren et al 1996, Bostrom et al 2006, Lerch et al 2011, Natelhoffer et al 1998, Powers et al 2002, Schweizer et al 1999, Wynn et al 2007). Balzotti et al (2013) reports shifts in ^{13}C greater than 3.5 indicate long term maize cultivation. Burnett et al (2009), and Webb et al (2004, 2007) indicated than ^{13}C shifts greater than 4 provide strong evidence of ancient vegetation changes from C_3 forest to C_4 crops. Enrichment values ranging from 2‰ to 4‰ provide weak evidence of these shifts while changes less than 2‰ provided no evidence. Beach et al (2011) indicated that changes greater than 3‰ could be ascribed to vegetation changes, rather than as a result of microbial isotopic discrimination. For the purpose of this study, shifts in ^{13}C greater than 3.5‰ will be considered strong evidence while shifts in ^{13}C between 2.5 and 3.5 will we considered weak evidence.

Changes in $\delta^{13}C$ throughout profiles will be used to determine levels of ancient maize production in the Blue Creek region of northern Belize. The frequency and distribution of these changes will be compared based on geography (comparing soils on the escarpment verses the soils on the coastal plain) and proximity to anthropogenic influences (comparing soils collected direct from sites or directly adjacent to ancient Maya sites with soils from areas with no indication of structural presence). Explanations of changes in $\delta^{13}C$ with depth and comparisons between each set groups (geography and anthropogenic influences) will be further justified with soil physical and chemical properties. It is proposed that soil chemical properties will indicate greater levels of maize production with closer proximity to ancient Maya sites than far from sites. An additional hypothesis is that maize production will be greater in lowland soils than in upland soils.

2. MATERIALS AND METHODS

2.1 Soil Profile Sampling and Preparation

Soil pits (profiles) were dug, with shovels and picks to the depth to bedrock, to groundwater or to a maximum depth of 170 cm. Bedrock was reached with the exception of profiles in the Crocodile Lake delta and Akab Muclil where near-surface groundwater was present. Samples were collected in 10-cm increments in each profile except RB73 Slope summit, where samples were collected in 9-cm increments (this was done to increase the number of horizons 1 but still maintains equal sampling depth ranges within the profile). Approximately 500g of soil from each depth was where placed in plastic bags and sealed for delivery to the Brigham Young University Environmental Analysis Laboratory, samples were air dried in preparation for physical and chemical characterization.

A mechanical flail grinder was used to crush air dried aggregates to pass a 10 mesh (2mm) sieve. Additional grinding was conducted on 5-gram subsamples to pass through a 100 mesh (0.1397 mm) sieve.

2.2 Magnetic Susceptibility

Magnetic susceptibility is a measurement of magnetization of a material in response to applied magnetic fields. These measurements in soils can be used to make inferences about changes in sources of parent materials. (Scholger et al 2002). Field measurements were collected with the SM20 magnetic susceptibility meter made by GF Instruments. Measurements were taken on the soil surface and in 5 or 10 cm increments throughout each profile.

2.3 Calcium Carbonate Equivalents

Calcium carbonate equivalents (CCE) was measured by reaction with 0.25M HCl and back titration with standardized NaOH. Soil samples 0.5 to 1.0 g were weighed out. Acid and samples were boiled for fifteen minutes to ensure complete dissolution of $CaCO_3$. Samples were cooled and back titrated with 0.25M sodium hydroxide until pH 7 was reached. The mass of required sodium hydroxide for pH 7 was then used to calculate the CCE (USDA Soil Salinity Laboratory 1954).

2.4 Mehlich P

Mehlich II extractable P was determined on 2-g air-dried samples sieved to 2mm. Samples were shaken in 20ml of Mehlich II extractant for five minutes. Samples were then filtered and 1ml of the extract was transferred to a colorimeter vial. Deionized water was added to create a 1:10 dilution. A pre-mixed chemical packet (PhosVer 3 Reagent: Hatch Company, Loveland, CO) was added and shaken for 60 seconds. After allowing the samples to sit for four minutes to permit color (blue) development, measurements were taken with a Hach DR/850 Colorimeter, with the % transmittance function at a wavelength of 690 nm. A standard curve was developed with known P concentrations; phosphorus concentrations (mg/kg) were calculated (multiplied by a dilution factor of 100). Further information of Mehlich II method modifications can be found in Terry et al (2000).

2.5 DTPA Extractable Metals

The DTPA (diethylenetriaminepentaacetic acid) extraction procedure was developed by Lindsay and Norvell (1978). Ten grams of 2mm ground soil were placed in vials with 20ml of 0.005M DTPA solution buffered at pH 7.3. Samples were shaken for two hours, after which the suspension was centrifuged for 5 minutes at 17,000rpm. The resultant supernatant was then filtered and the extract collected for ICP analysis. A Thermo Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) was used to determine the concentrations of Fe, Mn, Pb, Cu, and Zn simultaneously. DTPA solution used as a blank and a quality control sample was included in each run (Parnell et al 2002).

Chelate extraction of heavy metal ions from soils removes only a small portion of elements that are solubilized from soil mineral and organic matter surfaces. For the course of this study, only the surface horizons were subjected to 0.005M DTPA extraction with the exception of the full profiles at Crocodile Lake Delta 2 and RB73 Foot Slope were extracted and analyzed by ICP. Mehlich II P analysis was also done on the entirety of these two profiles to provide additional data for comparison. General surface samples were analyzed and correlated based on level of anthropogenic influence (ancient or contemporary) and geographic distribution (that compares the upland region with the lowland region). Profiles at Crocodile lake Delta 2 ("natural" environment) and RB73 Foot Slope (anthropogenic environment) will serve as comparison groups. These two profiles are most apt for comparative analysis because they are the deepest profiles (both exceed 150-cm in depth), thus providing the largest sample size. Additionally, Crocodile Lake provided no indication of ancient anthropogenic influence while the profile at RB73 was taken directly adjacent to an ancient structure.

2.6 Portable XRF

Portable X-ray florescence (pXRF) provides total element concentration in soils. This instrument functions with X-rays that excite individual elements to a higher orbital level. Constituent elements then emit fluorescent X-rays that return to the instrument. Element presence is determined based on the specific wavelength of each element and element concentration is determined based on the intensity of each wavelength. This analysis was primarily used to determine total concentrations of iron, zinc, copper, and magnesium. Data is reported as the total elemental concentration (mg/kg) present in the sample.

2.7 Laser Particle Size Analysis

Samples ground to 100 mesh were delivered to the University of Texas, Department of Geography and the Environment, Geomorphological Laboratory for laser particle size analysis. Samples were analyzed with an Analysette 22 (Produced by Fritch). This method determines particle size based on diffraction of light (ISO 13320 2009). Light scatters as it passes through soil particles; larger particles will scatter less light in comparison to small particles. This was an initial experiment on the validity of this method for soils. Further work may need to be done.

2.8 Hydrometer Texture Analysis

Hydrometer texture analysis is the traditional method used to determine the distribution of particle sizes in soils (Gee and Bauder 1986). Fifty grams of soil are placed in a *Blendtec* Blender. The *Blendtec* blender is useful for is programmability in controlling the rate of mixture during this process. 25 ml of sodium hexametaphosphate and 500ml water are added to the blender jar. Samples are blended in three times for one minute at a time and the samples were allowed to stand for five minutes between each blending. Three blending sets are used to limit the generation of heat into the suspension. Solution and soil are then placed into 1000ml cylinders and brought up to volume. Cylinders are capped and inverted and mixed for one minute. Temperature and hydrometer readings are taken at 30 seconds, and two hours. Percent sand, silt, and clay are calculated from these measurements (Gee and Bauder 1986).

2.9 Soil Color

Soil color properties were determined with the Mussel color charts. Dry and wet color was observed. Measurements were taken by a single individual in natural light in the shade. Analysis was conducted in the afternoons of summer 2014 on sunny days to ensure consistent light.

2.10 pH

Soil pH was measured with 1:1 ratio of soil and water that was allowed it to sit for an hour, and measured by glass electrode and a pH meter. Soil saturation was achieved by an addition of an equal amount of water as soil (by mass), that was thoroughly mixed.

2.11 Humic Acid Extractions

Webb et al (2004) proposed that the changes in $\delta^{13}C$ of soil humin fraction from the surface to depth could be used as an indicator of ancient vegetation change from C_3 forest to C_4 maize and other vegetation associated with clearing for ancient maize agriculture. The humin extraction procedure isolates the humin portion of the soil organic matter from the humic acid and fulvic acid portions of the soil organic matter. The humin fraction is considered the "oldest" organic matter. The $\delta^{13}C$ was determined solely on the humin fraction with isotope-ratio mass spectroscopy (Balzotti et al 2013).

Two grams of 100 mesh (149 um) air dried soils were weighed out to 100 ml tubes. 1M hydrochloric acid was added based on the levels of effervescence in each sample. Acid was added until effervescence ceased. The tubes were in a heated water bath (70°) for the duration of this process to increase reaction rates and to remove both calcium and magniesium carbonates.

This process removed carbonate that would skew ^{13}C results. The suspension was then transferred to 50ml Oak-Ridge centrifuge tubes and centrifuged for thirty minutes at 9000 rpm. The resultant liquid supernatant is poured out. After this, the samples were rinsed with water and the soil pellets detached from the centrifuge wall. The samples were shaken for at least 1 hour before centrifugation (9000rpm) for an additional thirty minutes. This rinse was repeated twice.

Humic and fulvic acid fractions of the soil organic matter were removed with an alkaline pyrophosphate extraction (0.1M sodium hydroxide and 0.1M sodium pyrophosphate). Extractant was added to fill roughly three quarters of the centrifuge tube. The soil pellet is loosened from the bottom of the centrifuge tubes and Teflon septum caps are placed on each vial. The headspace gasses were purged with pressurized nitrogen gas for one minute to remove O_2 that could oxidize extracted humic acids. After gas exchange, samples are shaken for 24 hour and then centrifuged for two hours at 17,000 rpm. The liquid supernatant was discarded. This process was repeated three times.

After the three extraction cycles, the samples were rinsed with water, shaken overnight and centrifuged. The supernatant is poured off following each centrifugation. Following the extraction the samples were rinsed twice with water, once with 0.05M phosphoric acid to remove alkalinity and once more with water. Pellets were dislodged from the tube and shaken for at least two hours before centrifugation for 2 hours at 17,000 rpm. Samples were dried in a 70°C bath until the soil pellets separate from the centrifuge tube walls. The soil was transferred to glass vials, oven dried at 105°C overnight and crushed in preparation for isotopic ratio mass spectroscopy. This will provide $\delta^{13}C$ values.

2.12 Statistical Analysis

Profiles are divided into two groups. Comparisons made between anthropogenic and natural soils provide evidences ancient human interaction with the environment. Soils classified as anthropogenic are collected directly adjacent or directly upon known ancient Maya structures. Natural soils are classified as such based on the lack of anthropogenic evidence present in the area immediately around the sampling profile.

A second set of profiles in this study compares soil chemical and physical composition along the Rio Bravo escarpment. Soils are classified as upland and lowland based on their position relative to the escarpment. These comparisons are used to make general statements of soil physical and chemical properties.

Comparisons are computed using a Welch T-test that assumes unequal variance. These tests are conducted on each group comprising surface samples, the top four samples, and all the samples within each profile. These comparisons are made at various depths due to unequal sampling depth between profiles. This is necessary because some physical and chemical properties vary based on depth and a use of complete profiles could result in skewed data. Phosphorus, for example, tends to accumulate on soil surfaces.

Additional statistical analyses conducted include a matrix regression analysis of soil physical and chemical properties using the surface samples, top four samples, and full profiles. These provide information of expected soil physical and chemical composition in the region. Various depths are used to include soil properties that are depth dependent and depth independent (Table 1, Table 2, Table 3).

3. RESULTS AND DISCUSSION

3.1 Physical and Chemical Characterization

Soil profiles in the study area in northwestern Belize encompassed a collection of archaeological sites and natural resources that represent both the upland karst escarpment known as the Rio Bravo Escarpment and lowland coastal plain known as the Three Rivers Coastal Plains (Figure 1).

The physical and chemical properties of the soil horizons are listed in Table 1, Table 2 , and Table 3. The soil texture analysis by both hydrometer method (Gee et al 1986) and laser particle size analysis are listed in Table 1. All of the surface A horizons textures measured by hydrometer method were higher than 46% clay. Ninety three of 104 horizon samples are classified as clay texture. The average clay content of all samples is 53%. Average clay percentages with depth are as follow: surface- 59%, 10-20 cm- 61%, 20-30 cm- 55%, upland- 58%, lowland- 56%, anthropogenic 51%, and natural 60%. No statistical differences were found between each group of soil depth samples (See Figure 2, Figure 3, Figure 4, Figure 5, Figure 6and Figure 7 for clay content distributions in each profile).

Laser particle size analysis theoretically provides the distribution of particle sizes in a solid sample. Results provided in this study found an amplification of silts in the soils. Only six of the one hundred and twenty four samples reported silts concentrations less than 50%. Only twelve sand percentages were found to be above 10%. These same soils reported a far greater number of samples with a clay percentage when using the hydrometer method. These differences in particle size distribution likely came as result of an error in sample preparation in the case of the laser diffraction method. Instructions given indicated that all samples should be ground to be pass through a #100 mesh (0.149 mm in diameter). This grinding process changed the ratio of sand, silt, and clay, resulting in an over-representation of silts.

The pXRF total element concentrations (mg/kg or %) of the soil horizons are listed in Table 4. Average total elemental concentrations are as follow: SiO_2- 41%, K 0.4%, Ca 7.3%, Ti- 1325 mg/kg, V- 5.9 mg/kg, Cr- 80 mg/kg, Mn- 655 mg/kg, Fe- 2.1%, Co 34 mg/kg, Ni 21 mg/kg, Cu 59 mg/kg, Zn- 75 mg/kg, Rb- 14 mg/kg, Sr 136 mg/kg, and Zr- mg/kg. Table 3 includes DTPA extractable metals, % total C, % total N, CO_3, and organic C. Average concentrations are as follow: Cd- 0.8 mg/kg, Cu- 1.1 mg/kg, Fe- 9.6 mg/kg, Mn- 7.9 mg/kg, Sr- 3.3 mg/kg, total N- 0.4%, total C- 8.2%, CO_3- 5.3%, and organic C- 3%.

3.2 Geography

Statistical comparisons of soil chemical and physical characteristics between the Rio Bravo Escarpment environment (includes all profiles at Crocodile Lake and RB73) and the lowland Three Rivers Coastal Plains (includes all profiles at Laguna Verde, Crystal Creek, and Akab Muclil) in northern Belize provide an approximation of chemical and physical variations in this environment as a result of topography. In order to account for individual variable depth dependency and independency, statistical analysis of complete profiles, without regard for sampling depth variations.

Inclusion of all samples, regardless of depth demonstrated percent sand, total SiO_2 ($p=0.0001$) total Ti ($p=0.0001$), total Mn ($p=0.0001$), total Fe ($p=0.0001$), total Sr ($p=0.0001$), and DTPA extractable Mn ($p=0.0002$) to be statistically higher in upland soils. Total Sr ($p=0.0001$), DTPA extractable Cu ($p=0.03$), and DTPA extractable Sr ($p=0.0001$) were found to be statistically higher in lowland soils. Analysis that includes only samples from 0-30 cm found total SiO_2 (p=0.01), total Ti (p=0.001), total Mn (p=0.0001), total Fe (p=0.007), total Zr (p=0.01), and DTPA extractable Mn (p= 0.0022) to be statistically higher in upland soils. Lowland soils found statistically higher total Sr (p=0.0005), and DTPA extractable Sr (p=0.001). Surface sample analysis found statistically higher total SiO_2 (p=0.02), total Ti (p=0.04), total Mn (p=0.002), DTPA extractable Mn (p=0.127), and DTPA extractable Sr (p=0.047). Lowland soils found statistically higher total Sr (p=0.0308) Table 7).

General physical characterization of soils in the Blue Creek region indicate high levels of clay that result from long term weathering in the region. Primary parent materials include various forms of calcareous rocks (limestone, marl, etc.). Individual profile physical characteristics can best be represented in changes of clay percentages throughout profiles (Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, and Figure 7).

Soils near Laguna Verde reflect little changes in physical properties throughout each profile, indicating gradual soil formation and deposition in the region. Soils at Akab Muclil present moderate clay values (40-50%) near the surface. Sub-surface horizons below 30 cm presented unreliable texture analysis due to the high calcium content of the marl or soft limestone parent material. Profiles at Crystal Creek indicate extremely high (<90%) clay content in the flood plain profile and significantly less (~60-70%) clay throughout the wetland profile. Such variations indicate unequal deposition of materials. Initial observations based on visual aspects of profiles at Crocodile Lake indicate an area dominated by erosion and deposition events. These observations are supported by the large shifts in clay content throughout profiles. Additionally, theses shifts occur simultaneously between three separate profiles. Profiles at RB73 mostly demonstrate little change. The exception is found at RB73 foot slope where large shifts in clay percentage at 30, 60, 90, and 120 cm can be attributed to the profile’s position in relation to structures. This can be attributed to the proximity of the steep slope (>20%), which results in the movement of large amounts of materials.

Statistical analyses indicate significantly greater concentrations of many heavy metals (both total and extractable) in the upland portions of the escarpment (Table 7). These observations demonstrate general soil chemical trends in the region and present the opportunity for further study in relation to soil chemical properties related to geography in the region.

Statistical comparisons between upland (Crocodile Lake and RB73) and lowland (Laguna Verde, Crystal Creek, and Akab Muclil) soils find little differences of note. Soils were classified based on position relative to the Rio Bravo Escarpment.

3.3 Anthropogenic Influence

Statistical comparisons of soil chemical and physical characteristics between the natural (Laguna Verde, Crystal Creek, and Crocodile Lake) and anthropogenic (Akab Muclil and RB73) soils of northern Belize provide possible indications of long term impacts associated with ancient anthropogenic influence in the region. Statistical analysis includes a group all samples, regardless of depth, as well as a group that top four samples, and a group that includes the surface samples (Table 8).

Complete profile analysis between natural and anthropogenic soils found statistically greater percent silt ($p=0.001$), pH ($p=0.002$), total Sr ($p=0.009$), and DTPA extractable Mn ($p=0.006$) in anthropogenic soils (Table 2). Natural soils were statistically higher percent clay ($p=0.001$), total Ti (0.0001), total Fe (0.0001), total Cu ($p=0.02$), total Zn ($p=0.0001$), total Zr ($p=0.0001$), DTPA extractable Cd ($p=0.0001$), DTPA extractable Cu ($p=0.0001$), and DTPA extractable Fe ($p=0.001$). Analysis that included only the top four samples found statistically higher percent silt (p=0.002), pH (0.0003), total Ca (p=0.008), total Sr (p=0.04), and DTPA extractable Mn (p=0.01) in anthropogenic soils. Natural soils at these depths found statistically higher percent clay, total SiO_2 (p=0.01), total Ti (p=0.0001), total Fe (p=0.001), total Cu (p=0.01), total Zn (0.0001), total Rb (p=0.03), total Zr (p=0.0001), DTPA extractable Cd (p=0.003), DTPA extractable Cu (p=0.005), and DTPA extractable Fe (p=0.003). Surface samples found statistically higher pH (p=0.01), and DTPA extractable Mn (p=0.01) in anthropogenic soils and statistically higher percent clay (p=0.03) in natural soils (Table 8).

Statistical analyses reported in Table 8 indicate that of anthropogenic influence produced statistically higher levels of Ca, $CaCO_3$, and pH near ancient Maya sites. This can be attributed to the use of limestone as the primary building material in the region, resulting in long term environmental influences. Natural soils indicate statistically higher concentrations of total and DTPA extractable heavy metals. The lower pH often indicates the availability of heavy metals.

Statistical differences between anthropogenic (RB 73 and Akab Muclil) and natural (Laguna Verde, Crystal Creek, and Crocodile Lake) soils find evidence of long term influences. Anthropogenic soils are classified based on direct proximity to known ancient Maya sites. Natural soils are far from any noted structures. These differences possibly come as a result of long term degradation of ancient Maya structures. The primary result this degradation is an increase in soil pH. This change then effects the availability of heavy metal and other micronutrients.

3.4 Carbon Isotopes

Isotopic analyses were conducted on the humin fraction of each 10-cm sampling depth from the nineteen profiles. The average surface (0-10 cm) and the first subsurface sample (10-20 cm) $\delta^{13}C$ ranged on average from -27.88‰ to -27.08‰ respectively (Table 6). These low $\delta^{13}C$ values reflect a landscape currently dominated by C_3 vegetation (Beach 2011). Isotopic examination of nineteen profiles in the region describes historical vegetation distributions across the region in reference to geography and proximity to ancient Maya habitation.

Laguna Verde

Laguna Verde is a lake found at the toe slope of the Rio Bravo Escarpment. This profile location was chosen because it provides an example of transition from the upland karst environment to the lowland coastal plain. These soils were still classified as lowland because they are still relatively low on the escarpment. In addition to representing the transition between the two landforms of interest, this area provides an example of contemporary anthropogenic influence with little evidence of ancient influences due to the road leading to Laguna Verde near the sample sites. The local Mennonites use the lake for recreational swimming and fishing. There is little or no evidence of ancient Maya activity in the area. Three profile comprising 17 horizon samples were taken at the toe slope, backslope, and slope summit of the escarpment.

Samples were taken at a slope summit on the escarpment. This slope summit is about halfway up the escarpment, has a slope of 4%, and exhibits an environment more associated with the upland areas than the lowland plains. Vegetation was fairly open and little disturbance was noted. Soil depth was moderately shallow. A 50-cm profile was exposed and horizon samples were collected at 10-cm depth intervals (Figure 8).

A soil profile on the backslope of the escarpment was examined and sampled. This profile provided a stronger transition between the upland and lowland environments. The slope was 25%. As with the slope summit, soil depth was moderately shallow. A 50-cm profile was exposed and samples were collected at 10-cm depth intervals (Figure 9).

Samples were taken at the toe slope of the escarpment. These samples provide a representation of the edge effects associated with the escarpment. A contemporary road was placed about fifty meters down slope from this sample location. Slope of sample location is 18.5%. Soil depth was increased at this location. A 70-cm profile was exposed and samples were taken in 10-cm increments (Figure 10).

Isotopic analyses of profiles at Laguna Verde indicate some strong evidence of maize production in two of the three profiles. Laguna Verde backslope presents a $\delta^{13}C$ shift with soil depth of 3.79 and a minimum $\delta^{13}C$ value of -23.65‰ at 30-40 cm represents weak ancient maize agriculture. Laguna Verde slope summit presents a $\delta^{13}C$ shift of 2.96‰ and a maximum $\delta^{13}C$ value of -24.13‰ at a depth of 30-40 cm . The profile at Laguna Verde Foot slope demonstrated no evidence of maize production with a $\delta^{13}C$ shift of 2.08‰ and a maximum $\delta^{13}C$ value of -25.88‰ at a depth of 50-60 cm (Figure 11). Profiles at Laguna Verde indicate some evidence of maize production in two of the three profiles. The profile found at the foot of the slope presents no evidence, while the profiles found along the slope present some evidence of ancient maize production. Indications of maize production along the slope of the escarpment may hint as possible terrace agriculture in this portion of the region. Field observations provided no indication of terrace construction, however, though the slopes were as steep as 18-25% at the toe slope and slope face profiles.

Crystal Creek

Crystal Creek is known for is turquoise waters (a clear blue green color caused by gypsum deposits in the aquifer system). It is located at the toe slope of the escarpment in a valley, or niche, that has formed as a result of large rainfall events. Information from locals indicated that this location is the edge of a region that experiences heavy flooding during the rainy season. This location hopefully provides an erosion record of the region. Due to the dynamic nature of the area, these samples can be considered uninfluenced by both ancient and contemporary anthropogenic influence. Indirect influences may be seen as a result of upstream deforestation that results in erosion.

The flood plain region near Crystal Creek as indicated by locals is also known to have a high water table for the majority of the year. Profile was dug ~50m from Crystal Creek. Sampling occurred just prior to the summer rainy season, that results in the lowest average water level. A 70-cm profile was exposed and samples were taken in 10-cm increments. With exception of the surface O horizon, little horizon definition was observed (Figure 12).

The wetland portion near Crystal Creek has been indicated by the locals to be saturated with near surface water for the majority of the year. Samples were collected just before the summer rainy season, which indicates that water levels would be at their average lowest, which created the best opportunity for greatest sample depth. A 60-cm profile was exposed and samples were taken in 10-cm increments. Little horizon definition was noted (Figure 13).

Isotopic analyses of profiles at Crystal Creek indicate weak evidence of maize production in one profile and strong evidence on the other. Crystal Spring wetland presents a $\delta^{13}C$ shift of 3.36‰ and a maximum $\delta^{13}C$ value of -25.35‰ at a depth of 40-50 cm. Crystal Creek flood plain presents a $\delta^{13}C$ shift of 2.78‰ and a maximum $\delta^{13}C$ value of -25.34‰ at a depth of 60-70 cm. (Figure 14) Some evidence of ancient maize production is present near Crystal Creek. These results are surprising due to the rapidly changing hydrologic activity in the area during the rainy season. While no permanent occupation of the area is likely due to the flooding issues of the wet season, indications of maize production provides the possibility of seasonal occupation of the area.

Akab Muclil

Akab Muclil (Mayan for "moonlight over the water") is an ancient Maya site located on the lowland flood plains to the east of the Rio Bravo escarpment on the edge of a current wetland system. The site is found south of Laguna Verde, and north of another ancient site known as Birds of Paradise (named so for the many Birds of Paradise plants found around the site). Akab Muclil is a collection of only a few residential buildings with no large structures noted.

A profile was examined and samples were collected near the eastern edge of the site about 50-m from the nearest mound. The purpose of this sample location was to represent the ancient lowland occupation of the region and the long term anthropogenic influences on the region. A single profile was initially dug to a depth of 60-cm near the edge of the wetland. Samples were collected in 10-cm increments from the east and west backslope of the profile. Additional profiles were dug closer to the site in an attempt to increase representation of ancient influence, but worked stone porches were discovered within 30-cm and it was determined that no further sample should be collected.

Isotopic analyses of profiles at Akab Muclil indicate strong evidence of maize cultivation in one of the two profiles. Akab Muclil foot slope east (the profile closest to the structures of

Akab Muclil) presents a $\delta^{13}C$ shift of 1.47‰ and a maximum $\delta^{13}C$ value of -27.19‰ at a depth of 30-40 cm. Akab Muclil foot slope west presents a $\delta^{13}C$ shift of 4.25‰ and a maximum $\delta^{13}C$ value of -24.10‰ at a depth of 20-30 cm (Figure 15). Two profiles from the same pit near Akab Muclil indicate two different observations. Eastern samples, closest to the structure, indicate no Maize production. Western samples, further from the structure, strongly indicate Maize production. These variations could come as a result of a midden or garden areas for maize production.

Crocodile Lake

Crocodile Lake is named such for the many crocodile sightings by local residents. The lake is located about 1km south of the central town center of Blue Creek. The area that surrounds the lake forms a bowl canyon with sides as steep as 30%. Water enters the lake from the west and no surface runoff or drainage sources were noted. While this location is inhospitable to settlement, the greater region to the west includes large amount of pasture and crop land.

A profile was dug near the northern edge of Crocodile Lake at the toe of the steep slope. The profile was ~5m from the lake edge. This location provides a sample that experiences little disturbance (both anthropogenic and environmental). A 60-cm profile was exposed and samples were taken in 10-cm increments. Even though this sample was collected as close to the lake as possible (while still deemed safe), the slope was still 25 degrees (Figure 16).

On the western edge of the lake the land is far move level (slope < 3 degrees) and the vegetation more open as a result of large water events. The night prior to sampling this region a large rain event deposited small fish from upper regions in this area where the fish died as a result of receding waters. Delta 1 and 2 were located in this flat region. Each of these profiles provide a possible record of erosion events in the region.

The profile, designated Delta 1, was found approximately 30m from the water's edge. The profile was dug until groundwater was present at 50-cm. Samples were collected in 10 -cm increments from both the western and eastern backslopes of the profile. Two additional samples were taken in 10-cm increments from the bottom of the pit with a soil auger (Figure 17 and Figure 18).

The second profile, designated Delta 2, was found approximately 200m west of Delta 1. The profile was dug until groundwater was present at 170-cm. Samples were collected in 10-cm increments from the south backslope of the profile. As given by the soil horizon and gravel deposition layers, this profile provides a record of proposed erosion events in the region. Variations in color and texture will hopefully provide quantifiable evidence of these observations. (Figure 19, Figure 20, Figure 21, Figure 22).

Isotopic analyses of profiles at Crocodile Lake indicate strong evidence of maize cultivation in three of the four profiles. Crocodile Lake back foot slope presents a $\delta^{13}C$ shift of 1.77‰ and a maximum $\delta^{13}C$ value of -26.23‰ at a depth of 30-40 cm. Crocodile Lake delta 1 east presents a $\delta^{13}C$ shift of 11.71‰ and maximum $\delta^{13}C$ value of -15.72‰ at a depth of 40-50 cm. Crocodile Lake delta 1 west presents a $\delta^{13}C$ shift of 5.45‰ and a maximum $\delta^{13}C$ value of -21.04‰ at a depth of 40-50 cm. Crocodile Lake delta 2 south presents a $\delta^{13}C$ shift of 15.04‰ with a maximum $\delta^{13}C$ value of -12.59‰ at a depth of 30-40 cm (Figure 23). Observations at Crocodile Lake provide the most interesting results related to isotopic analysis of this study. Three profiles (Delta 1 East, Delta 1 West, and Delta 2) all contain strong $\delta^{13}C$ signatures at similar depths. Recall Delta 2 is located slightly further up slope from Delta 1 profiles. Initial observations of the area surrounding the profiles indicated large amounts of water moving through the area following rain events (it rained the evening prior). It is hypothesized that the signature that indicates maize production was deposited by a mass movement event further up the slope where maize may have been produced or crop wasted deposed. The movement of large amounts of earth may result in the preservation of $\delta^{13}C$ signatures in the soil. The hypothesis of mass movement deposition is supported by large shifts in percent clay in each of these profiles.

RB73

The designation of RB73 has been given to a set of ruins under current investigation. RB73 is located along the road between the Programme for Belize visitor center and La Milpa. Samples in this area provide an example of upland ancient occupation of the region and the possible long term effects associated with this occupation. Eight profiles were collected in various locations across the site.

Slope summit was part of a four profile catena that ranges from the top of a structure, down to the lower region just off the edge of the site. The profile at the slope summit reached a depth of 45-cm. Samples were taken in 9-cm increments in order to increase the total sample size of the profile. Pottery was found in the profile (Figure 24).

Back Slope 1 was roughly two thirds down the slope from slope summit. The profile bottom reached worked stone at a depth of 40-cm. Samples were taken in 10-cm increments (Figure 25).

Back Slope 2 was roughly one third down the slope from slope summit. The profile reached worked stone at a depth of 30-cm. Samples were taken in 10-cm increments (Figure 26).

The foot slope of the catena provided a possible accumulation basin at the edge of the site. Investigation away from the site indicated little structures near this profile (with the exception of the structure included in the catena). Profile reached a depth of 130-cm with samples collected every 10-cm. Charcoal carbon samples were found at a depth of 85-cm, which provides radiocarbon dates on the deposition of this profile. This profile serves as a representation of close proximity to site in the upland region of Blue Creek. Pottery sherds were found throughout profile (Figure 27).

In the central region of the site, terracing was present that provides a possible site of agricultural production within the inner portions of the site. During the time of the investigation, archaeological studies in progress provided exposed profiles that fit the need of this study. Two sample locations were identified on the terrace. Each profile reached a depth of 30-cm, with samples collected every 10-cm (Figure 28and Figure 29).

Proposed water features in the site provided additional exposed profiles that allowed for further samples. Water feature 3 included a profile that reached a depth of 70-cm, with samples taken in 10-cm increments and water feature 4 included a profile that reached depth of 60-cm, with samples collected in 10-cm increments (Figure 30).

Isotopic analyses of profiles at RB 73 mostly indicate no evidence of maize production. The exceptions include RB73 foot slope and RB73 water feature 4. RB73 foot slope presents a $\delta^{13}C$ shift of 5.63‰ and a maximum $\delta^{13}C$ value of -22.57‰ at a depth of 90-100 cm. RB73 water feature 4 presents a $\delta^{13}C$ shift of 3.22‰ and a maximum $\delta^{13}C$ value of -25.92‰ at a depth of 50-60 cm (Figure 31, Figure 32, Figure 33). Profiles at RB73 mostly serve as controls for no ancient maize production. The majority of profiles were collected on top of structures where soil has accumulated since ancient abandonment. The profile RB 73 foot slope is the only profile to present an indication of maize production. Recall this profile is found on the edge of the site in a depression. The strong $\delta^{13}C$ evidence found in this profile may be the result of middens where maize material was deposited, or the result of ancient maize production.

4. CONCLUSION

Ancient activities result in a long term impact on the surrounding environment. Statistical comparisons found evidence long term influences on soil pH as a result of the decomposition of building materials in anthropogenic soils, directly influencing the availability of soil micronutrients. Often these impacts are determined through the use of environmental proxies. These proxies indicate that the effects ancient anthropogenic activities in the Blue Creek region persist today. Indications of maize production in the upper portions of the catena at Laguna Verde indicate possible terrace agriculture due to the steep slopes at the base of the Rio Bravo Escarpment. Profiles at Crystal Creek indicate maize production despite large quantities of water passing through the area on a regular basis. Isotopic analyses at Akab Muclil indicate maize production directly adjacent to structures. This indicates that the ancient Maya possibly engaged in gardening. Profiles at RB 73 serve as control groups for the region and demonstrate that the ancient Maya did not produce crops directly on structures. RB73 foot slope indicates high levels of C_4 plant material deposition. Additionally, carbon isotopic signatures at Crocodile Lake Delta 1 and 2 in concert with changes in soil clay content throughout each profile provide insights that were previously considered improbable; that is that isotopic signatures of ancient vegetation changes can move and be retained during mass movement events. Large scale analysis of all profile groups indicate that the lowland region may be better suited for lowland agriculture due to the greater availability of water and the ancient Maya's apparent success in consistently cultivating maize in lowland soils.

5. REFERENCES

Accoe, F., Boeckx, P., Van Cleemput, O., Hofman, G., Hui, X, Bin, H., and Guanxiong, C. (2002) Characterization of soil organic matter fractions from grassland and cultivated soils via C content and $\delta^{13}C$ signature. *Rapid commuications in mass spectrometry.* 16, pp. 2157-2164.

Agren, G.I., Bosatta, E., and Balesdent, J. (1996) Isotope discrimination during decomposition of organic matter: a theoretical analysis. *Soil Science Society of America*. 60, pp. 1121-1126.

Angelini, E., Grassini, S., Corbellini, S. Ingo, G.M. De Caro, T. Plescia, P., Riccucci, C., Bianco, A., and Agostini, S. (2006) Potentialities of XRF and EIS portable instrument for the characterization of ancient artifacts. *Applied Physics*. 83, pp. 643-649.

Anselmetti F.S., Hodell, D.A., Ariztegui, D., Brenner, M., and Rosenmeier, M.F. (2007) Quantification of soil erosion rates related to ancient Maya deforestation. *Geology*. 35:915-918.

Atran, S. (1993) Itza Maya tropical agro-forestry. *Current Anthropology*. 34:663-700.

Cowgill, U. (1962) An agricultural study of the Southern Maya Lowlands. *American Anthropologist.* 64:273-286Bai, E., Boutton, T.W., Liu, F, Wu, X.B., and Archer S.R. (2012) Spatial patterns of soil $\delta^{13}C$ reveal grassland-to-woodland successional processes. *Organic Geochemistry*. 42, pp. 1512-1518.

Balesdent, J., and Balabane, M. (1996) Major contribution of roots to soil carbon storage inferred from maize cultivated soils. *Soil biology and biochemistry*. 9, pp. 1261-1263

Balzotti, C., Golden, C., Scherer, A., and Terry, R.E. (2013) Stable carbon isotope signatures of ancient maize agriculture at El Kinel, Guatemala. *Central European Geology*. 56:59-74.

Balzotti, C., et al. (2013). Modelling the ancient maize agriculture potential of landforms in Tikal national park, Guatemala. *International Journal of Remote Sensing*. 34(16), pp. 5868-5891.

Beach, T., and Dunning, N. (1995) Ancient Maya terracing and modern conservation. *Journal of Soil and Water Conservation*. 50:138-145.

Beach, T. (1998) Soil catenas, tropical deforestation, and ancient and contemporary soil erosion in the Peten, Guatemala. *Physical Geography*. 19:378-405.

Beach, T., Luzzadder-Beach, S., Dunning, N., Hageman, J., and Lohse, J. (2002) Upland agriculture in the Maya Lowlands: ancient Maya soil conservation in northwestern Belize. *Geographical Review*. 92(3):372-397.

Beach, T., Dunning, N., Luzzadder-Beach, S., and Scarborough, V. (2003) Depression soils in the lowland tropics of Northwestern Belize: anthropogenic and natural origins. *The Lowland Maya Area: Three Millennia at the Human-Wetland Interbackslope*. pp. 139-174.

Beach, T., Luzzadder-Beach, S., and Dunning, N. (2006) A soils history of Mesoamerica and the Caribbean islands. *Soils and Societies: Perspectives from Environmental History*. pp. 51-90.

Beach, T., et al. (2006). Impacts of the ancient Maya on soils and soil erosion in the central maya lowlands. *Catena*. 65, pp. 166-178,

Beach, T., and Luzzadder-Beach, S. (2009). Arising from the wetlands: mechanisms and chronology of landscape aggradation in the northern coastal plain of Belize. *Annuals of the Association of American Geographers*. 99(1), pp. 1-26.

Beach, T., Luzzadder-Beach, S.L., Terry, R., Dunning, N. Houston, S., and Garrison, T. (2011) Carbon isotopic ratios of wetland and terrace soil sequences in the Maya Lowlands of Belize and Guatemala. *Catena*. 85:109-118.

Beach, T., et al. (2011). Carbon isotopic ratios of wetland and terrace soil sequences in the Maya lowlands of Belize and Guatemala. *Catena*. 85, pp. 109-118.

Beach, T., Luzzadder-Beach, S., Cook, D., Dunning, N., Kennent, D. Krause, S., Terry, R., Trein, D. and Valdez, F. (2015) Ancient Maya impacts on the earth's surface: An Early Anthropocene analog? *Quaternary Science Review*. In press.

Bernard, T.W., Crockett, M.I., Ivaldi, J.C., Lundburg, P.L., Yates, D.A., Levine, P.A., and Sauer, D.J. (1993). Solid-state detector of ICP-OES. *Analytical Chemistry*. 65, pp. 1231-1329.

Bernick, M. B., D. J. Kalnicky, G. Prince, and R. Singhvi. 1995. 'Results of Field-Portable X-Ray-Fluorescence Analysis of Metal Contaminants in Soil and Sediment. *Journal of Hazardous Materials* 43: 101–110.

Biedenbender, S.H., McClaran, M.P., Quade, J., and Weltz, M.A. (2004) Landscape patterns of vegetation change indicated by soil carbon isotope composition. *Geoderma*. 119, pp. 69-83.

Bostrom, B., Comstedt, D., and Eklad, A. (2007) Isotopic fractionation and ^{13}C enrichment in soil profiles during the decomposition and soil organic matter. *Oecelogia*. 153, pp. 89-98.

Boutton, T.W., Archer, S.R., Midwook, A.J., Zitzer, S.F., And Bol, R. (1998) δ^{13}C values of soil organic carbon and their use in documenting vegetation change in a subtropical savanna ecosystem. *Geoderma*. 82, pp. 5-41.

Bouyoucos, J.B. (1951). A recalibration of the hydrometer method for making mechanical analysis of soils. *Agronomy Journal*. 43 pp. 434-438.

Burnett, R.L. (2009) Stable carbon isotope evidence of ancient Maya agriculture at Tikal Guatemala. *Masters Thesis: Brigham Young University*.

Burnett, R.L., Terry, R.E., Alvarez, M., Balzotti, C. Murtha, T. Webster, D., and Silverstein, J. (2012) The ancient agricultural landscape of the satellite settlement of Ramonal near Tikal, Guatemala. *Quaternary International*. 265 pp. 101-1155.

Brenner M., Rosenmeier, M.F., Hodell, D.A., Curtis J.H. (2002) Peleolimnology of the Maya Lowlands. *Ancient Mesoamerica*. 13:141-157.

Chase, A.F., Chase, D.Z., Awe, J.J., Weishampel, J.F., Iannone, G., Moyes, H., Yaeger, J., and Brown, M.K. (2014) The use of LiDAR in understanding the ancient Maya landscape: Caracol and Western Belize. *Advanced Archaeological Practices.* 2(3):147-160.

Dahlin B.H., Beach, T., Luzzadder-Beach S., Hixson, D., Hutson S., Magnoni, A., Mansel E., and Mazeau, D.E. (2005) Reconstructing agricultural self-sufficiency at Chunchucmil, Yucatan, Mexico. *Ancient Mesoamerica*. 16:229-247.

Dahlin,. et. al. (2007). In Search of an Ancient Maya Marketplace. *Society for American Archaeology*. 18, pp. 363-384.

Dunning, N.P. (1996) A reexamination of regional variability in the pre-Hispanic agricultural landscape. *The managed mosaic: ancient Maya agriculture and resource use*. pp. 53-68.

Dunning, N.P. (2000) Long twilight or new dawn? Transformations of Maya civilization in the Puuc region. *Maya: Divine kings of the rain forest.* pp. 322-337.

Dunning, N.P., Beach, T. (2000) Stability and instability in pre-Hispanic Maya landscapes. *Imperfect Balance*. pp. 179-202.

Dunning, P.N., and Beach. T. (2003) Noxious or nurturing nature? *Maya civilization in environmental context. Maya Civilization in Environmental Context*. pp. 123-140.

Dunning, N.P., Beach, T. (2004) Fruit of the Luum: Lowland Maya soil knowledge and agricultural practices. *Mono y Conejo*. 2:3-15.

Dunning, N.P., and Beach, T. (2010) Farms and forests: spatial and temporal perspectives on ancient maya landscapes. *Landscapes and Socienties*. pp. 369-389

Fedick, S.L. (1995) Land evaluation and ancient Maya land use in the upper Belize River area, Belize, Central America. *Latin American Antiquity*. 6:16-34.

Feng, X. (2003) A theoretical analysis of carbon isotope evolution of decomposing plant litters and soil organic matter. *Global Biogeochemical Cycles*. 16, pp. 1-11.

Freitas, H.A., Pessenda, L.C.R., Aravena, R., Gouveia, S.E.M., Ribeiro, A.S., and Boulet, R. (2011) Late quaternary vegetation dynamics in the southern Amazon Basin inferred from carbon isotopes in soil organic matter. *Quaternary Research*. 55, pp. 39-46.

Gee, G.W., Bauder, J.W. (1986) Particle-size analysis. *Methods of soil analysis. Part 1, Soil Science Society of America*. pp. 383-411.

ISO 13320: (2009). Particle size analysis - Laser diffraction methods. ISO: Geneva, Switzerland.

Jensen, C.T., Terry, R.E., Johnson K.D., Nelson, S.D., Moriarty M., and Emery K.F. (2007) Settlement agriculture at a Late Classic Maya center: connections between soil classification and settlement patterns at Motul de San Jose, Guatemala. *Geoarchaeology: An International Journal*. 22:337-357.

Keeley, J.E., and Rundel, P.W. (2003) Evolution of CAM and C4 carbon concentrating mechanisms. *International journal of plant science*. 164, S55.

Lindsay, W.L., and Norvell, W.A. (1978). Development of a DTPA soil test for zinc, iron manganese and copper. *Soil Science Society of America Journal*. 42, pp. 421-428.

Lerch T.Z., Nunan, N., Dignac, M.F., Chenu, C., and Mariotti, A. (2011) Variations in microbial isotopic fractionation during soil organic matter decomposition. *Biogeochemistry*. 106, pp. 5-21.

Leyden, B.W. (2002) Pollen evidence for climatic variability and cultural disturbance in the Maya lowlands. *Ancient Mesoamerica*. 13:85-101.

Luzzadder-Beach, S., and Beach, T. (2009) Arising from the wetlands: mechanisms and chronology of landscape aggradation in the northern coastal plain of Belize. *Annals of the Association of American Geographers*. 99(1):1-26.

Luzzadder-Beach, S., Beach, T.P., and Dunning, N.P. (2011) Wetland fields a mirror of drought and the Maya abandonment. *PNAS*. 1114919109.

Luzzadder-Beach, S., Beach, T.P., and Dunning, N.P. (2011) Wetland fields as mirrors of drought and Maya abandonment. *PNAS*. 1114919109.

Luzzadder-Beach, S., Beach, T. and Dunning, N. (2012) Wetland fields as mirrors of drought and the Maya abandonment. *PNAS*. 109(10):3646-3651.

Mueller, C.W., Gutsch, M., Korthieringer, K., Leifeld, J., Rethemeyer, J., Brueggemann, N., and Kogel-Knabner, Ingrid. (2014) Bioavailability and isotopic composition of CO_2 released from incubated soil organic matter fractions. *Soil Biology and Biochemistry*. 69, pp. 168-178.

Natelhoffer, K.J., and Fry, B. (1998) Controls on natural nitrogen-15 and carbon-13 abundances in forest soil organic matter. *Soil science society of America journal*. pp. 1633-1640.

Nations, J., and Nigh, R. (1980) The evolutionary potential of Lacandon Maya sustained-yield tropical forest agriculture. *Journal of Anthropological Research*. 36:1-30.

Parnell, J.J., Et al. (2001). Using in-field phosphate testing to rapidly identify middens at Piedras Negras, Guatemala. *Geoarchaeology: An International Journal*. 16, pp. 855-873.

Powers, J.S., and Schlesinger, W.H. (2002) Geographic and vertical patterns of stable carbon isotopes in tropical rain forest soils of Costa Rica. *Geoderma*. 109, pp. 141-160.

Pessenda, L.C.R., Aravena, R., Melfi, A.J., Telles, E.C.C., Boulet, R., Valencia, E.P.E., and Tomazello, M. (1996) The use of carbon isotopes (^{13}C,^{14}C) in soil to evaluate vegetation changes during the holocene in central Brazil. *Radiocarbon*. 38, pp. 191-201.

Scholger, R., and Hanesch, M. (2002). Mapping of heavy metal loadings in soils by means of magnetic susceptibility measurements. *Environmental Geology*. 42, pp. 857-870.

Schweizer, M., Fear, J., and Cadisch, G. (1999) Isotopic (^{13}C) fractionation during plant residue decomposition and it implications for soil organic matter studies. *Rapic Communications in Mass Spectrometry*. 13, pp. 1284-1290.

Siebke, K, von Caemmerer, S., Badger, M., and Furbank, R.T. (1997) Expressin an rbcS antisense gene in transgenic *Flaveria bidentis* leads to an increased quantum requirement of CO_2 fixed in photosystems I and II. *Plant physiology*. 115, pp. 1163-1174.

Stinchcomb, G.E., Messner, T.C., Williamson, F.C., Driese, S.G., and Nordt, L.C. (2013) Climatic and human controls on Holocene floodplain vegetation changes in eastern Pennsylvania based on the isotopic composition of soil organic matter. *Quaternary Research*. 79, pp. 377-390.

Stinchcom, G.E., Messner, T.C., Driese, S.G., Nordt, L.C., and Stewart, R.M. (2011) Pre-colonial (A.D. 1100-1600) sedimentation related to prehistoric maize agriculture and climate change in eastern North America. *Geological Society of America*. 39, pp. 363-366.

Sweetwood, R.V. (2008) The Maya footprint: soil resources at Chunchucmil, Yucatan, Mexico. *M.S.Thesis. Brigham Young University, Provo, UT*. http://contentdm.lib.byu.edu/ETD/image/etd.2323.pdf

Sweetwood, R.V., Terry, R.E., Beach, T., Dahlin, B.H. and Hixson, D. (2009) The Maya footprint: soil resources of Chunchucmil, Yucatan, Mexico. *Soil Science Society of America*. 73:1209-1220.

Terry, R.E., P.J. Hardin, S.D. Houston, M.W. Jackson, S.D. Nelson, J. Carr, and J. Parnell, 2000 "Quantitative phosphorus measurement: A field test procedure for archaeological site analysis at Piedras Negras, Guatemala," *Geoarchaeology: An International Journal*, 15: 151-166.

Tuabe K.A. (1992) The major gods of ancient Yucatan. *Dumbarton Oaks*. pp.

Turner II, B.L. (1985) Issues related to subsistence and environment among the ancient Maya. *Prehistoric Lowland Maya Environment and Subsistence Economy*. pp. 195-209.

Tozzer A.M. (1941) Landa's relacion de las cosas de Yucatan: A Translation. *Papers at the Peabody Museum of American Archaeology and Ethnology*. vol. 18.

USDA Soil Salinity Laboratory (1954) Agricultural Handbook, *Riverside, CA.*

von Crammerer S., Millgate, A., Farquhar, G.D., and Furbank, R.T. (1997) Reduction of ribulose 1,5-biphosphate carboxylase/oygenase by antisense RNA in C_4 plant *Flaveria bidentis* leads to reduced assimilation rates and increased carbon isotope discrimination. *Plant physiology*. 113, pp. 469-477.

Webb, E., Schwarcz, H,, Jensen, C.T., Terry, R.E., Moriarty, M.D., and Emery, K.F. (2007) Stable carbon isotopes signature of ancient maize agriculture in the soils of Motul de San Jose, Guatemala. *Geoarchaeology: An International Journal*. 22, pp. 291-312.

Webb, E.A., Schwarcz, H.P., and Healy, P.F. (2004) Carbon isotope evidence for ancient maize agriculture in the Maya lowlands. *Journal of Archaeological Science*. 31, pp. 1039-1052

Wedin, D.A., Tieszen, L.L., Dewey, B., and Pastor, J. (1995) Carbon isotope dynamics during grass decomposition and soil organic matter formation. *Ecology*. 76, pp. 1383-1392.

Wells, E.C., Terry, R.E. (2007) Special issue: advances in geoarchaeological to anthrosol chemistry, part I: Agriculture- Introduction. *Geoarchaeology- an International Journal*. 22:285-290

Werth, M., and Kuzyakov, Y. (2008). Root-derived carbon in soil respiration and microbial biomass determined by ^{14}C and ^{13}C. *Soil Biology and Biochemistry*. 40, pp. 625-637.

Wilson, C.A., Davidson, D.A., and Cresser, M.S. (2008) Multi-element soil analysis: an assessment of it potential as an aid to archaeological interpretation. *Journal of Archaeological Science*. 35:412-424.

Wynn, J.G. (2007) Carbon isotope fractionation during decomposition of organic matter in soils and paleosols: implications for paleoecological interpretations of paleosols. *Palaeogeography, Palaeoclimatology, Palaeoecology.* 251, pp. 437-448.

Yang, W., Magid, J., Christensen, S. Ronn, R., Ambus, P., and Ekelund, F. (2013) Biological ^{12}C -^{13}C fractionation increases with increasing community-complexity in soil microbes. *Soil Biology and Biochemistry*. 69 pp. 197-201.

Zhang, N., Krause, K.P., Apel, P., and Sonnewald, U. (1996) Reduction of the cytosolic furctoase-1,6-bisphosphate in transgenic potato plants limits photosynthetic sucrose biosynthesis with no impact on plant growth and tuber yield. *Plant Journal*. 9, pp. 9438-9443.

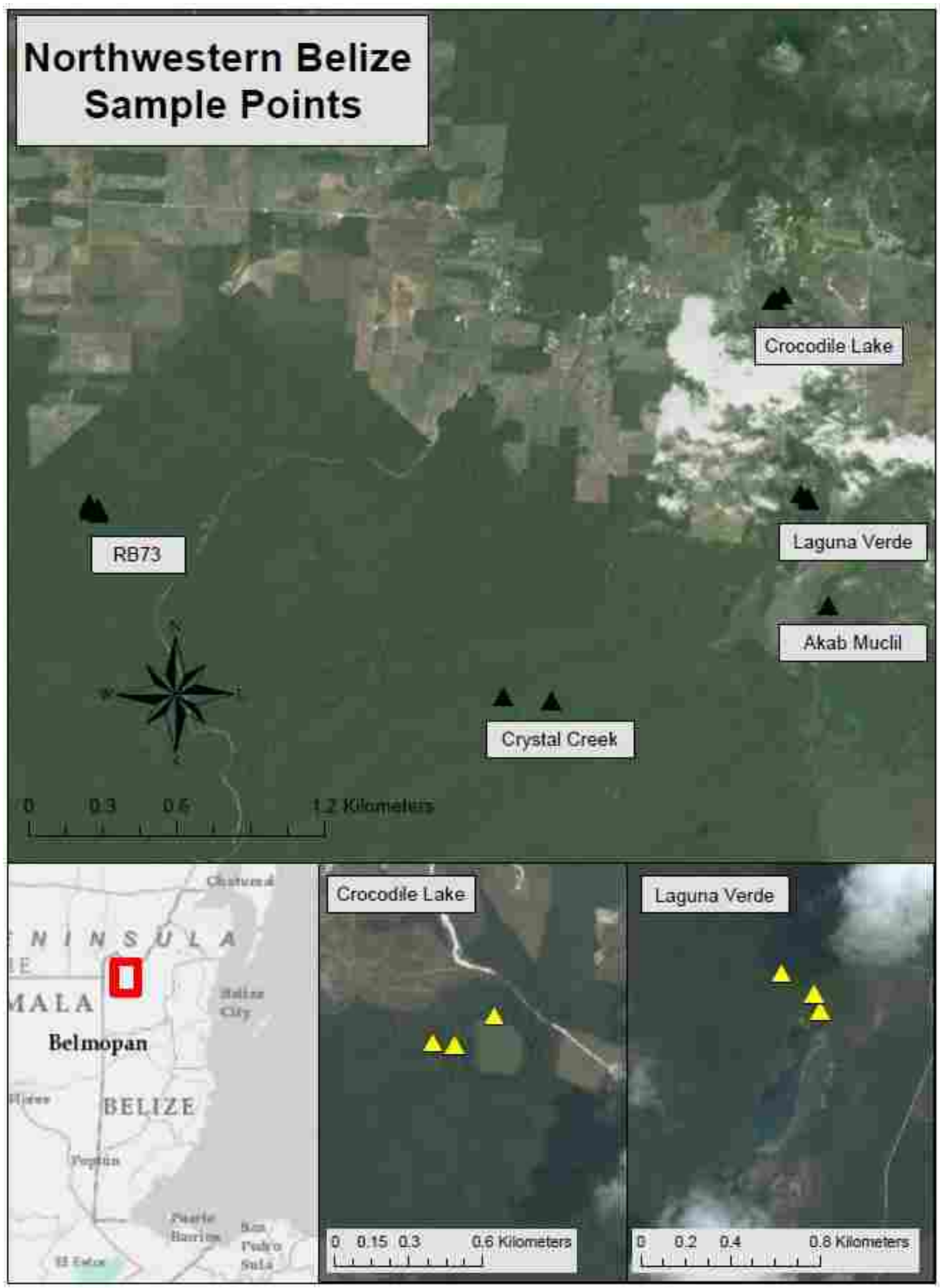

Figure 1 – Map of Northwestern Belize and Profile Locations

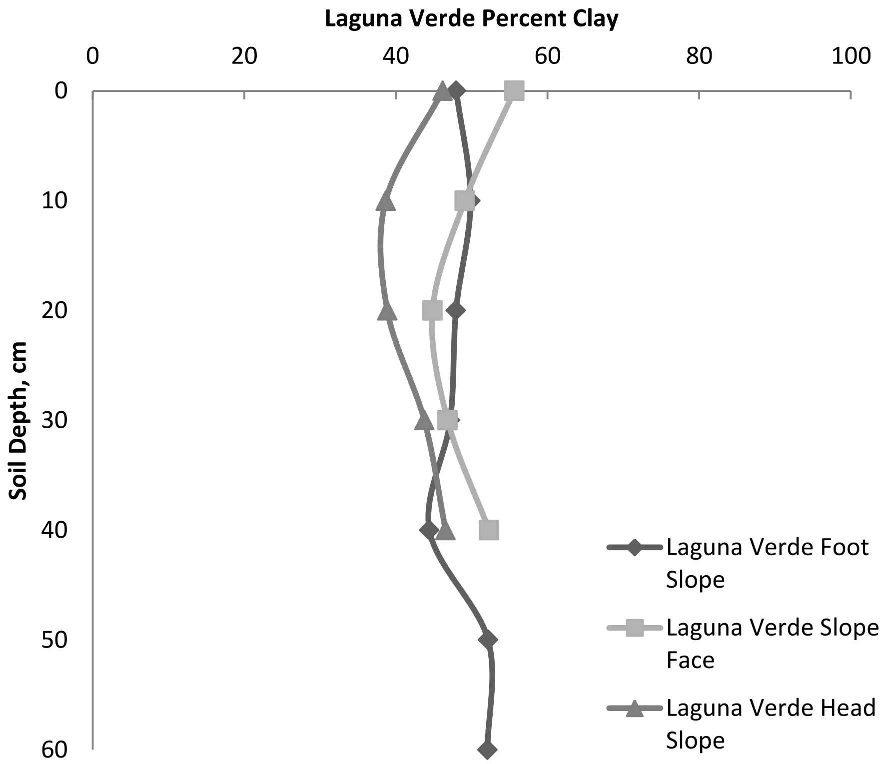

Figure 2- Clay Percentage Laguna Verde

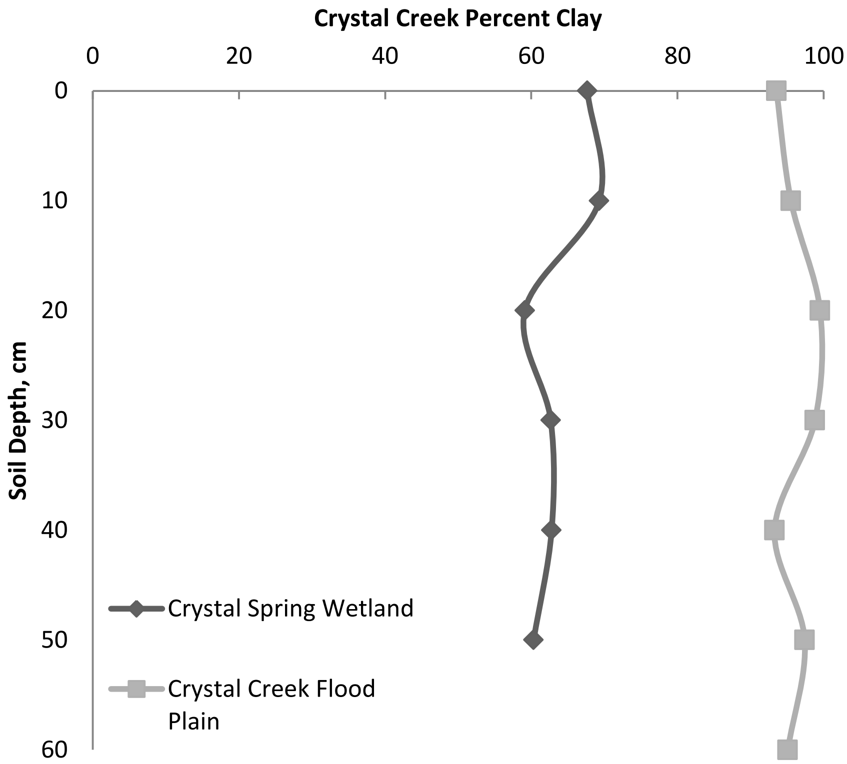

Figure 3- Clay Percentage Crystal Creek

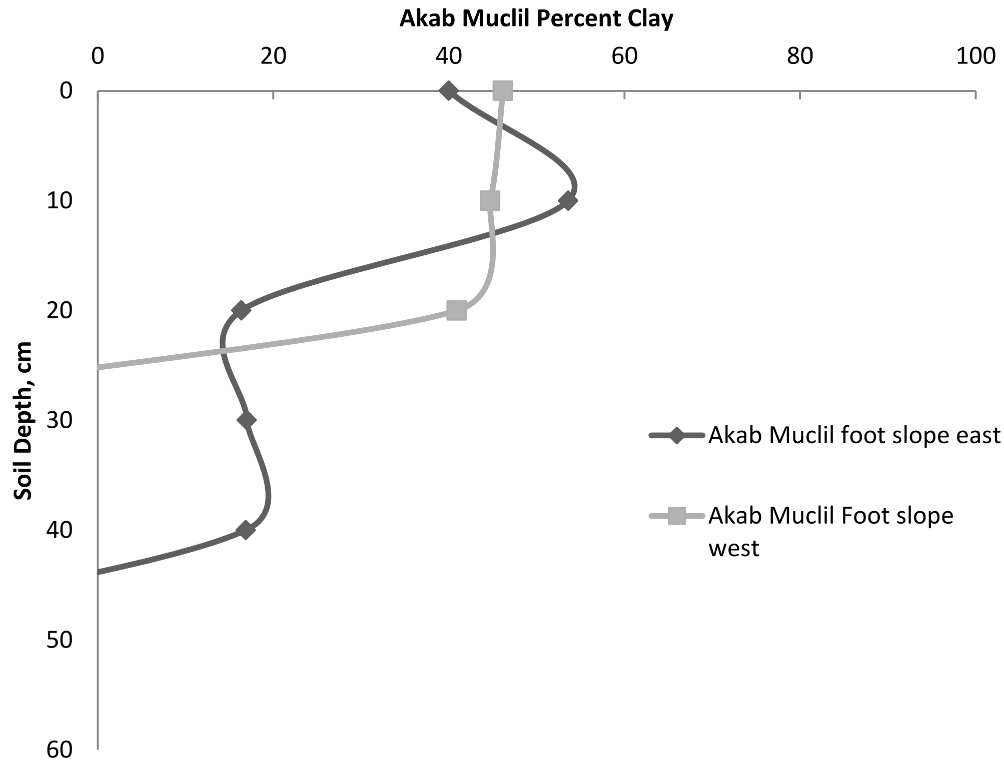

Figure 4- Clay Percentage Akab Muclil

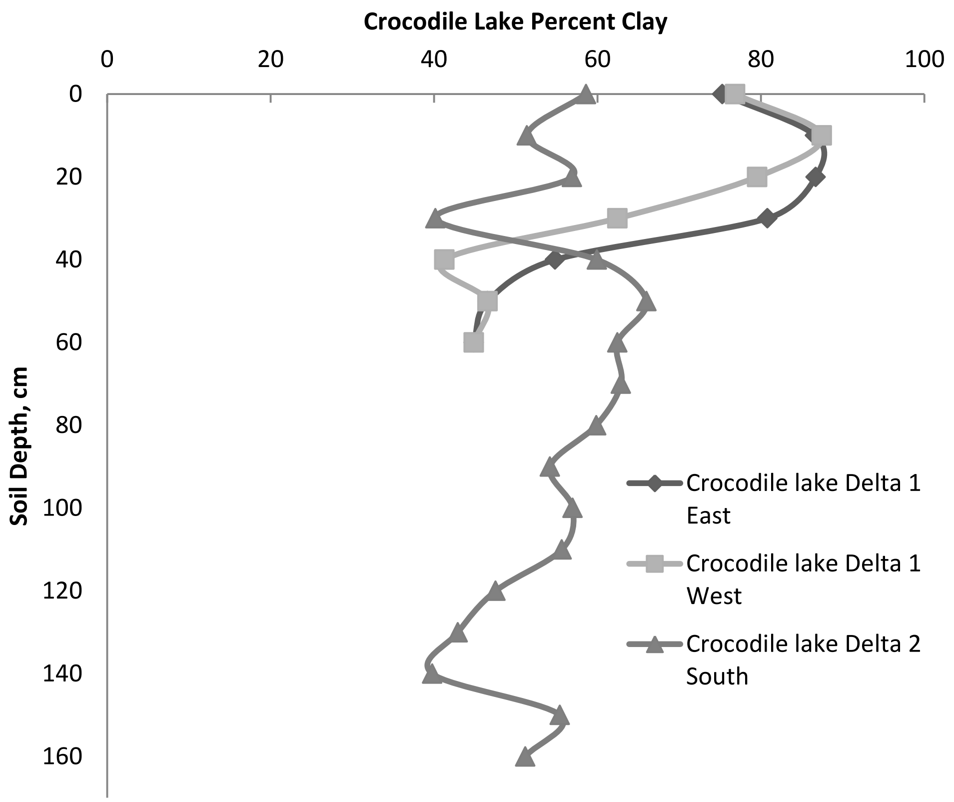

Figure 5- Clay Percentage Crocodile Lake

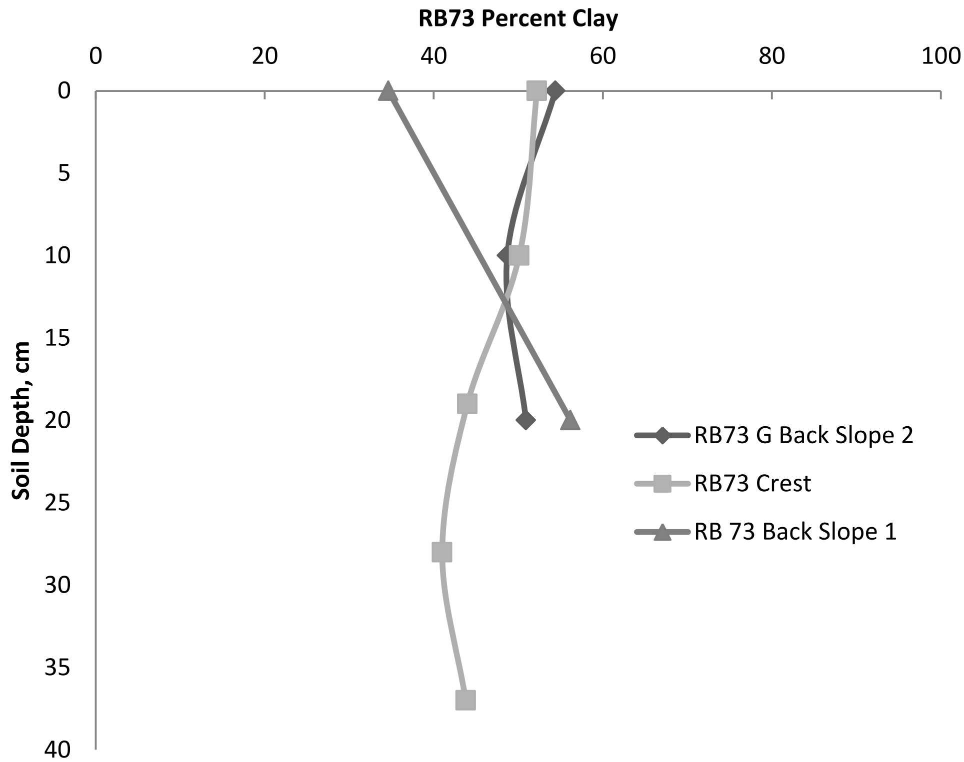

Figure 6- Clay Percentage RB73

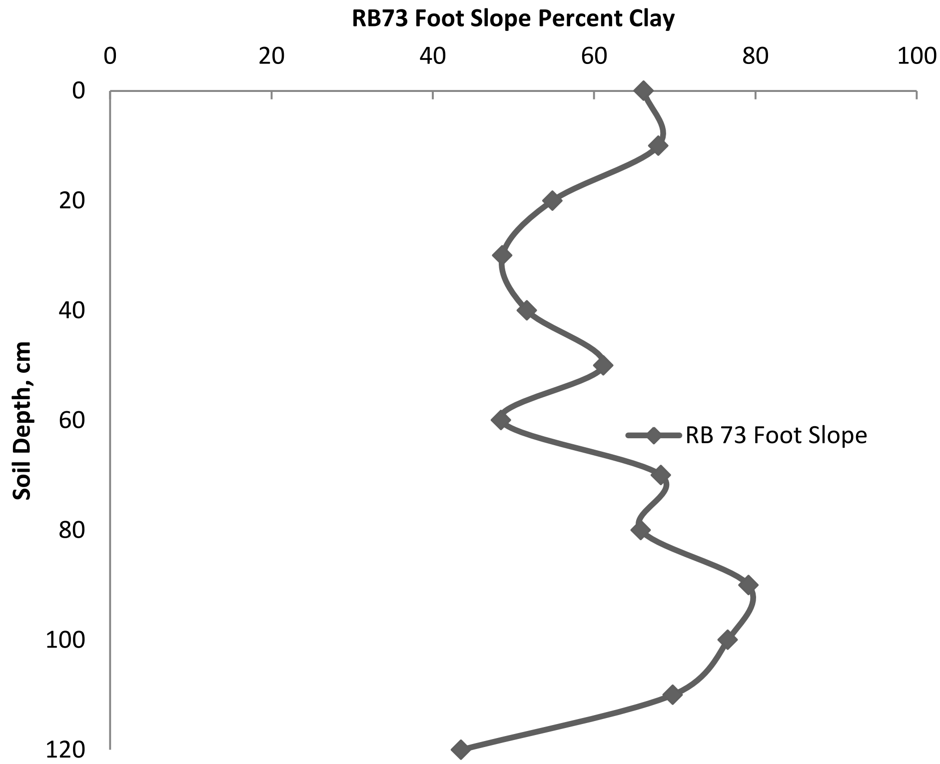

Figure 7- Clay Percentage RB73 Foot Slope

Figure 8– Laguna Verde Slope Summit: Lowland, Natural

Figure 9- Laguna Verde Back Slope: Lowland, Natural

Figure 10- Laguna Verde Toe Slope: Lowland, Natural

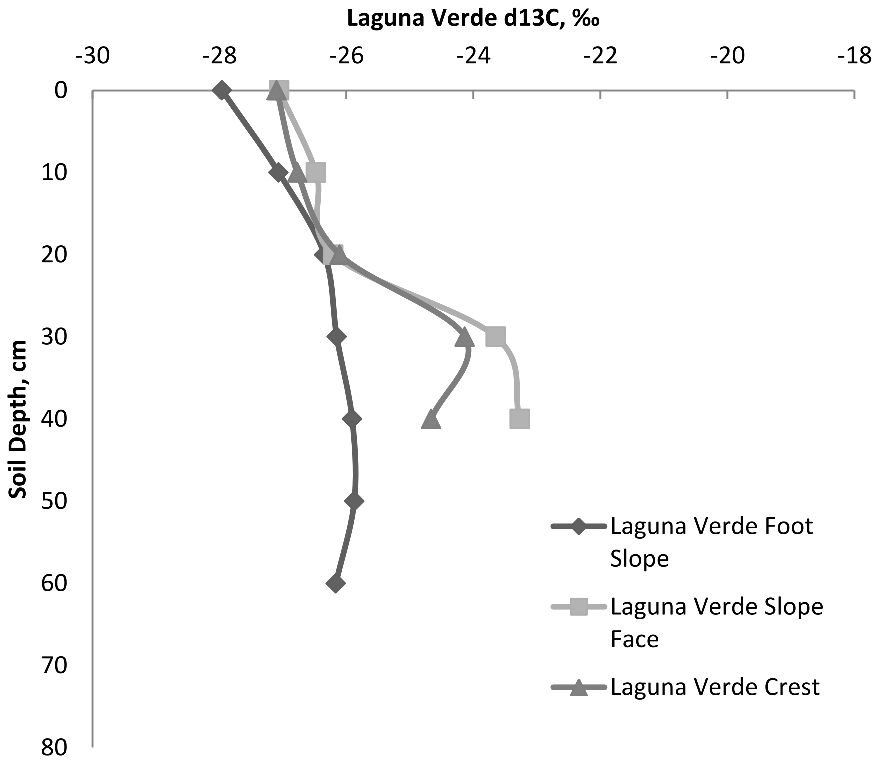

Figure 11- Isotope Profils Laguna Verde

Figure 12- Crystal Creek Flood Plain: Lowland, Natural

Figure 13- Crystal Creek Wetland: Lowland, Natural

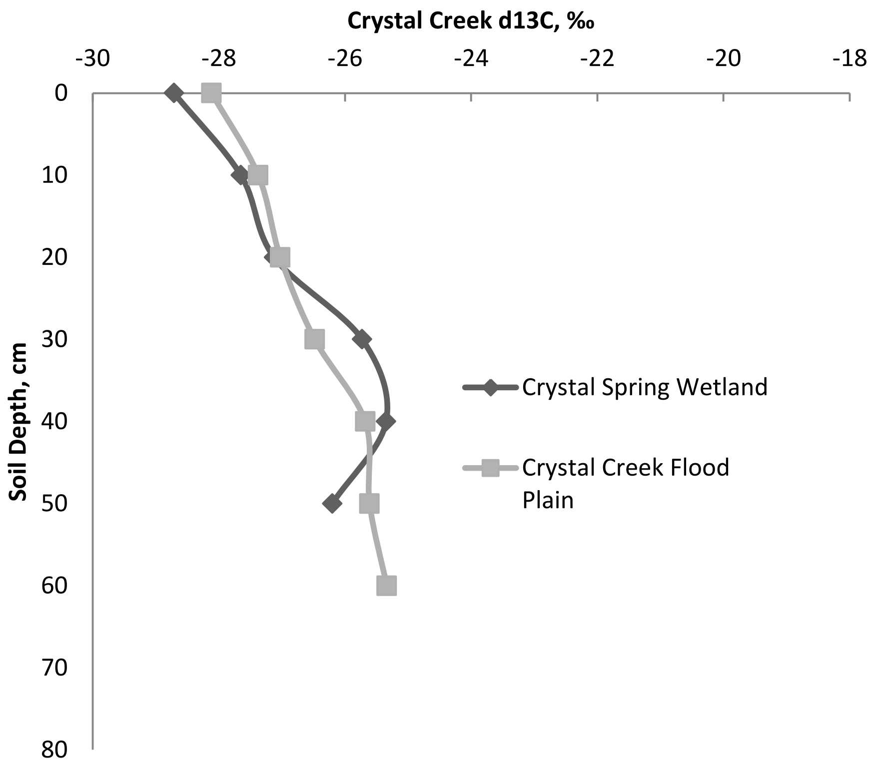

Figure 14- Isotope Profile Crystal Creek

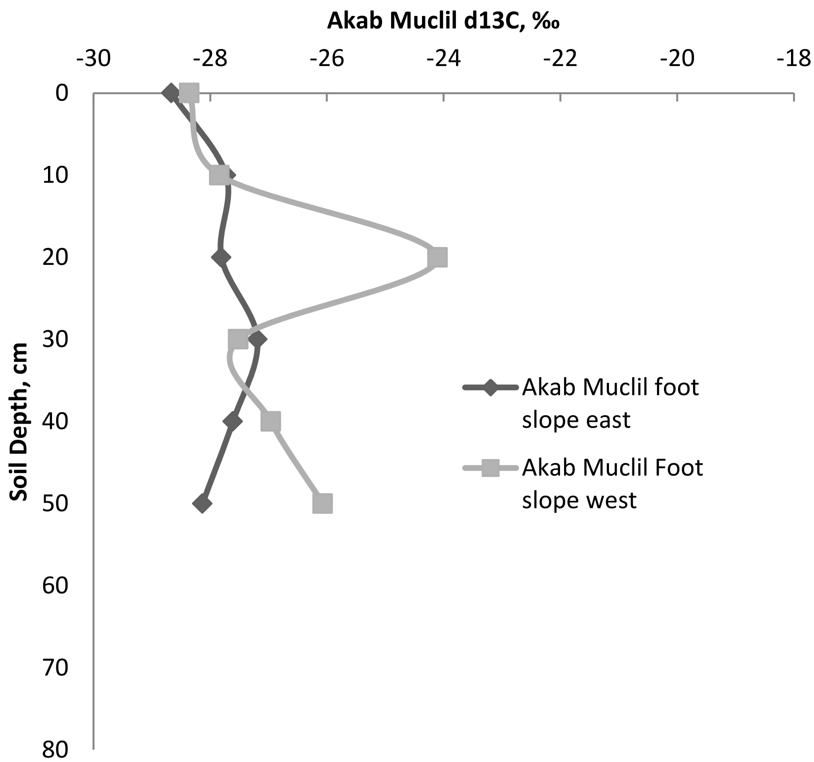

Figure 15- Isotope Profile Akab Muclil

Figure 16- Crocodile Lake Back Foot Slope: Upland, Natural

Figure 17- Crocodile Lake Delta 1 East: Upland, Natural

Figure 18- Crocodile Lake Delta 1 West: Upland, Natural

Figure 19- Crocodile Lake Delta 2 South: Upland, Natural

Figure 20- Crocodile Lake Delta 2 South: Upland, Natural

Figure 21- Crocodile Lake Delta 2 South: Upland, Natural

Figure 22- Crocodile Lake Delta 2 South: Upland, Natural

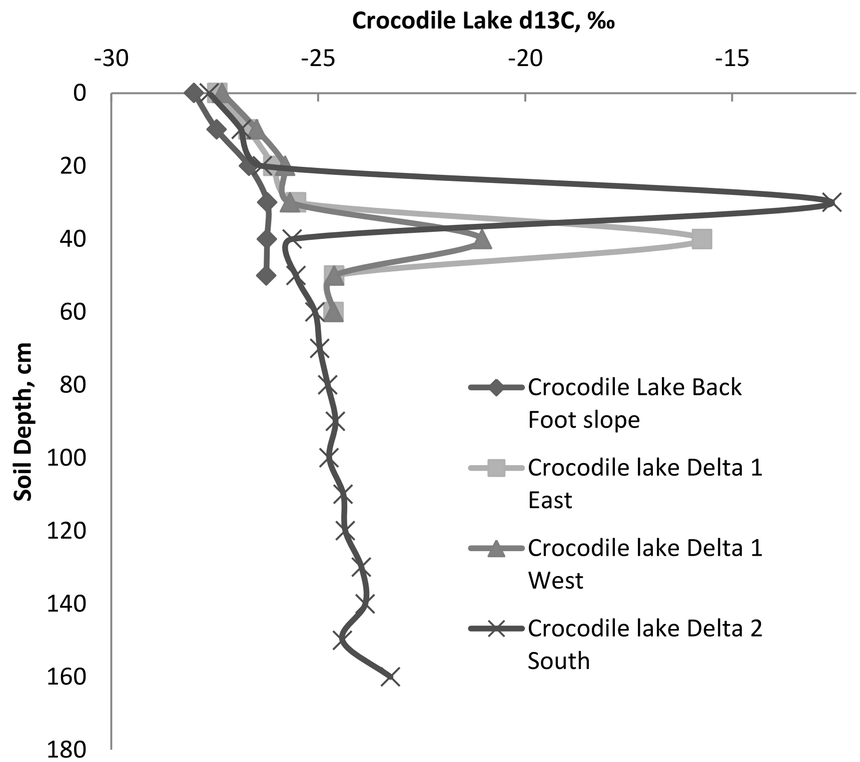

Figure 23- Isotope Profile Crocodile Lake

Figure 24- RB73 Slope Summit: Upland, Anthropogenic

Figure 25- RB73 Back Slope 1: Upland, Anthropogenic

Figure 26- RB73 Back Slope 2: Upland, Anthropogenic

Figure 27- RB73 Foot Slope: Upland, Anthropogenic

Figure 28- RB73 Lower Terrace: Upland, Anthropogenic

Figure 29- RB73 Back Slope Terrace: Upland, Anthropogenic

Figure 30- RB73 Water Feature 3 and 4: Upland, Anthropogenic

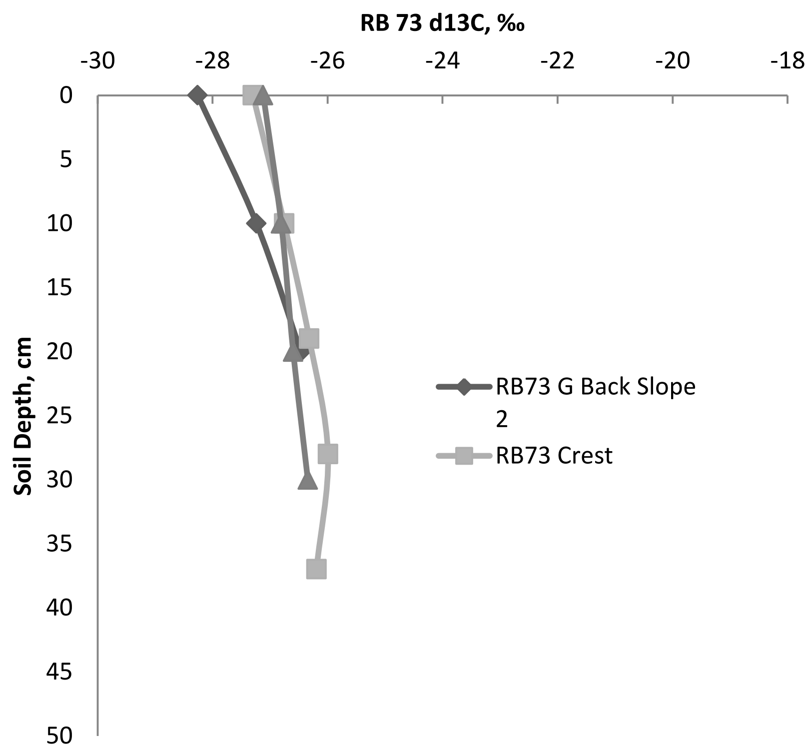

Figure 31- Isotope Profile RB73

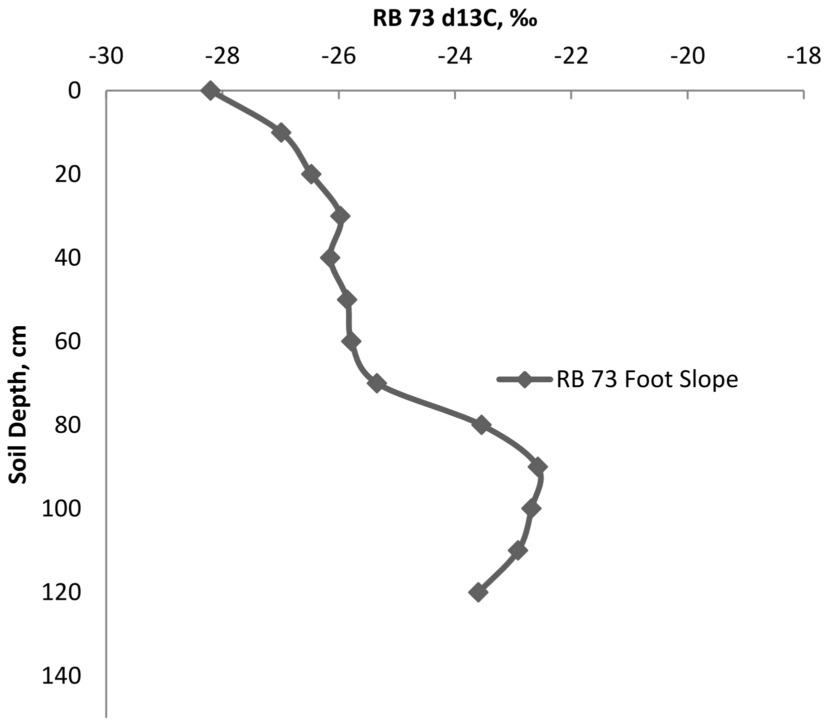

Figure 32- Isotope Profile RB73

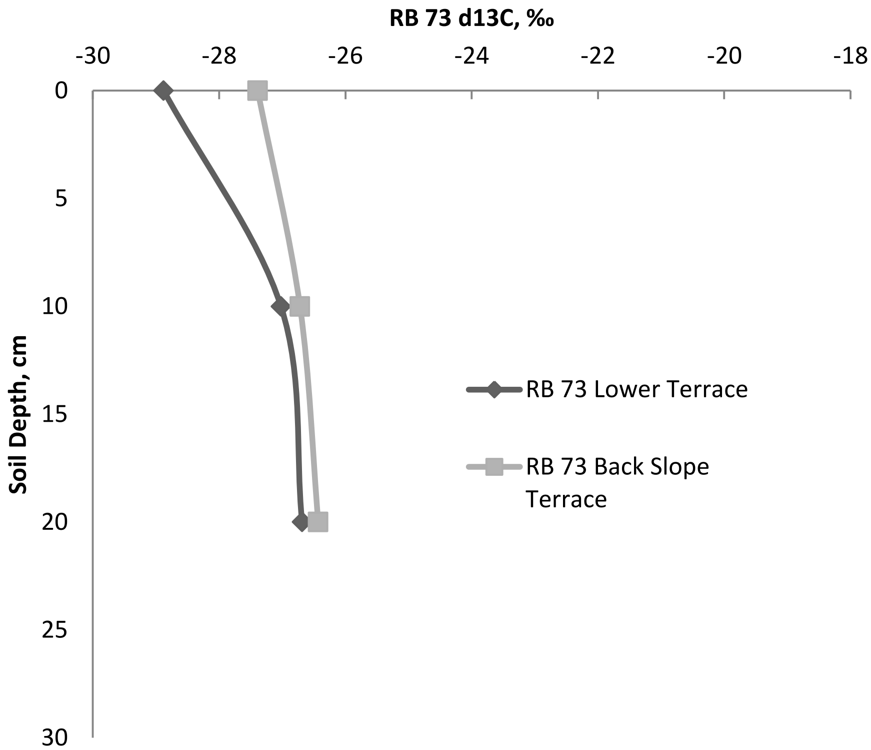

Figure 33- Isotope Profile RB73

Table 1- Correlation matrix of soil physical and chemical properties for all samples in all profiles

P	Sand%h	Silt%h	Clay%h	pH	SiO2 %	Ca %	Mn mg/kg	Fe %	Cu mg/kg	Zn mg/kg	Rb mg/kg	Sr mg/kg	Zr mg/kg	Cu	Fe	Mn	Sr	Zn	% total N	% total C	CO3-C	Organic C	
1	-0.11	0.22*	-0.03	0.01	-0.44**	0.07	-0.17*	-0.25**	0.09	-0.13	0.07	0.61**	-0.23**	0.03	-0.06	0.04	0.49**	0.14	0.49**	0.40**	0.03	0.51**	P
	1	-0.29**	-0.87**	0.46**	-0.43**	0.29**	-0.13	-0.43**	-0.07	-0.46**	-0.31**	0.57**	-0.41**	-0.59**	-0.23*	0.07	-0.45**	-0.20*	-0.24**	0.10	0.25**	-0.19*	Sand%h
		1	-0.20*	0.32**	-0.13	0.24**	-0.07	-0.38**	-0.18*	-0.38**	-0.04**	0.20*	-0.32**	-0.62**	-0.40**	0.20*	-0.37**	0.04	0.09	0.31	0.22*	0.16	Silt%h
			1	-0.64**	0.51**	-0.42**	0.17*	0.63**	0.17*	0.67**	0.34**	-0.69**	0.58**	0.75**	0.37**	-0.16	0.52**	0.12	0.20*	-0.26**	-0.37**	0.11	Clay%h
				1	-0.43	0.47**	-0.07	-0.52**	-0.04	-0.57**	-0.31**	0.46**	-0.51**	-0.60**	-0.34**	-0.06	-0.19*	-0.31**	-0.46**	0.14	0.48**	-0.41**	pH
					1	-0.38**	0.45**	0.57**	-0.14	0.54**	0.35**	-0.44**	0.63**	-0.10	0.01	-0.19*	-0.35**	-0.12	-0.14	-0.42**	-0.36**	-0.15	SiO2 %
						1	-0.30**	-0.75**	0.05	-0.84**	-0.35**	0.05**	-0.83**	-0.59**	-0.31**	0.21*	-0.37**	-0.17*	-0.04	0.57**	0.72**	-0.10	Ca %
							1	0.54**	-0.09	0.39**	0.29**	-0.33**	0.46**	-0.21*	-0.05	0.06	-0.35**	0.02*	-0.12	-0.27**	-0.22*	-0.14	Mn mg/kg
								1	0.05	0.93**	0.43**	-0.41**	0.93**	0.55**	0.48**	-0.24**	0.12	0.18*	-0.01	-0.56**	-0.58**	-0.04	Fe %
									1	0.10	0.01	-0.09	-0.01	0.46**	0.34**	0.18*	0.16	0.15	0.18*	0.14	0.06	0.09	Cu mg/kg
										1	0.41**	-0.28**	0.92**	0.71**	0.49**	-0.35**	0.44**	0.19*	0.02	-0.56**	-0.64**	0.02	Zn mg/kg
											1	-0.25**	0.51**	-0.07	-0.01	0.25**	-0.19*	0.15	0.31	-0.07	-0.28**	0.21*	Rb mg/kg
												1	-0.25**	0.13	-0.08	-0.23**	0.80**	-0.05	-0.18*	-0.12	-0.11	-0.04	Sr mg/kg
													1	0.46**	0.34**	-0.26**	0.11	0.19*	-0.03	-0.64**	-0.68**	-0.03	Zr mg/kg
														1	0.64**	-0.08	0.57**	0.20*	0.12	-0.34**	-0.61**	0.08	Cu
															1	-0.08	0.15	-0.01	0.02	-0.21*	-0.31**	-0.00	Fe
			n=124													1	-0.32**	0.06	0.55**	0.44**	0.09	0.52**	Mn
			Significant * (p<0.05)				0.174										1	-0.03	0.09	-0.14	-0.32**	0.10	Sr
			Highly significant ** (p<0.01)				0.228											1	0.30**	0.13	-0.15	0.31**	Zn
																			1	0.56**	-0.10	0.93**	% total N
																				1	0.69**	0.47**	% total C
																					1	-0.24**	CO3-C
																						1	Organic C

Table 2- Correlation matrix of soil physical and chemical properties of top four samples in all profiles.

P	Sand%h	Silt%h	Clay%h	pH	SiO2 %	Ca %	Ti mg/kg	Mn mg/kg	Fe %	Cu mg/kg	Zn mg/kg	Rb mg/kg	Sr mg/kg	Zr mg/kg	Cu	Fe	Mn	Sr	Zn	% total N	% total C	CO3-C	Organic C	
1	0.00	0.24*	-0.12	0.17	-0.30**	0.03	-0.24**	-0.04	-0.17	-0.23	-0.09	0.07	0.56**	-0.11	-0.21	-0.20*	-0.14	0.46**	0.00	0.20	0.22	0.02	0.27*	P
	1	-0.13	-0.81**	0.48**	-0.37**	0.50**	-0.44**	-0.19	-0.51**	-0.13	-0.53**	-0.12	0.35**	-0.51**	-0.75**	-0.29*	0.09	-0.41**	-0.25	-0.27*	0.34**	0.59**	-0.32**	Sand%h
		1	-0.47**	0.47**	-0.31**	0.32**	-0.50**	-0.15	-0.50**	-0.39**	-0.50**	-0.14	0.44**	-0.42**	-0.87**	-0.63**	0.12	-0.34**	-0.01	0.00	0.29*	0.24*	0.05	Silt%h
			1	-0.70**	0.52**	-0.63**	0.69**	0.26	0.75**	0.35**	0.77**	0.20	-0.57**	0.70**	0.93**	0.51**	-0.12	0.44**	0.17	0.24*	-0.48**	-0.67**	0.25*	Clay%h
				1	-0.37**	0.59**	-0.55**	-0.05	-0.61**	-0.16	-0.65**	-0.16	0.50**	-0.56**	-0.74**	-0.35**	0.08	-0.30**	-0.31**	-0.51**	0.20	0.60**	-0.50	pH
					1	-0.36**	0.75**	0.46**	0.66**	0.07	0.54**	0.26*	-0.43**	0.63**	0.29*	0.28*	-0.10	-0.22	0.05	-0.00	-0.44**	-0.42**	0.00	SiO2 %
						1	-0.71**	-0.31**	-0.83**	-0.23	-0.89**	-0.32**	0.09	-0.84**	-0.80**	-0.47**	0.15	-0.34**	-0.28*	-0.23*	0.55**	0.76**	-0.27*	Ca %
							1	0.51**	0.95**	0.19	0.87**	0.41**	-0.40**	0.92**	0.57**	0.61**	-0.19	-0.05	0.26*	0.06	-0.64**	-0.67**	0.07	Ti mg/kg
								1	0.51**	0.04	0.31**	0.37**	-0.33**	0.45**	-0.18	0.00	0.33**	-0.56**	0.22	0.04	-0.30**	-0.31**	0.03	Mn mg/kg
									1	0.24*	0.93**	0.46**	-0.36**	0.95**	0.73**	0.63**	-0.15	0.07	0.30**	0.14	-0.65**	-0.75**	0.15	Fe %
										1	0.31**	0.02	-0.11	0.21	0.52**	0.41**	0.16	0.07	0.08	-0.06	-0.25*	-0.20	-0.06	Cu mg/kg
											1	0.39**	-0.21	0.91**	0.87**	0.66**	-0.29*	0.39**	0.29*	0.16	-0.62**	-0.76**	0.20	Zn mg/kg
												1	-0.15	0.48**	-0.07	-0.03	0.27*	-0.21	0.16	0.36**	-0.10	-0.30**	0.26*	Rb mg/kg
	n=71												1	-0.22	-0.02	-0.16	-0.33**	0.81**	-0.14	-0.29*	-0.09	0.05	-0.20	Sr mg/kg
					r>									1	0.68**	0.50**	-0.16	0.11	0.34*	0.11	-0.70**	-0.78**	0.13	Zr mg/kg
	Significant * (p<0.05)				0.232										1	0.64**	-0.19	0.49**	0.12	-0.23*	-0.74**	-0.79**	-0.22	Cu
	Highly significant ** (p<0.01)				0.302											1	-0.20	0.13	-0.08	-0.26*	-0.51**	-0.45**	-0.25*	Fe
																	1	-0.40**	-0.04	0.48**	0.32**	0.02	0.41**	Mn
																		1	-0.12	-0.10	-0.23*	-0.27*	-0.03	Sr
																			1	0.14	-0.04	-0.25*	0.18	Zn
																				1	0.45**	-0.31**	0.96**	% total N
																					1	0.64**	0.43**	% total C
																						1	-0.37**	CO3-C
																							1	Organic C

Table 3- Correlation matrix of soil physical and chemical properties of surface samples in all profiles.

P	Sand%h	Silt%h	Clay%h	pH	SiO2 %	Ca %	Ti mg/kg	Mn mg/kg	Fe %	Cu mg/kg	Zn mg/kg	Rb mg/kg	Sr mg/kg	Zr mg/kg	Cu	Fe	Mn	Sr	Zn	% total N	% total C	CO3-C	Organic C	
1	0.12	0.18	-0.17	0.45*	-0.03	0.00	-0.02	0.05	-0.04	-0.26	0.01	-0.02	0.57**	-0.00	-0.18	-0.07	-0.28	0.63**	-0.13	-0.23	-0.04	-0.00	-0.05	P
	1	0.39	-0.91**	0.71**	-0.44	0.81**	-0.66**	-0.21	-0.75**	-0.51*	-0.75**	-0.13	0.27	-0.78**	-0.74	-0.40	0.06	-0.08	-0.43	-0.36	0.62**	0.88**	-0.46*	Sand%h
		1	-0.72**	0.49*	-0.35	0.69**	-0.62**	-0.22	-0.64**	-0.68**	-0.70**	0.05	0.19	-0.55*	-0.78**	-0.66**	0.06	-0.05	-0.29	0.06	0.67**	0.53**	0.07	Silt%h
			1	-0.74**	0.48*	-0.91**	0.76**	0.25	0.84**	0.68**	0.86**	0.08	-0.29	0.82**	0.89**	0.59**	-0.07	0.08	0.44*	0.24	-0.75**	-0.89**	0.31	Clay%h
				1	-0.26	0.64**	-0.54*	-0.02	-0.58**	-0.29	-0.55*	0.12	0.58**	-0.50*	-0.68**	-0.45*	0.06	0.31	-0.53*	-0.28	0.34	0.64**	-0.35	pH
					1	-0.61**	0.78**	0.76**	0.72**	0.21	0.56**	0.18	-0.43	0.72**	0.27	0.14	0.08	-0.34	0.31	-0.03	-0.69**	-0.71**	-0.01	SiO2 %
						1	-0.79**	-0.40	-0.84**	-0.49*	-0.89**	-0.19	0.27	-0.83**	-0.76**	-0.46*	0.08	-0.05	-0.48*	-0.13	0.74**	0.89**	-0.15	Ca %
							1	0.70**	0.98**	0.30	0.86**	0.32	-0.45*	0.94**	0.61**	0.53*	-0.05	-0.24	0.55*	-0.14	-0.89**	-0.82**	-0.12	Ti mg/kg
								1	0.67**	0.14	0.41	0.54*	-0.43	0.68**	0.05	-0.05	0.36	-0.43	0.31	-0.07	-0.61**	-0.49**	-0.18	Mn mg/kg
									1	0.31	0.90**	0.39	-0.40	0.97**	0.68**	0.51*	-0.05	-0.16	0.58**	-0.08	-0.90**	-0.86**	-0.09	Fe %
										1	0.46*	-0.00	-0.23	0.28	0.47*	0.32	0.30	-0.10	0.14	0.17	-0.19	-0.35	0.18	Cu mg/kg
											1	0.25	-0.12	0.88**	0.78**	0.61**	-0.22	0.13	0.59**	-0.11	-0.82**	-0.81**	-0.05	Zn mg/kg
												1	-0.19	0.47*	-0.01	-0.07	0.22	-0.17	0.13	0.08	-0.39	-0.23	-0.21	Rb mg/kg
			n=19										1	-0.34	-0.15	-0.15	-0.37	0.90**	-0.20	-0.29	0.21	0.35	-0.15	Sr mg/kg
							r>							1	0.61**	0.42**	-0.04	-0.11	0.57**	-0.09	-0.91**	-0.86**	-0.10	Zr mg/kg
			Significant * (p<0.05)				0.444								1	0.71**	-0.05	0.18	0.42	0.14	-0.55*	-0.72**	0.16	Cu
			Highly significant ** (p<0.01)				0.561									1	-0.17	0.08	-0.01	-0.08	-0.46*	-0.43	-0.06	Fe
																	1	-0.41	-0.11	0.47**	0.24	-0.04	0.33	Mn
																		1	-0.13	-0.16	0.01	0.02	-0.00	Sr
																			1	-0.09	-0.43	-0.44*	-0.01	Zn
																				1	0.40	-0.30	0.89**	% total N
																					1	0.68**	0.44	% total C
																						1	-0.34	CO3-C
																							1	Organic C

Table 4- Soil Physical Properties: Hydrometer and Laser Texure, Wet and Dry Color

Profile		Depth	Texture (Hydrometer) Sand	Silt	Clay	Texture (Laser) Sand	Silt	Clay	Color Wet	Dry
		cm	- - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - - - -							
Laguna Verde	FS	0-10	21	31	48	14	64	21	10yr 3/1	7.5yr 5/1
Argiaquolls	FS	10-20	31	19	50	3	69	28	2.5yr 3/1	2.5y 5/1
Lowland	FS	20-30	33	19	48	0	69	31	10yr 3/1	7.5yr 6/1
Natural	FS	30-40	36	16	47	0	63	37	10yr 4/1	7.5yr 6/1
	FS	40-50	37	19	44	11	69	19	7.5yr 4/1	7.5yr 6/1
	FS	50-60	31	17	52	1	68	31	7.5yr 4/1	7.5yr 6/1
	FS	60-70	34	14	52	8	67	25	7.5yr 4/1	7.5yr 6/1
Laguna Verde	BS	0-10	21	23	56	2	75	23	7.5yr 3/1	7.5yr 5/1
Argiaquolls	BS	10-20	31	20	49	1	71	28	7.5yr 4/1	7.5yr 6/1
Lowland	BS	20-30	34	21	45	5	68	27	7.5yr 3/1	7.5yr 6/1
Natural	BS	30-40	34	19	47	10	67	23	7.5yr 4/1	7.5yr 6/1
	BS	40-50	27	21	52	5	67	28	10yr 4/1	10yr 6/1
Laguna Verde	Shoulder	0-10	29	24	46	9	71	20	7.5yr 3/1	7.5yr 5/1
Argiaquolls	Shoulder	10-20	38	24	39	14	65	21	10yr 4/1	7.5yr 6/1
Lowland	Shoulder	20-30	35	26	39	14	64	22	10yr 4/1	2.5y 6/1
Natural	Shoulder	30-40	33	23	44	12	65	23	2.5yr 4/1	10yr 7/1
	Shoulder	40-50	35	18	47	1	67	32	2.5yr 4/1	7.5yr 6/1

Table 4 (continued)-_Soil Physical Properties: Hydrometer and Laser Texure, Wet and Dry Color

Profile		Depth	Texture (Hydrometer) Sand	Silt	Clay	Texture (Laser) Sand	Silt	Clay	Color Wet	Dry
		cm	- - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - - - -							
Crystal Spring	Wetland	0-10	8	25	68	8	66	26	10yr 2/1	7.5yr 4/1
Argiaquolls	Wetland	10-20	14	17	69	4	74	22	2.5y 8/1	7.5yr 5/1
Lowland	Wetland	20-30	22	19	59	3	67	30	2.5yr 3/1	10yr 5/1
Natural	Wetland	30-40	19	18	63	3	68	28	2.5y 2.5/1	2.5y 6/1
	Wetland	40-50	19	19	63	0	54	46	7.5yr 3/1	2.5yr 7/1
	Wetland	50-60	17	23	60	4	61	35	5yr 4/1	2.5yr 6/1
Crystal Creek	TS	0-10	-6	12	94	0	68	32	10yr 3/1	7.5yr 3/2
Argiaquolls	TS	10-20	-2	6	96	0	57	43	10yr 3/1	10yr 5/2
Lowland	TS	20-30	-3	4	99	0	52	48	10yr 3/1	10yr 4/2
Natural	TS	30-40	-3	4	99	0	48	52	7.5yr 3/2	7.5yr 5/2
	TS	40-50	6	1	93	0	53	47	5y 3/1	2.5yr 4/1
	TS	50-60	1	1	97	0	38	62	5y 3/1	2.5yr 5/1
	TS	60-70	-2	7	95	0	56	44	2.5yr 4/1	2.5yr 6/1
Akab Muclil	TS East	0-10	27	33	40	4	73	23	2.5yr 3/1	2.5yr 7/1
Argiaquolls	TS East	10-20	30	16	54	3	74	23	2.5yr 3/1	735yr 7/1
Lowland	TS East	20-30	17	67	16	13	56	31	7.5yr 5/1	7.5yr 7/1
Anthropogenic	TS East	30-40	4	79	17	7	41	51	10yr 5/1	7.5yr 8/1
	TS East	40-50	9	74	17	7	50	43	7.5yr 5/1	7.5yr 7/1
	TS East	50-60	138	0	-38	8	49	43	10yr 6/1	10yr 6/1

Table 4 (continued)-_Soil Physical Properties: Hydrometer and Laser Texure, Wet and Dry Color

Profile		Depth	Texture (Hydrometer) Sand	Silt	Clay	Texture (Laser) Sand	Silt	Clay	Color Wet	Dry
		cm	- - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - - - -							
Akab Muclil	TS West	0-10	27	27	46	8	70	22	10yr 3/1	2.5y 5/1
Argiaquolls	TS West	10-20	31	24	45	7	66	27	7.5yr 3/1	10yr 6/1
Lowland	TS West	20-30	36	23	41	1	67	32	7.5yr 4/1	10yr 6/1
Anthropogenic	TS West	30-40	137	0	-37	6	57	36	10yr 5/2	10yr 7/1
	TS West	40-50	138	0	-38	14	49	37	10yr 6/1	5yr 7/1
	TS West	50-60	138	0	-38	9	45	46	7.5yr 6/1	5y 7/1
Crocodile Lake	FS	0-10	18	20	62	1	67	32	10yr 3/1	7.5yr 7/1
Argiaquolls	FS	10-20	22	11	67	0	51	49	7.5yr 2.5/1	10yr 4/1
Upland	FS	20-30	32	7	61	4	68	28	7.5yr 2.5/1	10yr 4/1
Natural	FS	30-40	23	19	58	0	52	48	7.5yr 3/1	7.5yr 4/1
	FS	40-50	41	13	46	6	56	38	7.5yr 3/1	7.5yr 5/1
	FS	50-60				6	60	34	10yr 3/1	2.5y 3/2
Crocodile lake	D1 East	0-10	0	25	75	0	57	43	7.5yr 2.5/1	5yr 3/1
Argiaquolls	D1 East	10-20	5	8	87	0	58	42	10yr 2/1	7.5yr 4/1
Upland	D1 East	20-30	5	9	87	0	41	59	10yr 2/1	2.5y 4/1
Natural	D1 East	30-40	11	8	81	0	56	44	7.5yr 5/1	2.5y 4/1
	D1 East	40-50	32	13	55	5	65	30	10yr 3/1	10yr 5/1
Crocodile lake	D1 West	0-10	2	21	77	3	71	26	10yr 3/1	10yr 4/2
Argiaquolls	D1 West	10-20	1	12	87	0	55	45	2.5y 2.5/1	2.5y 4/1
Upland Natural	D1 West	20-30	9	12	80	0	54	46	2.5y 2.5/1	2.5y 4/1
	D1 West	30-40	21	16	62	0	61	39	5yr 2.5/1	5yr 5/1
	D1 West	40-50	33	26	41	7	60	33	7.5yr 3/1	2.5y 6/1

Table 4 (continued)- Soil Physical Properties: Hydrometer and Laser Texure, Wet and Dry Color

Profile		Depth	Texture (Hydrometer) Sand	Silt	Clay	Texture (Laser) Sand	Silt	Clay	Color Wet	Dry
		cm	- - - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - - - -							
Crocodile lake	D2 South	0-10	20	21	59	1	69	30	5yr 3/1	2.5yr 5/1
Argiaquolls	D2 South	10-20	29	20	51	1	67	32	10yr 3/1	7.5yr 5/1
Upland	D2 South	20-30	29	14	57	0	62	37	7.5yr 3/1	2.5yr 5/2
Natural	D2 South	30-40	41	19	40	4	64	32	5yr 4/2	5yr 7/1
	D2 South	40-50	29	11	60	1	63	36	10yr 3/1	5yr 5/1
	D2 South	50-60	20	14	66	0	51	49	2.5y 3/1	7.5yr 5/1
	D2 South	60-70	16	22	62	1	64	35	2.5y 3/1	2.5y 5/1
	D2 South	70-80	17	20	63	2	65	33	2.5y 3/1	2.5y 5/1
	D2 South	80-90	29	11	60	0	57	42	2.5y 3/1	2.5y 4/1
	D2 South	90-100	32	14	54	1	63	36	5y 3/1	5y 5/1
	D2 South	100-110	29	14	57	5	65	30	5y 3/1	10yr 5/1
	D2 South	110-120	28	16	56	0	52	48	10yr 3/1	10yr 5/1
	D2 South	120-130	34	19	48	1	62	37	10yr 4/1	2.5y 6/1
	D2 South	130-140	41	16	43	0	56	44	10yr 4/1	10yr 5/1
	D2 South	140-150	42	18	40	5	66	28	2.5y 4/1	10yr 6/1
	D2 South	150-160	24	21	55	0	51	49	2.5y 4/1	2.5y 6/1
	D2 South	160-170	35	14	51	1	56	43	2.5y 4/1	2.5y 5/1
RB73	BS 2	0-10	12	33	54	1	79	21	10yr 2/1	10yr 4/1
Argiaquolls	BS 3	10-20	28	23	49	0	73	26	2.5y 4/1	2.5y 6/1
Upland	BS 4	20-30	20	29	51	2	74	24	2.5y 2.5/1	2.5y 5/1
Anthropogenic										

Table 4 (continued)- Soil Physical Properties: Hydrometer and Laser Texure, Wet and Dry Color

Profile		Depth	Texture (Hydrometer) Sand	Silt	Clay	Texture (Laser) Sand	Silt	Clay	Color Wet	Dry
		cm	- - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - - - -							
RB73	Shoulder	0-9	10	38	52	2	79	18	10yr 2/1	10yr 5/1
Argiaquolls	Shoulder	10-18	18	32	50	4	75	21	7.5yr 2.5/1	7.5yr 5/1
Upland	Shoulder	19-27	22	34	44	1	73	26	5y 2.5/1	2.5y 7/1
Anthropogenic	Shoulder	28-36	31	28	41	4	73	23	7.5yr 2.5/1	10yr 8/1
	Shoulder	37-45	22	34	44	7	71	22	10yr 3/1	10yr 7/1
RB 73	BS 1	0-10	36	29	35	7	76	17	10yr 3/2	7.5yr 6/1
Argiaquolls	BS 2	10-20				10	75	14	2.5y 3/1	7.5yr 7/1
Upland	BS 3	20-30	24	20	56	7	75	18	10yr 3/1	10yr 7/1
Anthropogenic	BS 4	30-40				9	70	21	5yr 7/2	10yr 8/1
RB 73	TS	0-10	15	19	66	0	76	24	10yr 2/1	5y 2.5/1
Argiaquolls	TS	10-20	16	16	68	1	76	24	10yr 2/1	10yr 3/1
Upland	TS	20-30	14	31	55	1	73	26	10yr 2/1	10yr 3/1
Anthropogenic	TS	30-40	16	35	49	0	73	26	10yr 2/1	10yr 6/1
	TS	40-50	18	30	52	0	63	37	10yr 4/1	10yr 7/1
	TS	50-60	11	28	61	0	60	40	10yr 2/1	10yr 4/1
	TS	60-70	22	30	48	3	71	27	10yr 3/1	2.5yr 6/1
	TS	70-80	8	23	68	0	70	30	2.5y 2.5/1	5y 4/1
	TS	80-90	11	23	66	0	70	30	10yr 2/1	7.5yr 4/1
	TS	90-100	4	17	79	0	58	42	10yr 3/1	2.5y 5/1
	TS	100-110	6	17	77	0	55	45	5y 2.5/1	10yr 5/1
	TS	110-120	11	20	70	0	66	34	5y 2.5/1	2.5yr 5/1
	TS	120-130	16	40	44	2	72	26	2.5yr 5/2	5y 6/1

Table 4 (continued)- Soil Physical Properties: Hydrometer and Laser Texure, Wet and Dry Color

Profile		Depth	Texture (Hydrometer) Sand	Silt	Clay	Texture (Laser) Sand	Silt	Clay	Color Wet	Dry
		cm	- - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - - - -							
RB 73	TS	0-10	19	31	51	11	71	18	2.5yr 2.5/1	10yr 5/1
Argiaquolls	TS	10-20				5	73	21	2.5y 3/1	2.5y 7/1
Up/Anthro	TS	20-30				1	72	26	10yr 2/1	2.5y 5/1
RB 73	BS	0-10				1	73	27	10yr 3/1	10yr 4/1
Argiaquolls	BS	10-20				0	71	28	5y 2.5/1	10yr 6/1
Up/Anthro	BS	20-30				1	71	27	10yr 2/1	5y 6/1
RB 73 Water	4	0-10				12	74	13	7.5yr 2.5/1	10yr 3/2
Argiaquolls	4	10-20				4	78	18	10yr 3/2	10yr 5/2
Upland	4	20-30				3	74	23	10yr 3/2	10yr 6/1
Anthropogenic	4	30-40				2	71	28	10yr 5/2	10yr 7/1
	4	40-50				6	71	23	10yr 3/2	10yr 6/1
	4	50-65				3	66	31	10yr 4/1	10yr 6/1
RB 73 Water	3	0-10				12	76	12	7.5yr 3/1	10yr 5/1
Argiaquolls	3	10-20				3	74	23	10yr 4/2	7.5yr 7/1
Upland										
Anthropogenic	3	20-30				5	68	27	10yr 5/2	10yr 7/1
	3	30-40				6	66	27	10yr 5/2	7.5yr 7/1
	3	40-50				4	65	31	10yr 5/2	10yr 7/1
	3	50-60				6	63	30	10yr6/2	10yr 7/1
	3	60-67				7	69	24	10yr7/2	2.5y 7/1

Table 5- Soil Chemical Properties: pXRF Elemental Concentration and DTPA Extractable Metals

			pXRF											ICP						
Profile		Depth	SiO2	CaCO3	Ca	Fe	Ti	Mn	Cu	Zn	Rb	Sr	Zr	Cd	Cu	Fe	Mn	Pb	Sr	Zn
		cm	- - - - - - % - - - - - - -				mg/kg--mg/kg													
Laguna Verde	FS	0-10	22	95	11	0.9	545	365	57	59	14	88	35	0.1	0.3	1.3	5	0.4	3	0.6
Argiaquolls	FS	10-20	39	99	11	1.2	825	461	57	61	16	92	36							
Lowland	FS	20-30	27	100	11	1.0	815	391	57	59	14	88	44							
Natural	FS	30-40	40	90	10	0.9	700	348	62	65	13	91	26							
	FS	40-50	32	100	11	0.7	565	303	59	60	10	77	21							
	FS	50-60	26	100	11	0.8	580	321	62	60	12	88	27							
	FS	60-70	29	100	11	0.8	530	319	54	59	11	88	22							
Laguna Verde	BS	0-10	25	73	8	1.5	961	431	57	67	22	60	47							
Argiaquolls	BS	10-20	22	90	10	1.1	730	388	62	65	19	55	37							
Lowland	BS	20-30	23	100	11	0.8	545	326	63	60	11	77	20							
Natural	BS	30-40	33	100	11	0.8	565	289	62	62	14	66	22							
	BS	40-50	17	91	10	0.9	570	288	64	64	16	72	31							
Laguna Verde	Shoulder	0-10	19	67	8	1.1	605	448	62	74	26	58	33	0.1	0.5	1.6	7	0.4	2	0.3
Argiaquolls	Shoulder	10-20	23	91	10	1.0	670	428	62	66	23	65	36							
Lowland	Shoulder	20-30	14	99	11	0.8	540	339	67	61	17	70	18							
Natural	Shoulder	30-40	24	100	11	0.7	555	329	58	58	13	74	11							
	Shoulder	40-50	23	100	11	0.7	492	336	63	63	15	68	12							

Table 5 (continued)- Soil Chemical Properties: pXRF Elemental Concentration and DTPA Extractable Metals

			pXRF											ICP						
Profile		Depth	SiO2	CaCO3	Ca	Fe	Ti	Mn	Cu	Zn	Rb	Sr	Zr	Cd	Cu	Fe	Mn	Pb	Sr	Zn
		cm	- - - - - - % - - - - - - -				mg/kg---							-mg/kg						
Crystal Spring	Wetland	0-10	29	22	3	2.2	1056	444	60	81	16	143	121	0.1	0.7	1.4	2	0.7	8	0.8
Argiaquolls	Wetland	10-20	63	56	7	2.5	1592	441	60	86	18	176	134							
Lowland	Wetland	20-30	66	90	10	2.0	1547	389	59	74	14	239	91							
Natural	Wetland	30-40	66	100	11	1.5	1176	278	64	70	13	257	87							
	Wetland	40-50	61	98	11	1.5	1136	239	59	73	14	342	122							
	Wetland	50-60	63	100	11	1.3	1076	225	56	70	17	390	88							
Crystal Creek	TS	0-10	33	6	1	3.6	1747	284	65	102	11	169	152	3.2	4.0	37.9	7	1.4	13	1.0
Argiaquolls	TS	10-20	54	5	1	4.4	2238	366	60	111	13	151	174	2.0	4.1	24.3	7	1.0	14	0.3
Lowland	TS	20-30	58	4	1	4.3	2213	297	62	112	11	141	194	1.5	4.4	18.1	5	1.0	13	0.2
Natural	TS	30-40	39	4	1	3.6	1787	278	68	107	12	128	187	1.2	3.9	13.8	3	1.0	13	0.0
	TS	40-50	45	4	1	4.0	2078	836	61	112	12	122	195	0.8	2.2	9.0	2	0.9	12	0.0
	TS	50-60	45	4	1	3.9	1963	524	61	107	13	115	182	0.6	1.7	6.7	1	1.0	12	0.0
	TS	60-70	46	13	2	4.3	2103	783	53	107	12	159	175	0.5	1.4	5.9	1	1.0	12	0.0
Akab Muclil	TS East	0-10	12	78	9	0.7	377	384	53	71	15	566	27	0.1	0.2	0.8	4	0.1	19	0.1
Argiaquolls	TS East	10-20	24	94	11	0.7	370	323	59	68	17	752	40							
Lowland	TS East	20-30	11	76	9	0.3	157	228	60	62	12	1165	47							
Anthropogenic	TS East	30-40	0	54	6	0.2	107	217	57	58	7	1237	43							
	TS East	40-50	0	58	7	0.2	117	220	55	59	4	1135	38							
	TS East	50-60	0	64	7	0.3	167	260	60	58	6	1052	37							

Table 5 (continued)- Soil Chemical Properties: pXRF Elemental Concentration and DTPA Extractable Metals

			pXRF											ICP						
Profile		Depth	SiO2	CaCO3	Ca	Fe	Ti	Mn	Cu	Zn	Rb	Sr	Zr	Cd	Cu	Fe	Mn	Pb	Sr	Zn
		cm	- - - - - - % - - - - - - -				mg/kg---mg/kg													
Akab Muclil	TS West	0-10	16	89	10	0.7	320	346	61	75	14	478	31	0.1	0.3	0.9	5	0.2	11	0.3
Argiaquolls	TS West	10-20	0	75	8	0.5	265	294	63	71	12	315	13							
Lowland	TS West	20-30	25	100	11	0.6	396	298	62	66	11	446	20							
Anthropogenic	TS West	30-40	0	69	8	0.3	155	218	60	58	12	1145	40							
	TS West	40-50	0	51	6	0.2	14	182	59	56	7	1484	51							
	TS West	50-60	0	59	7	0.2	77	206	53	55	6	1114	39							
Crocodile Lake	FS	0-10	26	43	5	2.9	1757	392	61	94	14	31	121	3.3	1.4	38.3	4	1.3	2	1.5
Argiaquolls	FS	10-20	21	26	3	3.0	1647	435	62	92	17	25	131							
Upland	FS	20-30	43	41	5	3.3	2198	388	62	94	14	42	150							
Natural	FS	30-40	34	74	8	2.6	2128	315	60	84	16	48	141							
	FS	40-50	38	14	2	3.9	2118	917	62	101	21	15	178							
	FS	50-60	65	95	11	2.4	2383	377	61	79	8	62	79							
Crocodile lake	D1 East	0-10	54	11	2	4.3	2333	917	62	104	22	18	230							
Argiaquolls	D1 East	10-20	55	7	1	5.9	2323	1063	65	110	25	15	212	2.5	3.5	30.5	#	1.9	3	0.7
Upland	D1 East	20-30	52	20	3	4.1	2243	795	63	101	18	16	231							
Natural	D1 East	30-40	42	53	6	3.7	2273	818	63	91	17	30	156							
	D1 East	40-50	55	22	3	4.5	2479	1092	57	103	18	18	213							
Crocodile lake	D1 West	0-10	50	10	2	4.7	2464	1028	61	107	22	17	225	0.4	2.3	4.3	4	13.4	2	12.7
Argiaquolls	D1 West	10-20	67	18	2	4.6	2629	1063	61	103	19	19	212							
Upland	D1 West	20-30	54	41	5	3.6	2218	777	61	90	17	19	182							
Natural	D1 West	30-40	37	80	9	2.3	1356	2586	62	69	8	28	69							
	D1 West	40-50	45	74	8	2.6	1772	906	60	77	9	28	79							

Table 5 (continued)- Soil Chemical Properties: pXRF Elemental Concentration and DTPA Extractable Metals

Profile		Depth	pXRF SiO2	CaCO3	Ca	Fe	Ti	Mn	Cu	Zn	Rb	Sr	Zr	ICP Cd	Cu	Fe	Mn	Pb	Sr	Zn
		cm	- - - - - - % - - - - - - -				mg/kg--mg/kg													
Crocodile lake	D2 South	0-10	61	56	7	3.5	2273	1232	62	86	13	23	148	1.5	0.8	17.6	5	1.4	1	0.9
Argiaquolls	D2 South	10-20	52	41	5	3.5	2278	1075	63	89	19	22	129	2.4	1.4	27.3	9	1.8	1	0.4
Upland	D2 South	20-30	59	96	11	2.2	1817	581	61	81	10	41	80	2.0	1.6	23.5	8	1.4	1	0.1
Natural	D2 South	30-40	79	54	6	3.9	2925	1087	58	89	16	22	168	1.1	0.7	12.6	5	0.8	1	0.0
	D2 South	40-50	53	59	7	3.6	2544	1087	57	87	15	17	169	1.0	0.9	11.5	6	1.2	1	0.0
	D2 South	50-60	58	44	5	4.1	2594	1057	56	89	17	15	181	0.9	0.9	10.0	6	1.2	1	0.0
	D2 South	60-70	67	58	7	3.7	2629	693	54	87	16	16	151	0.8	0.7	9.0	6	1.1	1	0.0
	D2 South	70-80	58	49	6	3.6	2499	696	59	87	15	19	153	0.6	0.6	7.5	6	1.0	1	0.0
	D2 South	80-90	96	93	10	2.6	2779	941	63	80	8	19	94	0.6	0.6	7.1	6	1.1	1	0.0
	D2 South	90-100	58	60	7	3.4	2534	830	62	87	14	23	125	0.7	0.6	7.6	6	1.1	1	0.0
	D2 South	100-110	46	71	8	2.9	1892	435	58	81	9	20	90	0.7	0.7	8.3	8	1.1	1	0.0
	D2 South	110-120	47	56	6	3.3	2193	894	63	86	12	16	137	0.7	0.5	7.7	6	1.1	1	0.0
	D2 South	120-130	56	57	7	3.4	2378	1565	55	87	12	18	137	0.7	0.5	8.2	6	1.0	1	0.0
	D2 South	130-140	57	55	6	3.7	2348	941	56	91	14	14	129	0.6	0.5	6.7	5	0.8	1	0.0
	D2 South	140-150	85	78	9	3.7	2854	3613	54	87	10	27	130	0.7	0.5	7.9	7	0.8	1	0.0
	D2 South	150-160	51	34	4	4.3	2484	737	60	99	14	14	193	0.6	0.5	6.2	6	1.0	1	0.0
	D2 South	160-170	28	45	5	2.1	1066	717	49	71	13	20	69	0.5	0.5	6.0	6	1.0	1	0.0
RB73	BS 2	0-10	35	70	8	2.1	1156	682	52	72	14	31	80	0.2	0.4	2.2	9	0.9	1	0.7
Argiaquolls	BS 3	10-20	38	80	9	1.5	1031	516	56	67	10	28	92							
Up/Nat	BS 4	20-30	41	59	7	1.4	936	480	55	74	15	37	49							

Table 5 (continued)- Soil Chemical Properties: pXRF Elemental Concentration and DTPA Extractable Metals

Profile		Depth	pXRF SiO2	CaCO3	Ca	Fe	Ti	Mn	Cu	Zn	Rb	Sr	Zr	ICP Cd	Cu	Fe	Mn	Pb	Sr	Zn
		cm	- - - - - - % - - - - - - -				mg/kg---mg/kg													
RB73	Shoulder	0-9	40	68	8	1.3	800	428	59	70	18	41	63	0.4	0.4	5.0	7	0.7	1	0.5
Argiaquolls	Shoulder	10-18	46	100	11	1.0	695	440	62	65	12	48	40							
Upland	Shoulder	19-27	47	96	11	0.8	670	330	57	61	9	39	33							
Anthro	Shoulder	28-36	48	100	11	0.9	635	352	58	65	12	43	31							
	Shoulder	37-45	28	74	8	1.0	630	522	54	59	6	43	26							
RB 73	BS 1	0-10	27	88	10	0.9	575	426	51	57	6	53	18	0.4	0.4	4.2	#	0.4	1	0.1
Argiaquolls	BS 2	10-20	37	92	10	0.9	595	432	62	59	4	47	22							
Upland	BS 3	20-30	0	74	8	0.4	162	245	58	55	0	57	3							
Anthro	BS 4	30-40	52	16	2	2.9	1577	1227	59	88	20	15	130							
RB 73	TS	0-10	78	17	2	3.0	1812	1238	63	87	18	17	149	0.4	1.2	4.4	#	1.6	1	1.5
Argiaquolls	TS	10-20	41	47	6	2.3	1406	952	58	80	15	24	115	0.6	1.1	6.7	#	1.7	1	0.2
Upland	TS	20-30	62	62	7	2.3	1482	906	59	74	14	29	104	0.6	0.9	6.5	8	1.5	1	0.1
Anthro	TS	30-40	65	62	7	1.9	1311	783	59	70	13	33	112	0.5	0.5	6.5	7	1.0	1	0.0
	TS	40-50	89	46	5	2.5	1847	987	57	79	18	19	137	0.5	0.5	6.3	7	0.9	1	0.0
	TS	50-60	79	82	9	1.7	1296	709	64	71	13	34	87	0.6	0.6	7.0	5	0.9	1	0.0
	TS	60-70	66	23	3	2.9	1662	1069	57	83	22	18	147	0.6	0.4	6.7	5	0.7	1	0.0
	TS	70-80	100	24	3	2.1	2158	999	54	86	21	13	170	0.6	0.6	6.4	6	1.0	1	0.0
	TS	80-90	100	12	2	2.4	1973	801	55	87	23	10	174	0.5	0.6	6.1	6	1.1	1	0.0
	TS	90-100	100	20	3	2.5	2579	912	58	89	22	12	158	0.8	0.5	8.8	7	1.3	1	0.0
	TS	100-110	100	21	3	2.8	2238	865	49	90	22	12	170	0.7	0.5	8.6	#	1.5	1	0.0
	TS	110-120	53	56	7	1.9	1041	423	49	72	9	35	97	0.7	0.4	7.6	7	1.3	1	0.0
	TS	120-130	92	10	2	3.1	1998	1005	59	95	23	10	186	0.5	0.2	5.5	4	1.1	1	0.0

Table 5 (continued)- Soil Chemical Properties: pXRF Elemental Concentration and DTPA Extractable Metals

Profile		Depth	pXRF SiO2	CaCO3	Ca	Fe	Ti	Mn	Cu	Zn	Rb	Sr	Zr	ICP Cd	Cu	Fe	Mn	Pb	Sr	Zn
		cm	- - - - - - % - - - - - - -				mg/kg--mg/kg													
RB 73	TS	0-10	31	72	8	2.3	1201	912	61	73	29	22	115	0.5	0.9	5.4	#	1.1	1	1.6
Argiaquolls	TS	10-20	46	80	9	2.2	1326	923	63	70	25	29	114							
Up/Anthro	TS	20-30	48	83	9	2.2	1482	976	53	70	26	22	90							
RB 73	BS	0-10	34	46	5	3.5	1692	1285	58	83	43	11	181	0.9	0.8	11.0	#	1.2	1	0.2
Argiaquolls	BS	10-20	27	93	10	1.9	1021	789	65	70	26	21	87							
Up/Anthro	BS	20-30	33	75	9	2.2	1161	853	58	72	34	16	101							
RB 73 Water	4	0-10	18	58	7	0.9	560	545	63	69	9	21	17	0.4	0.7	4.2	#	0.7	1	1.0
Argiaquolls	4	10-20	35	89	10	1.2	710	667	60	62	10	30	46							
Upland	4	20-30	29	98	11	0.9	655	516	60	60	9	32	30							
Anthropogenic	4	30-40	41	100	11	0.8	670	526	63	58	7	32	18							
	4	40-50	33	100	11	0.7	625	368	63	60	7	39	13							
	4	50-65	42	100	11	0.8	625	400	58	57	8	33	16							
RB 73 Water	3	0-10	13	80	9	0.6	444	427	65	62	6	35	8	0.2	0.6	2.7	#	0.5	1	0.9
Argiaquolls	3	10-20	17	100	11	0.6	467	377	62	55	6	45	9							
Upland	3	20-30	0	100	11	0.5	332	294	57	55	4	47	19							
Anthropogenic	3	30-40	26	100	11	0.4	313	253	60	52	6	48	-1							
	3	40-50	23	100	11	0.5	336	261	62	52	4	51	3							
	3	50-60	19	100	11	0.4	231	247	62	51	0	50	0							
	3	60-67	0	98	11	0.3	221	217	53	51	4	52	-5							

Table 6- δ^{13}C, Mehlich Extractable P, Total C/N, CO_3, and Organic C.

Profile		Depth	d13C	Mehlich P	pH	Total N	Total C	CO3-C	Organic C
		cm	‰	ppm		%	%	mg/kg	mg/kg
Laguna Verde	FS	0-10	-28.0	5.3	7.2	0.9	15	6	9
Argiaquolls	FS	10-20	-27.1		7.3	0.8	13	7	6
Lowland	FS	20-30	-26.3		7.3	0.5	12	8	4
Natural	FS	30-40	-26.2		7.4	0.4	11	8	3
	FS	40-50	-25.9		7.4	0.3	11	9	2
	FS	50-60	-25.9		7.5	0.3	11	9	2
	FS	60-70	-26.2		7.5	0.2	11	9	2
Laguna Verde	BS	0-10	-27.1	5.0	7.3	0.8	13	6	7
Argiaquolls	BS	10-20	-26.5		7.4	0.6	11	7	4
Lowland	BS	20-30	-26.2		7.5	0.4	11	8	2
Natural	BS	30-40	-23.6		7.7	0.3	11	9	2
	BS	40-50	-23.3		7.6	0.3	11	8	2
Laguna Verde	Shoulder	0-10	-27.1	4.8	7.3	0.8	13	7	6
Argiaquolls	Shoulder	10-20	-26.8		7.4	0.5	12	8	4
Lowland	Shoulder	20-30	-26.1		7.5	0.4	11	8	3
Natural	Shoulder	30-40	-24.1		7.6	0.3	11	9	2
	Shoulder	40-50	-24.7		7.5	0.4	12	9	3

Table 6 (continued)- $\delta^{13}C$, Mehlich Extractable P, Total C/N, CO_3, and Organic C.

Profile		Depth	d13C	Mehlich P	pH	Total N	Total C	CO3-C	Organic C
		cm	‰	ppm		%	%	mg/kg	mg/kg
Crystal Spring	Wetland	0-10	-28.7	9.4	7.1	0.8	11	3	8
Argiaquolls	Wetland	10-20	-27.7		7.2	0.6	8	3	6
Lowland	Wetland	20-30	-27.1		7.4	0.3	8	5	3
Natural	Wetland	30-40	-25.7		7.2	0.2	8	6	2
	Wetland	40-50	-25.3		7.2	0.2	8	6	2
	Wetland	50-60	-26.2		7.4	0.2	8	7	2
Crystal Creek	TS	0-10	-28.1	5.3	6.9	0.9	9	0	9
Argiaquolls	TS	10-20	-27.4	3.9	6.6	0.6	5	0	5
Lowland	TS	20-30	-27.0	5.2	6.6	0.3	3	0	3
Natural	TS	30-40	-26.5	5.2	7.0	0.2	2	0	2
	TS	40-50	-25.7	5.0	7.3	0.1	1	0	1
	TS	50-60	-25.6	4.3	7.4	0.1	1	0	1
	TS	60-70	-25.3	4.5	7.6	0.1	2	0	1
Akab Muclil	TS East	0-10	-28.7	15.1	7.6	0.7	14	7	7
Argiaquolls	TS East	10-20	-27.7		7.8	0.3	11	8	3
Lowland	TS East	20-30	-27.8		8.0	0.2	8	6	2
Anthropogenic	TS East	30-40	-27.2		7.9	0.1	4	3	1
	TS East	40-50	-27.6		7.8	0.1	5	0	5
	TS East	50-60	-28.1		7.7	0.2	6	0	6

Table 6 (continued)- $\delta^{13}C$, Mehlich Extractable P, Total C/N, CO_3, and Organic C.

Profile		Depth	d13C	Mehlich P	pH	Total N	Total C	CO3-C	Organic C
		cm	‰	ppm		%	%	mg/kg	mg/kg
Akab Muclil	TS West	0-10	-28.4	5.1	7.5	0.5	13	9	4
Argiaquolls	TS West	10-20	-27.8		7.6	0.4	12	8	4
Lowland	TS West	20-30	-24.1		7.7	0.2	11	9	2
Anthropogenic	TS West	30-40	-27.5		7.7	0.2	8	7	1
	TS West	40-50	-27.0		7.7	0.1	3	2	1
	TS West	50-60	-26.1		7.7	0.1	4	3	1
Crocodile Lake	FS	0-10	-28.0	5.7	7.0	0.7	11	4	6
Argiaquolls	FS	10-20	-27.5		6.9	0.6	9	4	6
Upland	FS	20-30	-26.7		7.1	0.4	7	4	3
Nautral	FS	30-40	-26.2		7.2	0.3	7	5	2
	FS	40-50	-26.2		7.4	0.2	8	7	2
	FS	50-60	-26.3		7.3	0.2	5	7	-2
Crocodile lake	D1 East	0-10	-27.4	5.4	7.0	0.7	7	1	7
Argiaquolls	D1 East	10-20	-26.7		7.1	0.6	5	0	5
Upland	D1 East	20-30	-26.1		7.2	0.4	3	0	3
Natural	D1 East	30-40	-25.5		7.3	0.2	4	1	2
	D1 East	40-50	-15.7		7.3	0.2	7	5	1
Crocodile lake	D1 West	0-10	-27.3	5.3	6.9	0.7	7	1	6
Argiaquolls	D1 West	10-20	-26.5		7.1	0.5	5	7	-2
Upland	D1 West	20-30	-25.8		7.3	0.3	4	1	3
Natural	D1 West	30-40	-25.7		7.5	0.2	5	3	2
	D1 West	40-50	-21.0		7.6	0.1	8	7	1

Table 6 (continued)- $\delta^{13}C$, Mehlich Extractable P, Total C/N, CO_3, and Organic C.

Profile		Depth	d13C	Mehlich P	pH pH	Total N	Total C	CO3-C	Organic C
		cm	‰	ppm		%	%	mg/kg	mg/kg
Crocodile lake	D2 South	0-10	-27.6	10.1	7.4	0.4	8	4	4
Argiaquolls	D2 South	10-20	-26.9	3.8	7.4	0.3	8	5	3
Upland	D2 South	20-30	-26.3	3.7	7.4	0.3	8	5	2
Natural	D2 South	30-40	-12.6	3.4	7.7	0.2	9	8	1
	D2 South	40-50	-25.6	3.3	7.5	0.2	6	4	2
	D2 South	50-60	-25.5	3.5	7.2	0.2	5	3	2
	D2 South	60-70	-25.1	2.6	7.3	0.2	5	4	2
	D2 South	70-80	-25.0	4.0	7.3	0.2	6	4	2
	D2 South	80-90	-24.8	3.3	7.3	0.1	6	4	2
	D2 South	90-100	-24.6	3.9	7.4	0.1	6	4	2
	D2 South	100-110	-24.7	3.5	7.3	0.1	6	5	1
	D2 South	110-120	-24.4	3.4	7.3	0.1	7	7	0
	D2 South	120-130	-24.3	3.4	7.4	0.1	7	6	1
	D2 South	130-140	-24.0	3.7	7.3	0.1	6	5	1
	D2 South	140-150	-23.9	3.5	7.4	0.1	7	6	1
	D2 South	150-160	-24.4	2.8	7.4	0.1	6	5	1
	D2 South	160-170	-23.3	3.0	7.4	0.1	6	4	2
RB73	BS 2	0-10	-28.3	5.2	7.1	1.1	13	3	10
Argiaquolls	BS 3	10-20	-27.2		7.3	0.5	11	7	4
Up/Anthro	BS 4	20-30	-26.5		7.4	0.4	10	7	3

Table 6 (continued)- $\delta^{13}C$, Mehlich Extractable P, Total C/N, CO_3, and Organic C.

Profile		Depth	d13C	Mehlich P	pH	Total N	Total C	CO3-C	Organic C
		cm	‰	ppm		%	%	mg/kg	mg/kg
RB73	Shoulder	0-9	-27.3	5.7	7.3	0.8	13	5	7
Argiaquolls	Shoulder	10-18	-26.8		7.0	0.6	11	6	5
Upland	Shoulder	19-27	-26.3		7.3	0.6	11	6	5
Anthropogenic	Shoulder	28-36	-26.0		7.3	0.3	10	7	3
	Shoulder	37-45	-26.2		7.3	0.3	10	7	3
RB 73	BS 1	0-10	-27.1	4.5	7.2	0.5	12	8	4
Argiaquolls	BS 2	10-20	-26.8		7.3	0.4	11	9	3
Upland	BS 3	20-30	-26.6		7.4	0.3	11	9	2
Anthropogenic	BS 4	30-40	-26.3		7.4	0.1	12	11	1
RB 73	TS	0-10	-28.2	5.7	7.3	1.0	10	1	9
Argiaquolls	TS	10-20	-27.0	4.7	7.3	0.6	6	1	5
Upland	TS	20-30	-26.5	4.3	7.4	0.4	8	4	3
Anthropogenic	TS	30-40	-26.0	3.7	7.5	0.2	8	6	2
	TS	40-50	-26.1	4.0	7.6	0.2	8	5	3
	TS	50-60	-25.8	3.6	7.6	0.2	6	3	2
	TS	60-70	-25.8	3.7	7.6	0.2	8	5	3
	TS	70-80	-25.3	3.1	7.1	0.3	5	2	3
	TS	80-90	-23.5	2.5	7.1	0.2	4	2	2
	TS	90-100	-22.6	3.7	7.0	0.2	3	0	3
	TS	100-110	-22.7	3.3	6.9	0.2	3	0	2
	TS	110-120	-22.9	3.7	7.1	0.2	4	2	3
	TS	120-130	-23.6	3.6	7.3	0.1	7	6	1

Table 6 (continued)- $\delta^{13}C$, Mehlich Extractable P, Total C/N, CO_3, and Organic C.

Profile		Depth	d13C	Mehlich P	pH pH	Total N	Total C	CO3-C	Organic C
		cm	‰	ppm		%	%	mg/kg	mg/kg
RB 73	TS	0-10	-28.9	6.3	7.3	1.0	13	4	9
Argiaquolls	TS	10-20	-27.0		7.4	0.4	9	6	3
Up/Anthro	TS	20-30	-26.7		7.4	0.5	9	5	3
RB 73	BS	0-10	-27.4	6.0	7.4	0.8	8	4	4
Argiaquolls	BS	10-20	-26.7		7.4	0.4	8	5	3
Up/Anthro	BS	20-30	-26.4		7.3	0.3	8	5	3
RB 73 Water	4	0-10	-29.1	5.9	7.1	1.1	17	6	11
Argiaquolls	4	10-20	-27.2		7.4	0.5	11	8	3
Upland	4	20-30	-27.2		7.5	0.3	10	9	2
Anthropogenic	4	30-40	-26.9		7.5	0.2	10	9	1
	4	40-50	-26.4		7.5	0.2	10	8	3
	4	50-65	-25.9		7.6	0.1	10	10	0
RB 73 Water	3	0-10	-28.8	4.0	7.3	0.8	15	8	7
Argiaquolls	3	10-20	-27.4		7.4	0.3	10	9	1
Upland	3	20-30	-27.1		7.7	0.2	11	10	1
anthropogenic	3	30-40	-26.8		7.7	0.1	11	10	0
	3	40-50	-26.8		7.7	0.1	10	10	0
	3	50-60	-26.9		7.7	0.1	10	10	0
	3	60-67	-26.8		7.7	0.1	6	11	-5

Table 7- Geographical Statistical Comparison

	P-Values			Average Values Up			Average Values Low		
Test	All	0-30cm	Surface	All	0-30cm	Surface	All	0-30cm	Surface
P	0.06	0.30	0.42	4.3	1.1	5.8	6.0	2.3	7.1
Sand%h	0.048*	0.13	0.58	21%	0.2	0.1	32%	0.3	0.2
Silt%h	0.82	0.66	0.76	21%	0.2	0.3	20%	0.2	0.3
Clay%h	0.05	0.11	0.78	58%	0.6	0.6	47%	0.5	0.6
pH	0.08	0.22	0.36	7.3	7.3	7.2	7.4	7.4	7.3
SiO2 %	0.0001*	0.01*	0.02*	48.4	41.3	38.8	28.4	28.8	22.3
Ca %	0.12	0.23	0.53	7.0	7.2	6.0	8.0	8.2	7.1
Ti mg/kg	0.0001*	0.001*	0.04*	1576.5	1385.1	1422.3	833.9	841.4	801.4
Mn mg/kg	0.0001*	0.0001*	0.002*	812.7	737.0	792.7	349.3	343.9	386.0
Fe %	0.0001*	0.007*	0.10	2.4	2.3	2.5	1.4	1.4	1.5
Cu mg/kg	0.16	0.40	0.78	59.0	60.0	59.8	59.9	60.7	59.3
Zn mg/kg	0.07	0.28	0.49	77.8	76.6	80.2	72.0	72.3	75.3
Rb mg/kg	0.26	0.97	0.79	14.7	14.6	17.8	13.5	14.6	16.9
Sr mg/kg	0.0001*	0.0005*	0.047*	27.8	31.0	26.8	349.9	299.7	223.2
Zr mg/kg	0.001*	0.01*	0.12	106.3	99.3	112.8	66.9	63.1	63.7
Cd	0.89	0.86	0.80	0.8	1.0	0.8	0.9	0.9	0.6
Cu	0.03*	0.19	0.88	0.8	1.1	0.9	2.0	2.0	1.0
Fe	0.85	0.89	0.81	9.5	11.8	9.0	10.1	11.1	7.3
Mn	0.0002*	0.0022*	0.0127*	9.1	12.5	14.7	4.1	5.1	5.2
Sr	0.0001*	0.001*	0.0308*	1.1	1.3	1.3	10.9	10.5	9.2
Zn	0.45	0.23	0.23	0.6	1.3	1.9	0.3	0.4	0.5

P Vaule <.05 Is Significant

Statistical comparison of soil chemical properties based on geography and depth. “All” refers to all samples in every profile. “0-30cm” refers to the top four samples in each profile. “Surface” refers to the surface sample in each profile. Samples were characterized as upland and lowland based on position relative to the edge of the Rio Bravo Escarpment. Statistical analysis was conducted using a t-test; assuming unequal variance.

Table 8- Anthropogenic Influence Statistical Comparison

	P-Values			Average Values Natural			Average Values Antho		
Test	All	0-30cm	Surface	All	0-30cm	Surface	All	0-30cm	Surface
P	0.52	0.61	0.80	4.5	5.4	6.2	4.9	5.9	6.5
Sand%h	0.17	0.18	0.09	22%	19%	13%	31%	28%	22%
Silt%h	0.001*	0.002*	0.09	17%	17%	24%	28%	30%	30%
Clay%h	0.001*	0.0006*	0.03*	61%	63%	64%	41%	42%	48%
pH	0.002*	0.0003*	0.01*	7.3	7.2	7.1	7.4	7.4	7.3
SiO2 %	0.20	0.01*	0.51	44.2	41.6	35.4	38.9	30.8	29.8
Ca %	0.06	0.008*	0.11	6.8	6.7	5.4	8.0	8.7	7.6
Ti mg/kg	0.0001*	0.0001*	0.05	1683.1	1552.2	1489.6	943.0	755.5	864.6
Mn mg/kg	0.10	0.53	0.79	723.8	609.6	622.4	583.1	551.9	665.6
Fe %	0.0001*	0.0001*	0.06	2.7	2.6	2.7	1.4	1.2	1.5
Cu mg/kg	0.02*	0.01*	0.80	60.1	61.2	59.9	58.4	59.3	59.4
Zn mg/kg	0.0001*	0.0001*	0.06	83.0	82.6	84.5	68.2	66.5	71.6
Rb mg/kg	0.43	0.03*	0.97	14.8	16.0	17.4	13.6	13.1	17.6
Sr mg/kg	0.009*	0.04*	0.35	71.5	73.9	63.9	206.7	205.5	138.3
Zr mg/kg	0.0001*	0.0001*	0.12	115.8	112.7	119.1	68.6	55.0	67.6
Cd	0.001*	0.003*	0.17	1.1	1.5	1.1	0.5	0.4	0.4
Cu	0.001*	0.005*	0.17	1.4	2.0	1.3	0.6	0.7	0.6
Fe	0.001*	0.003*	0.18	12.6	17.0	13.1	5.7	4.9	4.3
Mn	0.006*	0.01*	0.01*	5.6	6.2	5.6	11.0	14.8	16.4
Sr	0.15	0.43	0.94	4.2	5.1	4.0	2.2	3.4	4.2
Zn	0.39	0.34	0.31	0.7	1.4	2.3	0.3	0.5	0.7

P Value <.05 Is Significant

Statistical comparison of soil chemical properties based on geography and depth. “All” refers to all samples in every profile. “Top 4” refers to the top four samples in each profile. “Surface” refers to the surface sample in each profile. Samples were characterized as natural and anthropogenic based on relative proximity to Maya structures. Samples classified as anthropogenic are found either directly on a structure or within 10m of the edge of a structure. All other samples are classified as natural. Statistical analysis was conducted using a t-test; assuming unequal variance.