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GARDEN SOILS: REVIEWING THE VIABILITY OF SOIL PHOSPHATE ANALYSES IN  
THE ARCHAEOLOGICAL IDENTIFICATION OF ANCIENT MAYA KITCHEN GARDENS

by

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A thesis submitted in partial fulfillment of the requirements  
for the degree of Master of Arts  
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in the College of Sciences  
at the University of Central Florida  
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## ABSTRACT

The study of ancient Maya intensive, intra-site agricultural systems, such as kitchen gardens, has gained new interest in recent years as a valuable way of interpreting numerous aspects of the ancient Maya's daily life (e.g. subsistence and settlement patterns, population growth, diet and nutrition, gender roles). However, while contemporary Maya kitchen gardens can often be easily identified and studied by cultural anthropologists and archaeologists, ancient kitchen gardens are usually much harder to identify by traditional archaeological techniques because of their lack of architectural structures and other identifying features. To compensate for this limitation, various forms of chemical testing (primarily phosphate analysis) are being used to positively identify kitchen gardens and other specific anthropogenically modified spaces that are invisible to standard archaeological techniques. The archaeological community trusts these methods to be a reliable way of testing soils in archaeological sites for specific agricultural features, even though there has been little research conducted to conclusively prove this assertion. In response to this lack of research, this thesis investigates the viability of phosphate analysis and other chemical tests through a comprehensive literary review of previous and current research and an analysis of the data presented within it. While soil phosphate analysis has been used in past and current research to identify general agricultural features with great success, the chemical signatures produced from this method only give vague information about the soil and what was done to it, making soil Phosphate analysis unreliable to definitively discern specific agricultural areas, such as kitchen gardens, from general agricultural areas.

## ACKNOWLEDGMENTS

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## TABLE OF CONTENTS

LIST OF FIGURES.....	vi
LIST OF TABLES .....	vii
CHAPTER 1: INTRODUCTION.....	1
CHAPTER 2: LITERATURE REVIEW AND PROBLEM STATEMENT.....	5
2.1 Agriculture and Kitchen Gardens.....	5
2.1.1 Ancient Maya Kitchen Gardens .....	13
2.2. Chemical Testing and Archaeological Investigations.....	19
2.2.1 Soil Phosphate Analysis in the Maya Region .....	30
2.3 Problem Statement.....	40
CHAPTER 3: DATA INTERPRETATION AND DISCUSSION.....	41
3.1 Introduction.....	41
3.1.1 Examination of Soil P Analysis in Regards to Artifacts.....	41
3.1.2 Examination of Soil P Extraction Procedures and Testing Methods.....	45
CHAPTER 4: CONCLUSIONS.....	49
LIST OF REFERENCES.....	52

## LIST OF FIGURES

Figure 1 Structure of an Ancient Maya kitchen garden.....	12
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## LIST OF TABLES

Table 1 Summary of Case Studies .....	39
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## CHAPTER 1: INTRODUCTION

There has been much discussion about ancient Maya agriculture (Chase and Chase 1983, 1998; Donkin 1979; Drucker and Fox 1982:183; Dunning 1993; Fedick and Ford 1990; Fedick and Morrison 2004; Harrison and Turner 1978; Hutson et al. 2007; Sanders and Killion 1992; Pohl 1985). Researchers have identified and studied several different kinds of agricultural practice including swidden farming, raised fields, and terraces. While the study of contemporary Maya peoples indicates that kitchen gardens are a major source of household produce, relatively little effort has been expended in studying the existence or impact of kitchen gardens in the ancient past. To date, archaeologists have only conclusively identified kitchen gardens at one ancient Maya site, Cerén (Sheets and Woodward 2002:188). However, possible identified kitchen gardens have been identified at Chunchucmil (Hutson et al. 2009:261) and Mayapán (Bullard 1952:38), based largely on spatial proximities combined with a lack of archaeological evidence (i.e. artifacts, architecture, large scale movement of soil, etc.).

To identify kitchen gardens, archaeologists (e.g. Hutson et al. 2009; Wells et al. 2000; Eberl et al. 2012; Webb et al. 2004; Webb et al. 2004; Cook et al. 2006) have begun incorporating chemical testing, such as Phosphate or P analysis, mass spectrometry, and stable isotope analysis in their archaeological investigations to test the soils where ancient Maya kitchen gardens have been suspected. Phosphate analysis is becoming the most common method of testing soil, due to its ability to indicate past human activity, especially in regards to agriculture (Holliday and Gartner 2007:301; Hutson et al. 2009:260; Parnell et al. 2002a:381, 2002b:332; Terry et al. 2000:151; Wells et al. 2000:450). However, while this method is gaining recognition in the archaeological community for general agricultural detection, there have been

relatively few studies focused on determining its viability in regards to identifying specific agricultural features, such as kitchen gardens and other anthropogenically altered soils.

Reviewing and reevaluating past and current research on soil chemical testing, particularly P analysis, will provide a new perspective on whether or not these types of tests are suited for identifying specific agricultural features, such as kitchen gardens.

Although there are many other forms of chemical testing available to archaeologists today, soil P analysis is the most widely used method and, thus, comprises the predominant method reviewed in this thesis. In order to present a comprehensive analysis of soil P analysis and its effectiveness in archaeological practices, its overall usage, both within the archaeological field and outside of it will be considered. The goal of this thesis is to examine the suitability of soil P analysis for positive identification of kitchen gardens and other small-scale intensive agricultural systems. This thesis will investigate the proposal that the chemical signatures produced from soil P analyses are too general and do not produce enough specific information about the activities of the ancient Maya and the impact of these activities on the soil to conclusively identify the presence or absence of ancient kitchen gardens.

As noted, ancient kitchen gardens are not well identified or studied. Thus, this evaluation of soil P analysis suitability for identifying ancient Maya kitchen gardens will enhance general discussions of this subject. The topic of the ancient Maya use of kitchen gardens is still debated in Maya archaeology, even though several scholars (Chase and Chase 1983, 1998; Fedick and Ford 1990; Fedick and Morrison 2004; Hutson et al. 2007; Sanders and Killion 1992) acknowledge that kitchen gardens were likely used. As mentioned above, this is largely due to the lack of ancient Maya sites that show conclusive evidence for their existence. Chase and

Chase (1983:2) credit this lack of evidence to the fact that the smaller scale kitchen gardens do not involve the degree of engineering that leaves the distinct archaeological evidence (i.e. architectural features or large scale movement of soil) that is commonly found with larger scale agricultural systems such as raised fields and terracing. Instead, they were situated in the areas around ancient Maya dwellings, analogous to what is seen in contemporary times in the Maya area. Although certain artifacts (such as water jugs and weeding tools), geological features (like a high water table), and specific pollen residues might delineate kitchen garden spaces, the probability of positively identifying kitchen gardens with standard archaeological technologies is low (Chase and Chase 1983:9).

This thesis examines the viability of soil P analysis and other chemical testing by addressing the following research questions regarding the identification of ancient Maya kitchen gardens in archaeological investigations. First, are the results of soil P analyses detailed enough to provide specific data that can positively locate the areas of soil that were used by the ancient Maya for kitchen gardens, including specific information on the limits of kitchen gardens in the soil and the identification of any boundaries between kitchen gardens and their surrounding areas? Second, can soil P analyses indicate whether garden plots were used for other purposes along with, or instead of, agriculture, such as a containment area for animals (i.e., domesticated livestock or dogs), stalls for markets, or beehive stands, as suggested by Chase and Chase (1983:8), Becker (2001), and Hutson et al. (2007:464)?

This reexamination of soil P analysis in archaeological practice should lead to a significant improvement to the dataset on kitchen gardens. Any refinement of technique might also make it possible for scholars to positively identify kitchen gardens at more ancient Maya

sites. Through these identifications, new information about the ancient Maya's subsistence technologies, population estimates, gender roles, nutrition and diet, and settlement patterns should become available. This will add to the corpus of Maya knowledge already in place and allow for new theories and insights into all aspects of ancient Maya life.

The research questions listed above will be addressed in the next three chapters. Chapter Two reviews previous and current research on kitchen gardens and soil P analysis. It outlines the global and geographically- specific histories of kitchen gardens and chemical testing in archaeological research, their usages, technologies, and methods. This chapter will also include descriptions of various chemical signatures used in chemical testing and what they indicate in archaeological testing. Finally, Chapter Two provides a thorough outline and discussion of the problems and research questions that are the main focus this thesis, specifically whether soil P analysis is detailed enough to positively identify ancient kitchen gardens in areas of known human activity and general agriculture. Chapter Three analyzes the data presented in Chapter Two and provides interpretations of the data specifically with regards to the research questions. Chapter Four wraps up the discussion of the data and proffers a final conclusion about the research questions.

## CHAPTER 2: LITERATURE REVIEW AND PROBLEM STATEMENT

The material presented in this chapter is intended to provide background information for the reader and to produce the necessary foundation for the discussion and interpretations of the subsequent chapters. The two main foci are ancient Maya kitchen gardens and soil P analysis within archaeological research in regards to small-scale intensive agricultural technologies. The global history and use of kitchen gardens and a brief overview of other chemical testing methods are also provided for a broader understanding of the two foci. A brief description of contemporary Maya kitchen gardens will also be presented to provide possible analogies between the past and present. Finally, this chapter will address various problems associated with each focus area in greater detail.

### 2.1 Agriculture and Kitchen Gardens

Although kitchen gardens are effectively the main focus of this thesis, a brief understanding of agriculture in general is required to provide context to kitchen garden origins and usages, elucidating why they are essential to many agricultural societies worldwide. Langlie et al. (2014:1601) define agriculture as a situation where “farming and/or herding predominate the activities of a particular community and determine the main diet, although hunting and gathering may continue.” Scientists have studied the issue of agriculture and its indisputable connection to humans since the Neolithic Revolution (a term created by V. Gordon Childe in 1934) for many generations. What is more, many scientists believe that the “invention” of agriculture was, at first, an unconscious action by early humans, simply because early humans had no previous idea or notion of agriculture (Maritsas 2013:23). Essentially, early hunter and

gatherers used wild plants that self-propagated, unconsciously depositing seeds where they were not usually found in nature; after this phenomenon happened regularly, future generations finally formed the idea of *purposely* depositing seeds in the ground to grow food (Maritsas 2013:23-25).

Furthermore, while it was assumed for many years that agriculture originated in specific, recognizable centers, as first suggested by N. I. Vavilov in 1926, further research suggests that agriculture appeared in several areas of the world simultaneously (Langlie et al. 2014:1601; Vavilov 1926). David Harris (1990:15) reviewed Vavilov's concept and argued that, even though Vavilov's "centers of origin" model has been disproved, it still holds strong influence over many new scholars (see also Langlie et al. 2014:1602). Recent studies propose that there are anywhere from 11 to 24 regions of the world where agriculture and cultivation first took hold, including Mesopotamia, Mesoamerica, Southwest Asia, and Northwest South America (Fuller and Hildebrand 2013:511; Langlie et al. 2014:1602). Also, archaeobotanical evidence shows that several different types of plants (i.e., wild barley, wheat, and grass peas) might have been domesticated multiple times in different places, such as Turkey, Iraq, and Syria (Fuller et al. 2011; Langlie et al. 2014:1604; Riehl et al. 2013; Tanno and Willcox 2006). This domestication of plants permitted early hunter and gatherer populations to become sedentary and, eventually, form communities and larger groupings of society.

Among scientists studying agriculture in Mesoamerica, it is generally accepted that there are three types, or zones, of agriculture (Sanders and Killion 1992:27). The first are outfields, which are large plots for cultivation, located some distance from the residential zone. Swidden farming (also known as slash-and-burn and shifting cultivation) is an example of this agricultural zone and is defined by Peter Harrison (1978:11) as "an extensive system of cultivation that tends

to maintain two to four or more years of fallow for every year of cultivation.” It is considered by Nigh and Diemont (2013:e45) to be the oldest subsistence practice in the Americas, and paleoarchaeological evidence suggests it was first used in Mesoamerica between 8,000 and 5,000 years ago (Zizumbo-Villarreal 2012:330). In the 19<sup>th</sup> century, Europeans were the first to discover that the ancient Maya practiced swidden farming, initiating the theory that the ancient Maya were solely swidden agriculturalists (Turner 1978:13). This theory persisted throughout much of the 20<sup>th</sup> century (see Harrison and Turner 1978:Note 1 for a partial list of scholars in support of swidden thesis 1921-1973), even though the use of swidden farming would have limited the ancient Maya’s conceivable carrying capacity (Chase and Chase 1998:60).

The nature of swidden farming requires the burning of plant remains after an area of land is cleared as well as a comparably lengthy period for renewal. Because of the burning, nutrients in the soil that are vital to crops, such as phosphorus, undergo chemical transformations that make them unavailable to crops, limiting the overall usefulness of an agricultural area after the first two years (Johnston 2003:143). Due to the growing understanding of this destructive cycle as well as archaeological investigations in the Petén of Guatemala, (specifically at Tikal) during the 1950s and 1960s (Harrison and Turner 1998), most researchers in the Maya area no longer believe that swidden farming was the sole agricultural technology being used by the ancient Maya. Instead, many researchers (i.e., Chase and Chase 1998:61; Donkin 1979; Drucker and Fox 1982:183; Dunning 1993; Harrison and Turner 1978; Hutson et al. 2007:445; Pohl 1985) now believe that the ancient Maya utilized a variety of subsistence practices to sustain their large populations, including the use of agricultural terraces and raised fields.

Raised fields are a second example of outfield intensive agricultural systems in the Maya region. Raised fields were created by piling earth in mounds or rows to make an area higher than the surrounding natural land. They were not largely studied until the 1970s (Turner and Harrison 1981:399). These raised fields were first discovered in the Rio Candelaria Basin in Campeche's southeast region, which led to the later detection of numerous raised fields in southern Quintana Roo, Mexico, as well as almost 3,200 hectares of raised fields, in the northern regions of Belize (Siemens and Puleston 1972:228; Turner and Harrison 1981:399). However, many of these discoveries were made solely by aerial observations and have been the subject of debate. Some scholars (i.e. Puleston 1978; W. R. Wood and D. L. Johnson 1978) have suggested that many of the fields in question could be natural formations caused by extreme seasonal changes. Nevertheless, recent excavations at Pulltrouser Swamp, Belize negate these assertions by producing evidence that the ancient Maya did utilize raised field technology (Turner and Harrison 2000). Continued research of the topography in the area show similarities to other parts of the Maya region, further reinforcing the belief that raised fields were used in conjunction with other agricultural systems.

Terraces are a third example of ancient Mesoamerican infield agricultural intensive practices. Excavations at Caracol, Belize indicate that ancient Maya terraces were constructed from roughly-cut limestone boulders, placed on the bedrock, and anthropogenically modifying the sides of hills and valleys. Fertile soils were placed behind these constructed features (Chase and Chase 1998:69; Coultas et al. 1993; Healy et al. 1983:402-404). Smaller rocks within the terraces could have also helped to aid water flow within the terraces, ensuring that the water flowed evenly, irrigating all the soil properly and increasing the nutrients in the soil (Chase and



Chase 1998:70; Coultas et al. 1984:107; Healy et al. 1983:404-406). The practice of terracing in the ancient Maya area required a substantial time investment and was generally used more often and for much longer periods of time than neighboring unterraced soils (Wilken 1971:434).

Ancient Maya terracing as a whole was not largely studied until the 1970's, when B. L. Turner (1978, 1983) conducted a two-year study on agricultural terraces in the Maya Rio Bec zone between Campeche and Quintana Roo in Mexico (see also Dunning and Beach 1994:52; Healy et al. 1983:399). From the 1920's until this time, only brief references were made about ancient Maya terraces, (e.g. Lundell 1940; Ower 1927; Thompson 1931; Willey 1965; Wright et al. 1959). Since the 1970s, researchers have increased the studies on ancient terraces in the Maya region, greatly contributing to the Maya's agricultural database (A. Chase and D. Chase 1987:53, 1990, 1994:6-7, 1998; D. Chase and A. Chase 2014; Coultas et al. 1993; Dunning and Beach 1994; Fedick 1994; Healy 1983; Healy et al. 1980, 1983; Laporte 1994:5; Lobato 1988:32; Turner 1978, 1979, 1983; Woods and Holley 1992).

Infield and houselot fields are the second and third agricultural zones recognized by researchers. Infield zones, like terraces, are usually located inside outfield zones and are generally adjacent to a community's residential area (Sanders and Killion 1992:27-29). Land inside this infield zone is often fertilized and is generally considered to be more intensive than outfield land. Houselot fields are located directly adjacent to or entirely enclosed within a community's residential area, and were probably highly productive in ancient Maya times, receiving constant care and fertilization. Houselot fields, commonly referred to as infield or kitchen gardens, were usually intended for non-staple crops and may have included orchards (Chase and Chase 1983:2-3).

Kitchen gardens, also called home gardens, house gardens, dooryard gardens, or *solares*, are controlled, multi-level mixtures of crops, trees, and other useful plants, located near dwellings, and occasionally associated with domesticated animals (Flores-Delgadillo et al. 2011:113; Kumar and Nair 2004:135; Sanders and Killion 1992:14). Several scholars (e.g. Anderson 1952:136-50; Doolittle 1992:85; 2004:392; Niñez 1987:168) use the theory that kitchen gardens originally stemmed from an unintentional action, the dumping of trash outside of ancient dwellings. It is generally posited that trash, including plant remains, was discarded in many ancient civilizations, by being thrown outside, the back of the residence, eventually turning into a pile of “well-fertilized microenvironments” (Doolittle 2004:392). Here, the discarded plant remains could thrive due to the constant fertilization of human trash and waste (in the Old World, latrines were commonly found behind the dwelling alongside or even within gardens) and the irrigation of human wastewater, as many trash heaps were located downhill from the dwelling, allowing wastewater to flow naturally to it (Doolittle 1992:85, 2004:392). These fertilization and irrigation acts are thought to have been inadvertent, but eventually ancient human populations realized the potential to this phenomenon and started interfering in the processes of gardening. The Maya went further, totally recycling their waste- often into agricultural fields (e.g. A. Chase and D. Chase 2015).

The intentional use of kitchen gardens dates back to the Neolithic Revolution and is documented for numerous civilizations throughout human history, such as those in Indonesia, East Africa, and India (Kumar and Nair 2004:135). In fact, William Doolittle claims that kitchen gardens “probably played a key role in the origins of agriculture” (1992:70), and Vera Niñez (1987:168) asserts that small gardens next to residential dwellings are the oldest form of

cultivation, as well as the most persistent throughout time. In the tropics, kitchen gardens are correctly regarded as one of the oldest managed agricultural systems and are at the zenith of the various forms of sustainability. The usefulness of these kitchen gardens has not diminished over time; with an estimated 5.4 million half hectare or similarly sized gardens in peninsular India alone, kitchen gardens are used for food production, medicine, shelter, ornamental manufacture, and economic profit through out most of the world's tropical and subtropical ecological zones (Fernandes and Nair 1986:279; Kumar and Nair 2004:135-36; Sanders and Killion 1992:15-20). On average, kitchen gardens found in these areas consist of three to five layers and contain a large variety of plant species (see figure 1). In general, the layer closest to the ground in most kitchen gardens is herbaceous, with the top layer being for trees and the middle layer being for other plants of intermediate height (Fernandes and Nair 1986:285).

The first, and sometimes the second, layers are commonly used for sub-ground vegetable and food crops, as well as medicinal plants (Fernandes and Nair 1986:285-90), such as beans, sweet potato, and manioc. The third and fourth layers are usually used for other food plants, such as banana, papaya, maize, and pepper (Fernandes and Nair 1986:290). Lastly, the fifth layer is where taller fruit trees and trees that are used for timber are placed, although this was not often done as these trees would shade too much of the ground below and would not allow the plants in lower levels to grow properly. While this structure is dynamic and can change in various aspects from area to area, there typically is a general continuity to the structure of kitchen gardens. It is also important to mention that the continuous addition and decomposition of plant nutrients and organic matter creates a balance that helps to stabilize the kitchen garden's ecosystem. This specific topic will be discussed later in this thesis.

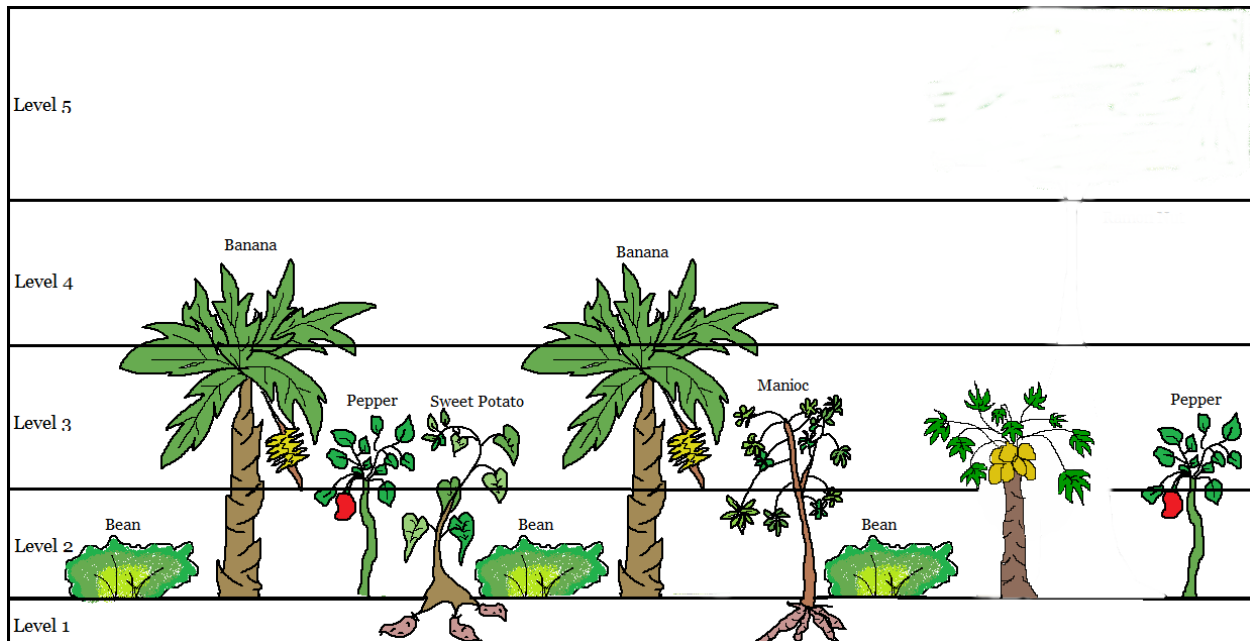


Figure 1 Structure of an Ancient Maya kitchen garden

In kitchen gardens around the world, the specific plant species that are used are determined largely by the region's climate and environmental factors. In essence, a plant that is commonly found in Central American kitchen gardens would not necessarily be included in African or Asian kitchen gardens. The plant diversity is also affected by socio-economic and cultural factors, market availability, and personal dietary preferences. A crop that is grown on a large scale for the benefit of the community, such as maize in Central America, would generally not be found in kitchen gardens, just as a crop that is not important to, or does not match, a specific family's needs would not be grown in that family's kitchen garden. This is effectively a small-scale illustration of Scott Fedick's (1996:347) "Managed Mosaic" theory, which states that areas such as the Maya Lowlands "comprise a complex mosaic of fine-grained heterogeneity at the local level, with significant variability in landscapes between subregions." Each of the ancient Maya's various subsistence practices (i.e. milpa/swidden, terraces, raised fields, kitchen

gardens) is one piece of the larger mosaic of the entire landscape, and, as such, each has its specific purpose, benefits, and limitations that enabled the Maya to thrive in their particular environment.

### 2.1.1 Ancient Maya Kitchen Gardens

This sub-section provides a necessary introduction to the ancient Maya in order to contextualize the civilization's use of kitchen gardens in terms of geography and climate. The ancient Maya civilization first appeared over 2,000 years ago in Mesoamerica (present day countries of Belize, Guatemala, Honduras, Mexico, and El Salvador), and was arguably one of the most advanced civilizations of the time with monumental architecture, a written hieroglyphic language, and significant advances in astronomy (Sharer and Traxler 2006:4). The Maya civilization went through several developmental periods that can be categorized chronologically: the Archaic, Early Preclassic, Middle Preclassic, Late Preclassic, Classic, and Postclassic (Demarest 2004:12-13). These are often broken down further into smaller classifications, such as the Late Classic, Terminal Classic, Early Classic, and sometimes the Proto-Classic. These developmental periods help to organize the ancient Maya's accomplishments and are often associated with certain events, such as the apex of the ancient Maya in the Classic Period (Demarest 2004:12-15).

The geography of the area is commonly split into three different regions: the lowlands to the north, the highlands in the middle, and the Pacific coastal plains in the south. Each region has its own subzones based on various environmental conditions (Sharer and Traxler 2006:30). The lowland area, which is generally below 800 meters, is the largest of the three in the Maya region

and is largely characterized by tropical rainforests that yield an enormous range of flora and fauna, as well as by a geology consisting of a karst topography with numerous rivers and lakes crisscrossing the landscape and the Maya Mountains in the southeast portion of the area (Sharer and Traxler 2006:42). The highland area, which is generally above 800 meters, is generally rich in resources and ecological diversity. It is also geologically precarious due to the convergence of three tectonic plates that cause volcanic eruptions and earthquakes. This topography is also intersected by several rivers that have carved valleys through the mountains (Sharer and Traxler 2006:34). Finally, the Pacific Coastal Plain is a fertile stretch of land between Chiapas, Mexico and northern El Salvador that is comprised of young sediments from the volcanoes in the neighboring Highland region and is known for its history of foreign invaders and migrants as well as for its chocolate and cotton production (Sharer and Traxler 2006:31-33).

The Maya area can also be categorized by climate, with the warmest area (*tierra caliente*) ranging from 0-800 meters, the temperate area (*tierra templada*) ranging from 800-2,000 meters, and the coldest area (*tierra fría*) ranging from 2,000 meters and above (Sharer and Traxler 2006:30). Generally, Mexico and Guatemala are categorized as mild temperate-subtropical and the rest of the Maya region as tropical, although the eastern side tends to have a more humid climate as a result of the humidity carried by the trade winds (Montagnini 2006:63). This eastern Caribbean side can receive annual rainfall averaging between 3,000 and 5,000 mm. The western Pacific side is often shielded from the rain-bringing winds by a central volcanic mountain range and therefore only receives between 300 and 2,000mm of rain per year (Montagnini 2006:63-64). These various climates and geographical areas that exist in Mesoamerica have led to differences in the ancient agricultural systems.

Although few ancient civilizations were able to successfully settle in tropical forest environments similar to the ancient Maya, it has been recognized that the ancient Maya were able to not only settle but also to thrive in this type of environment, due largely to their agricultural systems, both inter and intra-site (Gómez-Pompa 1987:1). Archaeologists (i.e. Drucker and Fox 1982; Dunning and Beach 1994; Turner and Harrison 1981; Wilken 1971; A. Chase and D. Chase 1998) have studied their agricultural systems, including terracing, raised fields, and swidden or slash-and-burn farming extensively in recent years. While each of these agricultural methods is a viable subsistence technology, each one would have produced slightly different crop yields depending on the particular environment and geography of the immediate area (Abramiuk et al. 2011: 260). This would have had an effect on the carrying capacity for a city's population (e.g. D. Chase and A. Chase 2014), and so these inter-site agricultural systems were implemented in particular cities according to their optimal crop yield compared to the population size, and were often practiced in conjunction with other subsistence technologies.

As previously mentioned, it is acknowledged that kitchen gardens probably existed in the Maya area in the Maya Lowlands during Prehispanic times (Fedick 1996:343; Fedick and Morrison 2003:213). Numerous researchers (e.g. Becker 2001:439; Bullard 1952; Chase and Chase 1983:3; Dunning and Beach 2011; Fedick 1995:29; Fedick and Morrison 2003; Hutson et al. 2007; Webster et al. 1997:48) have commented that household groups within cities were regularly spaced and sometimes walled, delineating plots of land for small-scale intensive gardening. Furthermore, some researchers (Fedick and Morrison 2003; Ball and Kelsay 1992; Killion et al. 1989) indicate that the soils within these spaces were chemically altered with nutrient enrichments. Chemical analyses have been used to suggest the locations of kitchen

gardens in multiple areas of the Maya area, including Sayil, Xunantunich, Cobá, the Belize River Valley, the Petexbatun region of Guatemala, and northwest Belize (Lohse and Findlay 2000:178). Archaeological excavations at Cerén, El Salvador have proved immensely important for understanding ancient kitchen gardens, due to the excellent preservation of the gardens and surrounding residential buildings caused by a volcanic eruption in A.D. 590 (Webster et al. 1997:43). Here, after the removal of over 5 meters of volcanic ash, it has been possible to determine the precise location and parameters of kitchen gardens within residential groups; gardens are located “immediately around house clusters” (Webster et al. 1997:48), and were approximately one-third hectare in area.

Although kitchen gardens are usually found on usable agricultural lands, archaeologists have found evidence of fertilizers in ancient Maya kitchen gardens dating from circa 100 B.C. to A.D. 350-450 (Fedick and Morrison 2003:209). Fertilizer or soil enhancements can come in several forms, such as mulching with household refuse as well as with human and animal feces (Hammond 1978:31). At Cancuén, Guatemala, imported seaweed and shell-sand was used as fertilizer (Cook et al. 2006:630). In areas such as the Yalahau region, where chemical fertilizers might have been lacking, periphyton-enriched soils may have been applied to kitchen gardens as a biofertilizer (Flores-Delgadillo et al. 2011:118). These fertilizers enhance the natural phosphates that are found in the soil, which means that the levels of phosphates in the soil will be increased, even after the plants are removed or decomposed (Parnell et al. 2002b:332). This allows soil scientists to determine which areas were likely used for agricultural areas and which ones were not by chemically testing the soils for phosphates.



Aside from this method of chemically testing soils in archaeological sites, kitchen gardens in the archaeological record are notoriously difficult to identify. Wilken (1974:441) and Chase and Chase (1983:2) attribute this mainly due to the lack of tangible evidence, such as architecture and engineering; Lohse and Findlay (2000:176) claim poor preservation due to environmental forces also as a contributing factor. As a consequence, this lack of tangible evidence in the archaeological record has forced researchers to find alternative ways of identification of these features at archaeological sites. As reported earlier, one archaeological approach to identifying kitchen gardens is through the existence of walled houselots (Lohse and Findlay 2000:178). Researchers have also investigated the paleoethnobotanical remains at archaeological sites, such as at Copán, Honduras (Lentz 1991:283). One of the most commonly used methods for the identification of possible kitchen gardens in recent archaeological work is the chemical testing of soils, particularly soil phosphates (Lohse and Findlay 2000:178). Finally, although the majority of this thesis is centered on ancient kitchen gardens, the study of contemporary Maya kitchen gardens can still yield useful information regarding ancient Maya kitchen gardens, and so this topic will be covered briefly.

Most researchers studying contemporary Maya kitchen gardens (e.g. Lohse and Findlay 2000; Wilken 1971; Gómez-Pompa 1987; Montagnini 2006) agree that the kitchen gardens of modern times can be traced back to Precolumbian times in the Maya region. The placement of modern Maya kitchen gardens directly adjacent to residential dwellings is thought to mirror the placement of ancient Maya kitchen gardens. Basic technologies and methodologies used in creating and caring for the gardens were similar (Caballero 1992:35-39). Although some practices and traditions might have been altered or lost after the Spanish Conquest, or even new

practices and traditions introduced by the Europeans during the Spanish Conquest, investigating contemporary Maya kitchen gardens helps give researchers a glimpse into how ancient Maya kitchen gardens might have looked. One of the main benefits of examining contemporary Maya kitchen gardens is the accumulation of knowledge relating to the kinds of flora that are being grown. The plants grown in kitchen gardens provide Maya families with food and herbs to diversify their diet, with medicines and construction materials (such as timber), and occasionally with additional income from selling surplus goods (Neulinger et al. 2013:106; Wilk 1991:108). Javier Caballero (1992:39) documented 83 species of flora in 60 gardens, Neulinger et al. (2013:105) identified 310 plant species from 20 kitchen gardens, and Montagnini (2006:73) claims species diversity in gardens can range from 96-745. These types of studies of contemporary kitchen gardens, combined with soil chemical analyses of ancient kitchen gardens, currently are the some of the best ways for researchers to ascertain what the ancient Maya were growing in their gardens.

As a comparison outside of the Maya region, research in the Amazon region of South America shows that humans have drastically altered the usually nutrient-poor soils in certain places, leaving behind rich, fertile areas of black soil known as Amazonian Dark Earth or *terra preta* (Glaser et al. 2004; Lehmann et al. 2004; Winklerprins 2009). Researchers know that these areas were altered by humans by the presence of ceramics and charcoal. The charcoal likely accumulated in the soils because of fires in hearths or slash and burn agriculture, whereas the ceramics were likely deposited as refuse (Glaser et al. 2004:12; Winklerprins 2009:205). What is more, analyses of the *terra preta* soils indicate higher levels of P, likely due to human or animal waste and bones (Glaser et al. 2004:14). Recent and current research attempt to draw

comparisons between kitchen gardens that exist in modern times and those that are believed to have existed in the past in order to determine when the soils were being altered, and, if possible, by which specific groups of people (Winklerprins 2009:205). Although the name for the soils may be different between the Amazonian and Maya regions, the overall characteristics of them are highly similar, meaning that researchers might be able to use the research from one area to aid in the studies of the other.

## 2.2. Chemical Testing and Archaeological Investigations

Many scientists (i.e. Cook et al. 2006; Holliday and Gartner 2007:301; Parnell et al. 2002a, 2002b; Wells et al. 2000; Wells and Terry 2007; Wilson et al. 2008) have acknowledged for some time that humans and their activities often alter the various properties of soils. As a result, archaeologists have used numerous criteria to detect these activities in archaeological soils, such as carbonates, color, and pH (Holliday and Gartner 2007:305-307; Manzanilla 1996:107). However, one of the most important criteria used to test archaeological soils since the early twentieth century is chemical analysis (Wells and Terry 2007:285). While early work in this field concentrated predominantly on the general identification of archaeological sites, the introduction of new ideas, technologies, and methodologies has allowed archaeologists to test soils for more complex forms of human activities, such as agriculture, rituals, and residences. Chemical testing is especially useful to archaeologists in areas where there is little to no architectural remains, artifacts, or written documentation because it can indicate sites of past human occupation (Cook et al. 2006:628).

The soils in and around archaeological sites are constantly being altered before, during, and after human occupation through a host of natural, chemical, anthropogenic, and post-depositional processes (Holliday and Gartner 2007:302; Wilson et al. 2008:412-413). These processes leave chemical and elemental traces in the form of manganese (Mn), calcium (Ca), phosphorus (P), zinc (Zn), strontium (Sr), nitrogen (N), and lead (Pb), among other elements (Holliday and Gartner 2007:302; Wilson et al. 2008:412). In order to identify and measure these traces in archaeological soils, researchers use multi-element analyses, such as X-ray fluorescence (XRF), inductively coupled plasma atomic emission spectrometry (ICP-AES), and inductively coupled plasma-mass spectrometry (ICP-MS). Multi-element analyses are popular for showing element concentration patterns that are representative of different use areas within an archaeological site (Wilson et al. 2008:413). For example, byres and middens are associated with high concentrations of P, suggesting the presence of dung, while hearths associated with high concentrations of many different elements suggest that many different fuel sources were used (Wilson et al. 2008:421). However, most of the publications dealing with chemical analyses in this project are focused primarily on P analysis.

Soil P analysis was first used by agriculturalists, possibly as early as 1911 in Egypt (Bethell and Máté 1989:1). However, the first systematic use of P testing in archaeological contexts was in Sweden in 1931 by Olof Arrhenius, who is the first scientist credited with the discovery of the relationship between human occupation and levels of P in soils (Arrhenius 1931; Bethell and Máté 1989; Eberl et al. 2012: 427; Eidt 1984; Holliday and Gartner 2007:305; Provan 1971:38; Terry et al. 2000:152; Wells et al. 2000:450; Woods 1975). Arrhenius published numerous reports (1931, 1934, 1935, 1938, 1950, 1955a, 1955b, 1963) on his work in Sweden

and Gotland, which laid the groundwork for future researchers. In the 1930s and 1940s, German archaeologist Walter Lorch (1940) continued Arrhenius' work by distinguishing types of settlements based on different P signatures (Holliday and Gartner 2007:305; Bethell and Máté 1989:2; Wells et al. 2000:450). Bagge (1937) used P analysis to investigate known Neolithic sites in Sweden, and Christensen (1935, 1940) used P analysis to detect archaeological sites near Copenhagen (Bethell and Máté 1989:11). Johnson and Nicol (1949) were the first to test for total P, using a method first developed by McLean in 1936.

In the second half of the twentieth century, Johnson (1956), Shipley and Romans (1962), and Conway (1983) investigated available P and total P, finding that total P was better than available P at reproducing the archaeological record. Lutz (1951) studied P, N, and Ca enrichment in soils in Alaska (Provan 1971:38). The use of elemental analysis to date archaeological sites was first used by Sokoloff and Carter (1952) in Georgia and Florida. Mattingly and Williams (1962) studied the fluctuations in the nutrient content of submerged soils in Wiltshire, England. Cook and Heizer (1965) provided a comprehensive (to date) overview of P analysis, including the proclamation that P analysis needs to be studied with other elements, the deposition of the environment, and the materials that are left at sites (Holliday and Gartner 2007:305). Also during this time, new techniques were being invented for faster and more reliable ways of analyzing soil P, such as: Feigl's (1958) simple spot test method, which made P analysis in the field almost instantaneous and more wide-ranging; Dick and Tabatabai's (1956) method for determining total P; and, Anderson and Hepburn's (1985) method for the determination of P fractions (Bethell and Máté 1989:12-13). As of 2007, there were more than

30 methods for soil analysis that could be applied to archaeological investigations (See Holliday and Gartner 2007:Table 3).

The 1970s, in particular, saw an uptick in the amount of publications on the various methods and applications of soil P analysis (Eidt 1973, 1977, 1984, 1985; Eidt and Woods 1974; Holliday and Gartner 2007:305; Woods 1975, 1977). Since then, there have been limited comparative studies regarding the laboratory methods of soil P analysis in archaeological research, leaving the subject packed with uncertainties and questions (Holliday and Gartner 2007:316). Ahler (1973) provides one of the earliest comparative studies, using the Bray-1 acid extraction method, followed closely by Eidt (1973), who used the ring or spot test. Proudfoot (1973:95) took a more geoarchaeological approach and investigated available P levels using a mixture of extractants. In 1980, Bakkevig produced a very useful overview of P analysis, noting that HCl works better at extracting P than citric acid. Kamprath and Watson (1980) tested the Bray-1, Mehlich-1, and Olsen P methodologies and concluded that they are largely comparable to one another. Olsen and Sommers (1982) discussed a bicarbonate extraction method, which was later studied in comparison with the Mehlich II dilute acid procedure by Terry et al. (2000). Skinner (1986) studied several types of P methods, including the ring test, Truog H<sub>2</sub>SO<sub>4</sub> extraction for available P, perchloric acid extraction for total P, and HCl extraction for inorganic P, and found that the perchloric acid method was the best at detecting anthrosols, which are soils that have been heavily altered by human activities.

Of particular interest to this thesis, Leonardi et al. (1999:352) investigated various extraction methods and forms of P in regards to agricultural uses, including organic P, total P, and P fractionation, finding that total P is the fastest and cheapest method. Macphail et al.

(2000:72) examined the earliest method of P extraction still in use today, which is established on 2% citric acid, and argued that it removes inorganic P. Lastly, Holliday and Gartner (2007:316-324) compared various extraction methods at 3 different archaeological sites and found that the same soil P sample can produce vastly different results based on the method used.

Soil P testing has a myriad of applications in archaeological investigations, such as being “an aid in locating a settlement, in determining the limits of a settlement, as a guide to the diet of a settlement, in determining the probable use of the various buildings on an abandoned farm site, and in differentiating between a grave mound and a mound produced by land clearance” (Provan 1971:37). Anthropogenic P accumulations in soils are a consequence of prolonged deposition of organic materials in sites of human occupation, such as human and animal waste, refuse (such as bone, meat, plants, and fish), burials, and deliberate soil enhancement (Holliday and Gartner 2007:301-302; Hutson et al. 2009:260; Parnell et al. 2002a:381; Terry et al. 2000:152; Wells et al. 2000:450). Sverre Bakkevig (1980:Table 1) lists some of these materials and their approximate natural phosphorus content: soil= 0.05-0.01%, human skeleton= 20%, human feces= 0.2%, cattle meat= 0.4%, cattle feces= 0.15%, and fish flesh= 0.3%. He continues to state that, according to a handbook for North American farmers, if a meadow has a demand of approximately 40 to 50 kgP per hectare and normal soil contains 0.05% phosphorus on the surface, then the meadow will only be sufficient for 40 crops of corn without the aid of fertilizers (1980:75). This seems to indicate that large-scale societies, such as the ancient Maya, had to incorporate fertilizers into their soils in order to provide enough food for their sizeable populations (see also A. Chase and D. Chase (2012). Proudfoot (1976:94) relates the equation that a group of 100 living humans would expel approximately 62 kg of phosphorus during the

course of one year, with a similar amount possibly added through refuse deposition, although he does concede that variability does exist within populations based on lifestyles and different phosphorus levels within their residues.

While humans leave many chemicals in the soil, P is largely considered to be the most omnipresent, sensitive, and persistent; therefore, it is often considered to be the best indicator of past human occupation (Holliday and Gartner 2007:301; Hutson et al. 2009:260; Parnell et al. 2002a:381, 2002b:332; Terry et al. 2000:151; Wells et al. 2000:450). Phosphate additions to soils in the form of organic products or inorganic compounds join with iron, calcium, or aluminum ions to become “relatively stable chemical compounds of inorganic phosphate minerals and organic phosphate esters” (Holliday and Gartner 2007:302). These accumulations of compounds can become significantly larger than the surrounding P in the natural soil, especially when humans are depositing them over a sustained period of time. Bethell and Máté (1989:9) give an excellent account of human interaction with P in soils:

“Human activities can strongly redistribute P in soils. Plants take up P from the soil. They can be eaten by animals or harvested. The animals themselves can be moved or ‘harvested’; they can be enfolded, concentrating P in a particular area. Dung residues can be collected and used as manures, respread over the fields; on the other hand they may be used as a fuel, as a walling material, or ignored...As part of the produce of an economic system, P is very mobile; its importance lies in the strong fixative powers of the soil. When P enters the soil system it is relatively immobile compared to other elements concentrated by the activities of humans.”



The durability of P in soils is largely due to its high resistance to leaching, oxidation, plant uptake, or reduction (Holliday and Gartner 2007:302). This persistence was tested during an eight year study during which water was percolated through soil and was then collected and analyzed to determine its nutrient contents (Provan 1971:40). The determination that the test did not show any substantial amounts of P in the drainage water, coupled with the fact that heightened amounts of P are present in archaeological soils hundreds or even thousands of years after first being deposited, is compelling evidence that P is comparably rigid in soils. However, the organic matter and pH of soils, the moisture and type of soils, and time itself can all affect how long P remains in archaeological soils (Holliday and Gartner 2007:305-306).

The complexity of soil P analysis, combined with the lack of a thorough understanding exhibited by previous researchers, has resulted in a vast assortment of terms regarding soil P (Holliday and Gartner 2007:303). For instance, P can be referred to by its chemical makeup, such as inorganic P, organic, P, and total P. While both inorganic and organic P compounds can remain in soils for an extensive period of time, inorganic P can be found “dissolved in soil solution, as a chemical precipitate, as orthophosphate ions...absorbed onto particle surfaces, or as orthophosphate ions occluded within particles” (Holliday and Gartner 2007:303), while organic P is usually absorbed when it becomes part of a plant, which will then become mineralized or integrated into microorganisms when the plant dies (Bethell and Máté 1989:8) . Total P, as the name suggests, refers to the total amount of P found within the soil sample, and is generally made up of 20-80% of organic P. However, when referring to the total P in soils, the term ‘phosphorus’ should be used instead of ‘phosphate,’ as some organic P compounds are not

phosphates, meaning ‘phosphate’ is a general term (Bethell and Máté 1989:5). Additionally, terms such as ‘active P’ (P molecules that are more vulnerable to dissolution and transformation) and ‘stable P’ (P molecules that are more sedentary) can increase a researcher’s inability to fully understand soil P, which can lead to inconsistencies and complications within data (Holliday and Gartner 2007:304-305).

Aside from various factors that can make P analysis difficult to use and understand, there are a number of issues that researchers must keep in mind when performing soil P analysis. For example, the result of the test is determined by the accuracy of the question asked beforehand and how the samples are analyzed (Bakkevig 1980:78; Holliday and Gartner 2007:327). Before the actual testing is done, researchers must decide what they will test for, such as the available P or the total P, as each has specific strengths and weaknesses (Holliday and Gartner 2007:313). The technique used to test soils is also a contributing factor in the accuracy of soil P analyses. While portable techniques such as the ring test (also known as the Gundlach method) were introduced to give archaeologists a quick field test in archaeological sites, they have often produced ambiguous results, which has often lead archaeologists to reject these testing methods (Bethell and Máté 1989:12; Eidt 1973, 1977, 1984:36-38; Gundlach 1961; Gurney 1985:2; Hammond 1983:55-61; Hassan 1981; Holliday and Gartner 2007:313; Keeley 1981; Sjöberg 1976:451).

Furthermore, the soil sample taken from the archaeological site must be comprehensive, meaning that it is representative not only from the specific test area but also from the surrounding land within the site in order to detect the natural content in the soil, which could be significantly different from one area to another (Bakkevig 1980:73-75; Holliday and Gartner

2007:327; Provan 1971:40). The land itself must also be taken into consideration, as the soil type and particular makeup can have drastic effects on test results. This can be seen on sand beaches with shifting sand, where the P content from humans is likely to have shifted significantly more than other areas over a period of time. Combined with other natural sources of P or soils with leached iron components and humus, the thick top layer of soil will hinder the percolation of water and therefore will make P distribute more horizontally than usual (Bakkevig 1980:78).

Another criterion that should be considered when performing soil P analyses in archaeological excavations is the effect of other cultural factors that might have been in play in that area (Holliday and Gartner 2007:308). Certain human activities increase levels of soil P, while others decrease the levels. At Piedras Negras, the highest concentrations of P in tests were associated with kitchen middens, while the lowest concentrations were associated with the acropolis. Rituals and ceremonies might have influenced which areas of the site were swept frequently to remove refuse, causing low P concentrations, as opposed to which areas were designated for feasts, which, according to Dahlin et al. (2010:194), is the “single most challenging alternative explanation for geochemical patterning in public, private (household), and parochial spaces,” causing high P concentrations. Several other researchers within the Maya area have also noted the low phosphorus accumulations associated with pathways heavy with foot traffic and areas that were swept frequently (i.e. Parnell et al. 2002a:386; Parnell et al. 2002b:336; Eberl et al. 2012; Wells et al. 2000). In fact, Parnell et al. (2002b:340) state that the “interpretative potential of ancient activity areas through the use of soil chemical analyses is limited only by our understanding of specific ancient activities,” meaning that soil chemical analyses can only help researchers verify what they already understand.

It is also necessary to review Michael Schiffer's (1987:7) formation processes, since these processes affect both the soils and artifacts of archaeological sites. Formation processes, both cultural (formation processes that alter or transform artifacts and sites after their initial use by human behavior) and noncultural (formation processes that alter or transform artifacts and sites by any incident of the natural environment) can affect every aspect of an archaeological site. Schiffer (1987:27-140) states that cultural formation processes can include an assortment of human behaviors, ranging from reuse of artifacts and soils, discard, ritual caches, abandonment, reclamation, and disturbance, among others. Noncultural formation processes on artifacts and soils can include decay, earthquakes and storms, and disturbances through growing plant roots, burrowing animals, and even gravity (Schiffer 1987:143-234). Therefore, since many of the case studies that will be detailed in the following section (see Table 1 for a summary of the studies) involve the use of comparisons between soil P analyses and the artifactual record found in and around the testing area, it should be cautioned that every aspect of the subsequent studies had been changed in some way prior to, and during, archaeological excavations.

Regardless of these criteria and issues, soil P analysis is becoming more important to archaeologists who wish to study the agriculture of past societies. This is especially true in the Maya area, as it was believed until the mid-to late-twentieth century that the soil of the Maya area was thin, ill-suited for plowing, and essentially incapable of supporting a vast population (Flores-Delgadillo 2011:113). As previously stated, while some agricultural technologies leave architectural, artifactual, or topographical traces (i.e. terraces and raised fields) that can be identified through traditional archaeological methods, others, such as kitchen gardens and other

small-scale agricultural technologies, do not. However, gardening leaves chemical traces, specifically P, which can be measured using soil P testing (Dunning et al. 1997:260).

When growing (in kitchen gardens and in general), plants acquire their necessary phosphate from the soil, where it is found naturally, remaining at a comparably constant value unless it is disturbed by natural or cultural processes (Parnell et al. 2002b:332). When plants are harvested from gardens or transplanted to different garden areas, the phosphates from the soil are transferred with them. These plants are then turned into food waste as discard or, alternatively, are eaten and expelled in the form of human or animal waste. These remains then decay in the environment, leaving the phosphates on the soil surface, presumably in a localized area such as a midden or as a fertilizer spread over a garden area. Over time, the agricultural area where the plant was grown will show a decreased P concentration as the P is taken away, while the areas associated with the plant's preparation (kitchens), consumption (eating areas), or final resting place (midden, outhouse, or fertilized soil) will show an increased P concentration as P is gradually deposited.

Some researchers (e.g. Johnston 2003; Smyth et al. 1995; Hutson et al. 2009; Dunning et al. 1997) argue that the ancient Maya used fertilizers and soil enhancement techniques to improve and extend the life of their garden soils. For example, mulching can help provide more nutrients for crop growth by freeing nutrients in the soil that would usually be taken up by weeds and other intrusive plants (Johnston 2003:133). Mulch can come in many forms, such as leaves, unused materials from crops, green manures, compost, and weeds (Johnston 2003:135). Mulching of weeds is especially important because weeds monopolize nutrients found in the soil, meaning that the removal of these weeds and the redistribution of them in the form of mulch

reintroduces vital nutrients, such as P, back into the soil for crops (Johnston 2003:146). Evidence suggests that mulched weeds can provide agricultural areas with more nutrients than were originally lost through crop removal (Johnston 2003:147).

Other fertilizers used by the ancient Maya include green manures (plants grown for the specific purpose to be harvested and deposited back on to the ground as mulch) and non-plant substances from other locations (Johnston 2003:148). These substances can be fresh or dried and can include human excrement, bat guano, fish remains, and household ash. Due to the time and labor expenses of mulching and other fertilizers (Johnston 2003:151), it can be assumed that larger outfield agricultural areas, such as milpas, were not regularly or widely enhanced, whereas infield agricultural areas, such as kitchen gardens and probably terraces, received frequent soil enhancements, an assumption buttressed by soil P analyses (e.g. Parnell 2002; Flores-Delgadillo et al. 2011; Dunning et al. 1997).

### 2.2.1 Soil Phosphate Analysis in the Maya Region

The use of soil P analysis within the field of Maya archaeology is a relatively recent development, only taking hold in the late twentieth century. Studies involving soil analyses in the Maya area began in the late 1980s with Tourtellot (1988) in Sayil, Yucatan, Mexico, where the author mapped community patterns using various methods. The soil samples collected in this study were not chemically tested, but were examined for their general makeup; it was found that there were 7 different soil types present at Sayil, although no definitive correlations could be made regarding the soils and specific settlement features (Smyth et al. 1995:324; Tourtellot 1988:14). However, actual soil P testing was performed at Sayil in 1987, using the ring test

method, and the combined evidence of a complete absence of artifactual materials, elevated P levels in the soil, and a P fractionation test identified a possible 40 sq m garden area, labeled the “Miguel T garden” (Dunning 1989, 1992; Killion et al. 1989; Smyth et al. 1995:326). The elevated P signature was indicative of long-term fertilizer use in this area, and was similar to an elevated P signature found at Sayil in 1989 from a possible agricultural terrace (Smyth et al. 1995:326-327). Soils tested in the extra-urban region of Sayil showed notably low P levels, indicating their use as long-term cultivated fields without the aid of fertilizers.

At Piedras Negras, Guatemala, Wells and colleagues (2000) investigated the chemical signatures of soils in residential areas, using the Mehlich II dilute acid extraction method. The team primarily tested the soils of middens (determined by the presence of high sherd concentrations, including serving plates and storage jars, high P levels, indicating food waste was being deposited, and occasional obsidian and chert debris), attributing high P levels in certain middens with food waste disposal and low P levels in other middens with an absence of food waste, and asserting that “chemical analysis of midden materials may prove very useful in identifying the types of debris that accumulated at ancient activity areas” (Wells et al. 2000:456). Additionally, it was suggested that the absence of phosphates in and around structures could be indicative of ritual use, possibly as a result of habitual sweeping (even though food remains would have left increased P levels from the point of deposition to the point of removal by sweeping), a proposition that is repeated by several other researchers (Eberl et al. 2012:433; Hutson et al. 2007:457; Parnell et al. 2002a:384; Parnell et al. 2002b:336). During this study, the soils were tested for kitchen gardens and elevated P levels were found, but the authors caution

that the spaces between the residential mounds in which these signatures were found are very small (Wells et al. 2000:459).

Terry and colleagues (2000:151) developed a methodology based on the Mehlich II method to test accurate acid-extractable P concentrations. They used this new methodology at Piedras Negras, Guatemala in the hope of finding cultural features and spatial patterns in agricultural landscapes. The authors compared this method to the Olsen bicarbonate method and the ring test. It was found that the Mehlich extraction method was superior, due to its enhanced sensitivity to lower P levels, its lowered susceptibility to residual P in water, and its usefulness on both acid and alkaline soils (Terry et al. 2000:162).

A third study at Piedras Negras, by Parnell et al. (2002a:379-380), used soil chemical analyses to test for various human activities in conjunction with high artifact concentrations. The authors compared Mehlich extractable P with total P and total nitric-perchloric digestion with the DTPA extraction method to determine which methods were superior. The patterns of P concentrations found during this study are similar to those of previous ones, in that areas surrounding buildings generally had lower P concentrations, which possibly indicates where rain water dripped off roofs and washed away P in soils, while areas immediately surrounding structures often had higher P concentrations (Parnell et al. 2002a:386-387). This is most likely where trash and other debris was swept out of buildings before being transported to a refuse dump. The study found strong parallels between high P levels and high artifact concentrations, and asserts that chemical analyses can aid archaeologists in determining diminutive variations between cultural features, such as kitchen gardens and middens (Parnell et al. 2002a:398-400).



At Nacimiento, in the Petexbatun region of Guatemala, Eberl et al. (2012:426) looked at the chemical signatures of middens, and compared the results to ceramic sherd densities to draw conclusions. The Mehlich II extraction method was used to evaluate the soil P samples, and it was found that areas such as patios, which were likely heavy with foot traffic and were often swept, had lower P levels, while structural areas associated with food storage, preparation, and disposal had higher P levels (Eberl et al. 2012:433). What is more, this study differs from Parnell and colleague's (2002a) study, in that the sherd densities did not correlate significantly with P levels, although Eberl and colleagues suggest that ancient construction activities could have influenced this phenomenon (2012:436). The authors (Eberl et al. 2012:436) conclude by stating that P levels "fail to provide a complete picture of midden distribution and diversity", and assert that a complete understanding of local contexts and human activities is required in order to fully utilize soil chemical testing.

Dunning et al. (1997:255) used soil chemical analyses to test the agricultural soils of three sites in the Petexbatun region of Guatemala: Dos Pilas, Tamarindito, and Aguateca. Soil P mapping and P fractionation were used to test seasonal wetland sites, but the resultant data was ambiguous (Dunning et al. 1997:259). Therefore, while the authors believed the ancient Maya used cultivation techniques in the seasonal wetland areas of the sites, the precise nature and magnitude of these techniques remained elusive. However, in the upland areas of the sites, particularly at Quim Chi Hilan, soil chemical tests showed an increased amount of soil P in areas identified as kitchen gardens (Dunning et al. 1997:261). In contrast, soil P testing at Dos Pilas showed no evidence of agricultural activities, giving rise to three different hypotheses: 1) gardens were present in Dos Pilas, but were overlooked in the chemical surveys performed at the

site; 2) gardens were not present at Dos Pilas, meaning that the city's inhabitants were solely dependent on crops grown elsewhere or through other means; or, 3) the P levels are significantly lower than those of the surrounding area because Dos Pilas was inhabited for a shorter amount of time (Dunning et al. 1997:263).

Also in Guatemala, Terry et al. (2004) researched both ancient and modern human activities in regards to households at Aguateca. Soil P samples were tested using the Mehlich II extraction method (Terry et al. 2004:1242). The ethnoarchaeological and soil P analyses of the modern guardhouse showed elevated P levels in the kitchen and the kitchen's disposal area. These elevated levels extended eastward of the building, owing to a slanted board in the east window used for food soaking and cleaning and dishwashing. Phosphates present in food and other organic products would have been washed with wastewater down the hillside, elevating P levels in that particular area. It is worth noting that the north and west walkways and bunkhouse floors contained low amounts of P, similar to Eberl et al. (2012), Parnell et al. (2002a), and Wells et al. (2000). The archaeological data from the ancient site correlates well with these findings.

Dahlin et al. (2007) compared the soil P levels of an ancient market at Chunchucmil, Mexico to the soil P levels of a modern marketplace at Antigua, Guatemala. Soil P levels were measured using the dilute acid and Mehlich II extraction methods (Dahlin et al. 2007:371-372). By comparing the resultant data from Chunchucmil and Antigua, the authors claimed that Chunchucmil did have a marketplace, based on architectural remains associated with a higher concentration of soil P (Dahlin et al. 2007:380). A subsequent study by Dahlin et al. (2010) at these same two sites tested for food exchanges on plaza surfaces through soil chemical analyses. The Mehlich II extraction method was used for this study as well and the soil P results are

largely congruent with Dahlin et al. (2007). Dahlin et al. (2010:221-222) conclude by stating that the soil P signatures of marketplaces are different enough from soil P signatures of feasting (defined by Dahlin et al. [2010:199] as the exchange “of food in ceremonial activities”) areas to conclude that marketing was taking place in some areas of the Maya region.

In Mexico, Hutson et al. (2007:444) compared various field methods, including soil analysis, paleoethnobotany, and traditional archaeological excavation and sampling to investigate formation processes of houselots at Chunchucmil. After the study concluded, it was revealed that the surface collection and archaeological excavation methods produced similar results in regards to sherd distribution, but also showed discrepancies in the same area, in that subsurface excavations revealed more than surface collecting did (Hutson et al. 2007:450). Soil chemistry and phytolith analyses presented strong evidence that Chunchucmil had kitchen gardens, similar to other ancient Maya sites, such as Cerén (McKee 1999), Chan Nòohol (Robin 1999), Cobá (Manzanilla 1987), Guerra (Ball and Kelsay 1992), and Sayil (Killion et al. 1989; Smyth et al. 1995) (Hutson et al. 2007:467). The culmination of this study substantiates the assertion that traditional archaeological excavations and surface collections should be supplemented with various laboratory methods, such as P analysis and other chemical analyses (Hutson et al. 2007:468).

Another study at Chunchucmil (Hutson et al. 2009:260) used P fractionation to test garden areas to determine if the ancient Maya or the site’s modern inhabitants were responsible for the activities. Although the authors indicated that P fractionation has several drawbacks in archaeological use and must be used cautiously, they paired it with other lines of evidence, such as paleoethnobotany, archaeology, and geochemistry to produce their results. Employing the

Mehlich II extraction method, Hutson and colleagues used the ratio of fraction 2 (P that is more firmly fixed with weakly crystalline iron and aluminum minerals) and fraction 1 (P that is loosely fixed with iron and aluminum) to relatively date the soils of Chunchucmil in support of their hypothesis that higher P levels were a consequence of ancient activities, as opposed to modern ones (2009:264-266). While the resultant fractionation ratios are not easily compared to those of other ancient Maya sites due to specific local conditions, it was tentatively shown that the high P levels at Chunchucmil were a result of ancient, not modern P enhancement of garden soils (Hutson et al. 2009:266). However, the authors do admit several limitations of P fractionation, including its inadequacy in determining the differences between anthropogenic and non-anthropogenic contexts, and the lack of academic research on its overall capability in establishing chronologies and discerning activities in archaeological soils (Hutson et al. 2009:267-278).

Near the Mopan River in Belize, Ball and Kelsay (1992:234-235) combined archaeological excavations, artifact analyses, soil P analysis, and conventional map and test pit data to investigate possible land-use patterns at two ancient Maya sites: Buenavista del Cayo and Guerra. Using the ring chromatography method (Eidt 1973, 1977, 1984), Ball and Kelsay argue that Guerra did contain kitchen gardens at one time, but were unsuccessful at finding any evidence for the existence of kitchen gardens at Buenavista del Cayo (1992:257-258). While the authors concede that simpler investigative means, such as the inspection of settlement maps and surface collections can produce similar conclusions, they maintain that the soil P analyses used in this study can only confirm and therefore advance future examinations of settlement and agricultural processes in the Maya region.

Also in Belize, Coultas et al. (1984) used soil chemical analyses to investigate ancient Maya agricultural soils at Caracol, including terraces and bajos. The Mehlich III extraction method was used to test soils found in and around ancient terraces, bajos, and non-terraced soils found around the site (Coultas et al. 1984:22). It was found that the total P and extractable P levels in terraced soils were highest near the surface, and non-terraced soils are highly comparable in regards to their P levels and distribution (Coultas et al. 1984:23-24). Also, the terraced soils were high in several key nutrients needed for growing crops, and were probably enhanced with composts, meaning that they were likely very productive to the ancient Maya (Coultas et al. 1984:26-28).

Parnell et al. (2002b) provide one of the few publications on soil P analysis in El Salvador. Here, soil samples were collected from areas of known human agricultural activity at Cerén and were tested using the Mehlich II extraction method (Parnell et al. 2002b:334-335). Analogous to many of the studies described above, the highest concentrations of P were found in middens, while the lowest were found in pathways and the milpa (Parnell et al. 2002b:336). The authors of this study also assert that P levels in soils often compare well with ethnoarchaeological data, making soil P analysis a valuable proxy for determining archaeological sites and activity areas when other evidence might be lacking (Parnell et al. 2002b:336-340).

Finally, current work in the Maya region using P analysis is largely focused on the identification of ancient marketplaces. Chase et al. (2015) present their findings from soil chemical tests on two termini plazas at Caracol, Belize, the Ramonal Plaza and the Conchita Plaza. Soil P analyses, using the Mehlich extraction method, revealed that the Ramonal Plaza exhibited no significantly elevated P signatures, while the area surrounding the Ramonal Plaza

did show slightly higher P concentrations. This leads the authors to posit that foodstuffs were not located or traded in this area. In contrast, the Conchita Plaza did exhibit a strong pattern of extractable P in its western area, suggesting that foodstuffs were present or being traded here. Chase and colleagues also acknowledge that, since each market plaza at Caracol is in a different location and likely contained different activities and items, the chemical signatures are liable to change from plaza to plaza. Other sites, such as Chunchucmil (Dahlin et al. 2007), Mayapán (Bair 2010), Ceibal (Bair 2010), Trinidad de Nosotros (Dahlin et al. 2010), and Cobá (Coronel 2011) also show strong soil chemical evidence for the existence of marketplaces. While these researchers accept the validity of soil P analysis, there remain uncertainties on its reliability in detecting specific agricultural features.

Table 1 Summary of Case Studies

<b>Authors</b>	<b>Study Site</b>	<b>Testing Method Used</b>	<b>Compared with Artifacts?</b>	<b>Matched Artifactual Data?</b>	<b>Confirmed Hypothesis or Positive Conclusion?</b>
<b>Wells et al. 2002</b>	Piedras Negras, Guatemala	Mehlich II	Yes	Yes	Yes
<b>Terry et al. 2000</b>	Piedras Negras, Guatemala	Mehlich II	Yes	Yes	Yes
<b>Parnell et al. 2002a</b>	Piedras Negras, Guatemala	Mehlich/ Total P	Yes	Yes	Yes
<b>Eberl et al. 2012</b>	Nacimiento, Guatemala	Mehlich II	Yes	Partially	No
<b>Dunning et al. 1997</b>	Dos Pilas, Guatemala	P Fractionation	No	N/A	Partially
<b>Terry et al. 2004</b>	Aguateca, Guatemala	Mehlich II	Yes	Yes	Yes
<b>Dahlin et al. 2007</b>	Chunchucmil, Guatemala	Mehlich II	Yes	Yes	Yes
<b>Dahlin et al. 2010</b>	Chunchucmil, Guatemala	Mehlich II	Yes	Partially	Yes
<b>Hutson et al. 2007</b>	Chunchucmil, Guatemala	Unknown	Yes	Partially	Yes
<b>Hutson et al. 2009</b>	Chunchucmil, Guatemala	Mehlich II/ P Fractionation	Yes	Yes	Partially
<b>Ball &amp; Kelsay 1992</b>	Mopan River, Belize	Ring Chromatography	Yes	Partially	Partially
<b>Coultas et al. 1984</b>	Caracol, Belize	Perchloric Acid Digestion	No	N/A	Yes
<b>Parnell et al. 2002b</b>	Ceren, El Salvador	Mehlich II	Yes	Yes	Yes
<b>Chase et al. 2016</b>	Caracol, Belize	Mehlich	Yes	Yes	Yes

### 2.3 Problem Statement

The literature review presented above indicates two major issues with using soil P analysis to detect and define specific ancient agricultural areas, such as kitchen gardens. First, soil P analyses are not detailed enough to positively locate kitchen garden areas within the broader agricultural landscape often present at ancient Maya sites without the aid of artifactual evidence. The literature from Chapter 2 has shown that, with corroborating archaeological evidence, soil P analysis is capable of locating areas of human activity and aiding archaeologists in the interpretation of these areas. However, since kitchen gardens spaces are largely vacant of artifactual remains, the same procedures cannot be used in their identification and interpretation.

Second, soil P analysis results often provide inconclusive or erroneous data. Many of the researchers referenced in previous sections (Bakkevig 1980:73; Bethell and Máté 1989:19; Eberl et al. 2012:432; Dunning et al. 1997:259; Holliday and Gartner 2007:316; Hutson et al. 2009:268; Keeley 1981:90-93; Provan 1971:48) reported that their soil P analysis data did not match their hypotheses or the artifactual data, if applicable. While the methods and procedures have evolved since its first use in the early 1900s, there are too many factors that could influence the P signatures found in ancient soils, such as accidental and intentional P additions to the soil by humans (i.e., fertilizers, mulching, ritualistic activities), soil erosion and P movement through the soil, and modern contamination. The limitations of the major extraction methods and testing procedures will be discussed further in Chapter 3. All of the data presented here comes from second-hand accounts of soil P studies, as there are no actual soil P analyses being performed for this thesis.



## CHAPTER 3: DATA INTERPRETATION AND DISCUSSION

### 3.1 Introduction

The use of soil chemical analyses is becoming more and more common in current archaeological work. The breadth of this research is extensive in regards to the identification of past human activities, especially land areas altered by humans for agricultural purposes. As such, a complete investigation of the history, use, methodology, and results of soil chemical analysis, and soil Phosphate analysis in particular, is required in order to ascertain its true viability in archaeological research. This is the approach this thesis has taken. I have sought to fully understand soil P analysis and its use in archaeological investigations in the ancient Maya area of Mesoamerica through the examination of previous and current archaeological research using this analysis method. The preceding chapter provided the essential background information on both ancient Maya kitchen gardens and the history of soil P analysis, as well as the previous and current research using soil P analysis. The comprehensive investigation of soil Phosphate analysis has allowed for new interpretations regarding its specific use in the identification of ancient Maya kitchen gardens. This chapter will begin with an examination of soil P analysis and its usefulness in regards to artifactual remains, and will end with an examination of the limitations of some of the extraction and testing methods of soil P analysis.

#### 3.1.1 Examination of Soil P Analysis in Regards to Artifacts

Based on the studies presented in Chapter 2, it can be stated that soil P analysis is effective in distinguishing general areas of human occupation and activity. Archaeological

research concerning human occupation and activity areas as a whole has indeed benefited greatly by this procedure. However, although many archaeologists now use soil P analyses in their research, there are still some who have expressed their concerns over the lack of tests validating soil P analysis and its methods and its applicability to the field of archaeology (e.g. Bakkevig 1980:73; Bjelajac et al. 1996; Holliday and Gartner 2007:316; Hutson et al. 2009:268). Since the main corpus of soil P analysis testing in archaeological research in this thesis is predicated on the existence of artifactual evidence to lead scholars to a particular area or to help clarify or substantiate the results of soil P testing, this is especially problematic in studies where the artifactual evidence is lacking or missing completely from an area in question.

Within the ancient Maya area, general activity areas such as kitchens, middens, workshops, marketplaces, ritual spaces, and walkways have been positively correlated to elevated levels of soil P (Bair 2010; Ball and Kelsay 1992; Chase and Chase 2015; Coronel 2011; Dahlin et al. 2007; Dahlin et al. 2010; Dunning et al. 1997; Eberl et al. 2012; Hutson et al. 2007; Hutson et al. 2009; Parnell et al. 2002a, 2002b; Terry et al. 2004; Wells et al. 2000). Artifactual evidence in the archaeological record often positively corresponds with elevated or lowered P levels in the soil to inform archaeologists about what an area was used for. For example, P levels rising in the direction of refuse or a trash pile indicates that debris was swept from an area or room (perhaps a kitchen or ritual space) to that midden or trash pile (Eberl et al. 2012:433; Hutson et al. 2007:457; Parnell et al. 2002a:384; Parnell et al. 2002b:336; Wells et al. 2000:456). However, in areas where the archaeological record is largely void of artifacts, architecture, or both, such as kitchen gardens, there is nothing to corroborate the data provided by soil P analyses.

It has long been assumed that the ancient Maya kept small, intensive gardens in close proximity to their residences, as is seen in contemporary Maya towns and as is evidenced by walled house-lots in the archaeological record. However, the data presented in Chapter 2 does not show that soil P analysis is detailed enough to positively conclude that the P signatures found in the soils surrounding ancient Maya dwellings were kitchen gardens. Soil P analyses often indicate higher P levels in these areas, but largely just confirms that these were sites of human occupation and activity. To emphasize, Holliday and Gartner (2007:326) maintain that soil P analysis often “tended to support conclusions already drawn, has been used for a kind of fishing expedition [...], and has rarely been used to find unseen and unknown sites.” The signatures assessed by soil P analyses have not been shown to detect the specific identities of the non-staple food crops that were frequently grown in kitchen gardens.

Of the 14 case studies reviewed in Chapter 2.2.1, 12 used artifactual evidence (Ball and Kelsay 1992:234-259; Chase et al. 2015; Dahlin et al. 2007:380; Eberl et al. 2012:433; Hutson et al. 2007:457-464; Parnell et al. 2002a:386; Parnell et al. 2002b:335; Terry et al. 2000:158; Terry et al. 2004:1237-1243; Wells et al. 2000:455-458) and 3 used architectural evidence (A. Chase and D. Chase 2015; Coultas et al. 1984:22; Dunning et al. 1997:259-261) to help draw conclusions of what an area might have been used for. As an example, ceramic assemblages, grinding stones, and benches coincide with high P levels to indicate places where food was processed, consumed, stored, or disposed, while these same artifacts found with low P levels often indicated areas where food was not present, such as reception areas or sleeping quarters. This being said, the absence of artifacts were also used as indicators. As mentioned in Chapter 2, the most prevalent assumption concerning the absence of artifacts and the presence of low P

levels in and around architectural spaces is that the area was frequently swept or was used for rituals.

However, a few studies (i.e. Hutson et al. 2007:464; Smyth et al. 1995:326) suggest that kitchen gardens were implemented in areas where there is an absence of artifacts, based on elevated P signatures in the soil. This is predominantly due to the assumption that the area was chemically enhanced with fertilizers, which leave no artifactual remains. But, do an increase in the P levels in the soil actually improve the productivity of the kitchen garden? One question that should be asked: does the lack of artifacts coupled with the presence of elevated P levels *only* indicate the use of fertilizers for garden enhancement?

Some researchers (i.e. Becker 2001:440; Chase and Chase 1983:8; Hutson et al. 2007:464) have alluded to the possibility that the house-lot areas assumed to be kitchen garden could have been used as animal pens, market stalls, beehive stands, or other domestically related alternatives. Of these possibilities, it is expected that most would leave tangible evidence in the archaeological record, such as specialized vessels (Chase and Chase 1983:9). However, animal pens would not have left many artifactual remains, possibly aside from the low rock walls delineating the house-lot area. Furthermore, it is likely that soil P levels would be elevated in this scenario due to the continued presence of animal dung and foodstuffs used as animal feed. Marshall Becker (2001:440) mentions that the ancient Maya might have kept bees and turkeys in their house-lots. While these creatures require enclosures more secure than the low rock walls of house lots, such enclosures were likely made out of organic materials (i.e. timbers, branches, and vines) and would, therefore, leave few discernable traces in the archaeological record.

Ultimately, the lack of artifactual evidence combined with heightened levels of soil P in plots of land adjacent to ancient Maya dwellings could indicate other possible scenarios. One such scenario could be that wastewater from the dwelling with high levels of P was travelling through that particular area (see Terry et al. 2004). Another possible scenario could be that food was being processed or consumed in ways that left little to no artifactual evidence, leaving rotting food on the ground, which would heighten the P amounts in the soil. Possible examples of this scenario include spontaneous food or drink consumption (see Eberl et al. 2012:433), areas where slaughtered animals were hung to bleed-out before processing, maize shucking, etc. (see Hutson et al. 2007:467). These situations could have altered the natural levels of P in the soil without leaving artifactual evidence that would lead archaeologists to these interpretations. While it is true that ethnohistorical accounts and comparative studies of contemporary Maya practices indicate that kitchen gardening was the primary activity being performed in these spaces, in the end the current methods for extracting and testing soil P levels are not detailed enough to positively identify ancient kitchen gardens without sufficient, corroborating artifactual evidence.

### 3.1.2 Examination of Soil P Extraction Procedures and Testing Methods

The case studies from Chapter 2.2.1 were presented in order to detail the kind of research being undertaken in the Maya area using soil P analyses and the findings that have been generated. In general, researchers discussed are in favor of soil P analysis, but many acknowledge various drawbacks or deficiencies with some aspect of the method (Bakkevig 1980:73; Bethell and Máté 1989:1-19; Eberl et al. 2012:432; Dunning et al. 1997:259; Holliday

and Gartner 2007:316; Hutson et al. 2009:268; Provan 1971:48). In fact, the actual methods of testing the P levels in soils are often lacking in precision and overall consistency. Although there is no inclusive review of all the soil P methods used in archaeology (Holliday and Gartner 2007:309), many of them have been evaluated individually, and most of them were found to have at least one drawback or limitation that could inhibit ideal results.

For instance, the spot or ring test was often found to produce inconsistent results. This test, initially used by Gundlach (1961), uses ascorbic acid when breaking down the chemicals (Deotare 1983:40). This test has long been one of the fastest qualitative methods and, as a result, is often used directly on archaeological sites for a quick approximation of P levels. Out of the 20 studies that used the spot test method in Great Britain and Peru, only ten were actually successful, four gave partial information, and six provided no significant relationships between P signatures and human activities and were deemed failures (Holliday and Gartner 2007:313; Keeley 1981:90-93). While some researchers have acknowledged this problem and found ways of modifying the spot test method to their advantage (Bjelajac et al. 1996; Lippi 1930; Terry et al. 2000), the spot test largely produces results that are qualitative and difficult to reproduce by other researchers (Holliday and Gartner 2007:313; Sánchez et al. 1996:152).

Other examples are the Mehlich-II extraction method and Edit's method of P fractionation. The Mehlich-II extraction method was used in several of the case studies presented in this thesis (i.e. Dahlin et al. 2007; Eberl et al. 2012; Parnell et al. 2002a; Terry et al. 2000), but has yielded some concerning results. It cannot be used to evaluate total P concentrations (Terry et al. 2000:158); also, tests have shown that it does not correlate well with artifact distributions (Eberl et al. 2012:432). What is more, Edit's method is probably the best-known fractionation

technique, but is also one of the most controversial in archaeology (Holliday and Gartner 2007:314-315). Eidt's (Holliday and Gartner 2007:314) method involves the extraction of "solution P, P resorped by CaCO<sub>3</sub>, and loosely bound Al and Fe phosphates" (Fraction I), "tightly bound or occluded forms of Al and Fe oxides and hydrous oxides" (Fraction II), and "occluded Ca phosphates" (Fraction III). However, while these forms of inorganic P are extracted, Eidt's fractionation method is not known to extract all inorganic P. Additionally, it is known to be costly, time and labor consuming, and often has perplexing results (Holliday and Gartner 2007:315; Sánchez et al. 1996:152). While the theory behind Edit's method appears to be firm, additional research is needed in several areas before this method is fully reliable.

The literature presented in Chapter 2 does indicate that the extraction and testing methods mentioned above can detect areas of activity based on significantly high or low soil P values. Phosphorus is present in the soil by a host of natural and unnatural processes (Cook et al. 2006; Holliday and Gartner 2007; Parnell et al. 2002a; Parnell et al. 2002b; Wells et al. 2000; Wells and Terry 2007; Wilson et al. 2008). This makes it differentially dispersed in soils and is, therefore, a superior indicator of human activity and occupation because it can help archaeologists determine why a particular area has a higher or lower P level than surrounding areas. However, the P values indicative of these areas are not detailed enough to determine if specialized plants were being grown in a kitchen garden or if the area was merely used as a sort of catch-all for general domestic activities, such as food preparation and consumption, animal domestication, or run-off of household wastewater.

Lastly, of the 14 case studies reviewed in this thesis, 10 of them are either authored or coauthored by Richard Terry, a prominent Maya scholar whose research is largely centered on

the use of soil P analyses in archaeological investigations. What is more, a further comparison of the case studies shows that, of the 10 studies that Terry was a part of (Wells et al. 2002; Terry et al. 2000; Parnell et al. 2002a, 2002b; Eberl et al. 2012; Terry et al. 2004; Dahlin et al. 2007; Dahlin et al. 2010; Hutson et al. 2007; Hutson et al. 2009), eight were able to confirm the research hypothesis (Wells et al. 2002; Terry et al. 2000; Parnell et al. 2002a, 2002b; Terry et al. 2004; Dahlin et al. 2007; Dahlin et al. 2010; Hutson et al. 2007). The other two studies either were not able to confirm at all (Eberl et al. 2012) or were only able to partially confirm the hypothesis (Hutson et al. 2009). In fact, almost all of the soil P analysis results in previous ancient Maya archaeological studies were influenced by Terry. Of the four case studies that were *not* influenced by Terry, three produced a partial confirmation of the hypothesis (Dunning et al. 1997; Ball and Kelsay 1992; Chase and Chase 2015), while only one proved the hypothesis correct (Coultas et al. 1984). The inconsistencies in the results of these 14 case studies could indicate that there is a bias in soil P analysis results according to who the researcher doing the actual testing is and what that person's specific methods and procedures are. This seems to reinforce the assertion that soil P analysis results are unsuitable to give results that can be reproduced time after time, no matter what researcher is performing the test.



## CHAPTER 4: CONCLUSIONS

The use of soil P analysis in archaeology has been steadily increasing over the past 40 years. While it certainly has value in the detection of past human activities, it is by no means comprehensive and applicable to every archaeological research topic. This thesis investigated the viability of soil phosphate analysis in one particular archaeological area: its use in the detection and identification of ancient Maya kitchen gardens. This topic has been relatively under-reported in the realm of Maya Studies, but is slowly growing in popularity as more research is being done on ancient Maya households and subsistence practices.

To complete this investigation, past and present literature on the topics of ancient Maya kitchen gardens and soil P analyses was reviewed. In order to draw necessary comparisons and to have the appropriate contexts, it was also necessary to review the history of kitchen gardens across various cultures, contemporary Maya kitchen gardens, and other methods of soil chemical analyses. Special emphases were placed on literature reviews of the methods and procedures of soil P analyses, as well as on studies using soil P analyses to identify agricultural features in the Maya region. After the literature was presented, I then summarized and analyzed the data in relation to my research questions.

After reviewing and interpreting the data presented, I find that soil P analysis is not a viable method for identifying ancient Maya kitchen gardens by itself because it is not able to detect the specific, non-staple food crop identities that are grown in kitchen gardens and that largely define these agricultural spaces, nor is it able to delineate the boundaries between kitchen gardens and the vacant terrain that often surrounds them within the walled houselots. Therefore, I also find that soil P analysis is unable to accurately indicate whether areas thought to be kitchen

gardens were actually used for other purposes, such as animal pens, market stalls, or beehives. Soil P analysis is often highly confusing and the outcome frequently varies according to many factors, such as geographic area, research question, control sample, extraction method, and the researcher performing the test (as detailed in Section 2.2). Furthermore, many of the case studies found above (in Section 2.2.1) indicate limitations and irregularities of soil P analysis for detection of agricultural activity in Chapter 3.

In light of the data this thesis has presented, future studies on the detection of ancient Maya kitchen gardens should incorporate multiple lines of evidence in order to make a conclusive identification. Soil P analyses should be paired with archaeological evidence (if available), paleoethnobotanical tests, or multi-element analyses. Moreover, more comparative studies using soil P analyses could be conducted between known ancient Maya kitchen gardens (i.e. Cerén and Mayapán) and contemporary Maya kitchen gardens to determine any possible proxies and similarities. Finally, any further advancements made to soil P analyses in the future will possibly erase the discrepancies discussed previously.

Finally, there is one obvious limitation that must be mentioned. Since this thesis is purely qualitative in nature and deals only with the research of others, there was no experiment performed to test my hypotheses first-hand. Should a study of this caliber been executed, it would have likely produced stronger results and reinforced these conclusions in other ways. In addition, while I would have liked to provide more in-depth analyses of each of the soil P extraction methods, space restrictions prohibited this indulgence. However, the reexamination of soil P analysis and its use in the archaeological detection of ancient Maya kitchen gardens should encourage other researchers to improve soil P testing and, if possible, find new ways of

investigating the specifics of ancient human activities in the soil. It is hoped that this will lead to the identification of new kitchen gardens at ancient Maya sites, which will certainly provide additional information on copious facets of ancient Maya life.

Sverre Bakkevig testifies that it is “difficult to reveal all the hidden information about agricultural activity. The whole history can not be forced out of a single soil sample from a certain depth [...]” (1980:77) and therefore “the use of P-values should in archaeology be indicative, not absolute” (1980:80). This is concurrent with most of the data presented above; soil P analysis is wholly sufficient to aid archaeologists in the identification of human activity sites when used in conjunction with other examination methods or to merely indicate where sites might be. In conclusion, each study discussed in this thesis attests to the applicability of soil P analysis for the archaeological identification of middens, ritual spaces, kitchens, eating areas, agricultural fields, etc. Soil P analyses can interpret the general levels of phosphorus in the soil and aid researchers in making inferences about an area’s use, but only when combined with other lines of evidence. Thus, the specific characteristics of kitchen gardens are too elusive and imperceptible to be positively identified by the inconsistent and often inconclusive methods of current soil P analyses.

## LIST OF REFERENCES

- Abramiuk, Marc A., Peter S. Dunham, Linda S. Cummings, Chad Yost, and Todd J. Pesek  
2011 Linking Past and Present: A Preliminary Paleoethnobotanical Study of Maya Nutritional and Medicinal Plant Use and Sustainable Cultivation in the Southern Maya Mountains, Belize. *Ethnobotany Research and Applications* 9:257-273.
- Ahler, S. A.  
1973 A Chemical Analysis of Deposits at Rogers Rock Shelter, Missouri. *Plains Archaeologist* 18:116-131.
- Anderson, Edgar  
1952 Dump Heaps and the Origin of Agriculture. In *Plants, Man, and Life*, Vol. 1, edited by Edgar Anderson, pp. 136-150. University of California Press, Los Angeles, CA.
- Anderson, H., and Hepburn A.  
1985 Biochemical and Other Soil Analyses. *Proceedings of the Prehistoric Society* 51:157-161.
- Arrhenius, Olof  
1931 Markanalysen I Arkeologiens Tjanst. *Geol. Foren. Forbandlingar*  
1934 Fosfathalten I Skanska Jordar. *Sveriges Geol. Undersokning Ser. C(No. 383)*  
1935 Markundersökning och arkeologi. *Fornvännen* 30:65-76.  
1938 Den Gotlandska Akerjordens Fosfathalt. *Sveriges Geol. Undersokning Ser. C(No. 412)*  
1950 Förhistoriska Bebyggelser Antyddas Genom Kemisk Analys. *Fornvännen* 45:59-62.  
1955a Åkermarkens Urgamla Hävd. *Fornvännen* 50:80-87.  
1955b The Iron Age Settlements on Gotland and the Nature of the Soil. In *Vallhager*, Vol. 2, edited by M. Stenberger, pp. 1053-64. Munksgaard, Copenhagen.  
1963 Investigations of Soil From Old Indian Sites. *Ethnos* 2(4):122-36.
- Bagge, A.  
1937 Stenaldern Vid Torne Trask. *Norrbottnens Lans Hembygdsforen* :89-106.
- Bair, Daniel A.

2010 The Dirt on the Ancient Maya: Soil Chemical Investigations of Ancient Maya Marketplaces. Masters Thesis, Brigham Young University, Provo, UT.

Bakkevig, Sverre

1980 Phosphate Analysis in Archaeology- Problems and Recent Progress. *Norwegian Archaeological Review* 13(2):73-100.

Ball, Joseph, and Richalene Kelsay

1992 Prehistoric Intrasettlement Land Use and Residual Soil Phosphate Levels in the Upper Belize Valley, Central America. In *Gardens of Prehistory: The Archaeology of Settlement Agriculture in Greater Mesoamerica*, Vol. 1, edited by Thomas W. Killion, pp. 234-262. The University of Alabama Press, Tuscaloosa, AL.

Becker, Marshall Joseph

2001 Houselots at Tikal Guatemala: It's what's Out Back that Counts. Electronic document, <http://dialnet.unirioja.es/servlet/oaiart?codigo=2776126>.

Bethell, Philip, and Ian Máté

1989 The Use of Soil Phosphate Analysis in Archaeology: A Critique. In *Scientific Analysis in Archaeology and Its Interpretation*, edited by Julian Henderson, pp. 1-29.

Bjelajac, Victor, Edward M. Luby, and Rose Ray

1996 A Validation Test of a Field-Based Phosphate Analysis Technique. *Journal of Archaeological Science* 23:243-248.

Bullard Jr., William R.

1952 Boundary Walls and House Lots at Mayapan. *Current Reports of the Carnegie Institution of Washington Department of Archaeology* 1(13):245-246.

Caballero, Javier

1992 Maya Homegardens: Past, Present and Future. *Etnoecológica* 1(1):35-54.

Chase, Arlen F., and Diane Z. Chase

1983 Intensive Gardening among the Late Classic Maya. *Expedition* 25:2-11.

1987 Investigations at the Classic Maya City of Caracol, Belize: 1985-1987. In Vol. 3, *Pre-Columbian Art Research Institute*, San Francisco, CA.

1990 Los Sistemas Mayas de Subsistencia y Patron de Ascentamiento: Pasado y Futuro. In *Los Mayas: El Esplendor de Una Civilizacion*, Vol. 1, edited by L. Y. Garcia and A. C. Ruiz, pp. 38-48. Sociedad Estatal Quinto Centenario, Turner Libros, Madrid.

- 1994 Details in the Archaeology of Caracol, Belize: An Introduction. In *Studies in the Archaeology of Caracol, Belize*, Vol. 7, edited by D. Chase and A. Chase, pp. 1-11. Pre-Columbian Art Research Institute, San Francisco, CA.
- 1998 Scale and Intensity in Classic Period Maya Agriculture: Terracing and Settlement at the "Garden City" of Caracol, Belize. *Culture & Agriculture* 20(2-3):60-77.
- 2015 The Domestic Economy of Caracol, Belize: Articulating with the Institutional Economy in an Ancient Maya Urban Setting. *Research Reports in Belizean Archaeology* 12:15-23.
- Chase, Arlen F., Diane Z. Chase, Richard Terry, Jacob Horlacher, and Adrian S. Z. Chase  
2015 Markets Among the Ancient Maya: The Case of Caracol, Belize. In *The Ancient Maya Marketplace: The Archaeology of Transient Space*, edited by E. King, pp. 226-250. University of Arizona, Press, Tucson (in press).
- Chase, Diane, and Arlen Chase  
2014 Path Dependency in the Rise and Denouement of a Classic Maya City: The Case of Caracol, Belize. *Archaeological Papers of the American Anthropological Association* 24(1):142-154.
- Childe, V. G.  
1934 *New Light on the Most Ancient East: The Oriental Prelude to European Prehistory*. Vol. 1, Appleton-Century, Bloomington, IN.
- Christensen, W.  
1935 Jordens Fosforsyreindhold som Indikator for Tidligere Kultur og Bebyggelse. *Danske Geol. Undersok* 2(57)  
  
1940 Fosfatanalysen i Arkaeologiens Tjeneste. *Fortid of Nutid* 12:129-155.
- Conway, J. S.  
1983 An Investigation of Soil Phosphorus Distribution Within Occupation Deposits from a Romano-British Hut Group. *Journal of Archaeological Science* 10:117-128.
- Cook, Duncan E., Brigitte Kovacevich, Timothy Beach, and Ronald Bishop  
2006 Deciphering the inorganic chemical record of ancient human activity using ICP-MS: a reconnaissance study of late Classic soil floors at Cancuén, Guatemala. *Journal of Archaeological Science* 33(5):628-640.
- Cook, S. F., and R. F. Heizer  
1965 *Studies on the Chemical Analysis of Archaeological Sites*. Vol. Anthropology 2, University of California Publications, Berkeley, CA.

- Coronel, Eric G.  
2011 Geochemical Analysis of Ancient Activities at Two Plazas in Coba, Mexico. Masters Thesis, Brigham Young University, Provo, UT.
- Coultas, C. Lynn, Mary E. Collins, and Arlen F. Chase  
1984 Some Soils Common to Caracol, Belize and Their Significance to Ancient Agriculture and Land-Use. In *Studies in the Archaeology of Caracol, Belize*, Vol. 7, edited by D. Chase and A. Chase, pp. 21-33. Pre-Columbian Art Research Institute, San Francisco, CA.  
  
1993 Effect of Ancient Maya Agriculture on Terraced Soils of Caracol, Belize. Paper presented at the Proceedings of the First International Conference on Pedo-Archaeology, Knoxville, TN.
- Dahlin, Bruce H., Christopher T. Jensen, Richard E. Terry, David R. Wright, and Timothy Beach  
2007 In search of an ancient Maya market. *Latin American Antiquity*:363-384.
- Dahlin, Bruce H., Daniel Bair, Tim Beach, Matthew Moriarty, and Richard Terry  
2010 The dirt on food: ancient feasts and markets among the lowland Maya. In *Pre-Columbian Foodways*, pp. 191-232. Springer,
- Deotare, B. C.  
1983 Determination of the Extent of Settlement Area by Phosphate Analysis. *Bulletin of the Deccan College Research Institute* 42:40-45, 47.
- Dick, W. A., and M. A. Tabatabai  
1956 An Alkaline Oxidation Method for Determination of Total Phosphorus in Soils. *Journal of the Soil Science Society of America* 41:511-514.
- Demarest, Arthur  
2004 *Ancient Maya: The Rise and Fall of a Rainforest Civilization*. Vol. 1, Cambridge University Press, Cambridge, UK.
- Doolittle, William E.  
1992 House-Lot Gardens in the Gran Chichimeca: Ethnographic Cause for Archaeological Concern. In *Gardens of Prehistory: The Archaeology of Settlement Agriculture in Greater Mesoamerica*, Vol. 1, edited by Thomas W. Killion, pp. 70. The University of Alabama Press, Tuscaloosa, AL.  
  
2004 Gardens Are Us, We Are Nature: Transcending Antiquity and Modernity. *Geographical Review* 94(3):391-404.
- Drucker, Philip, and John W. Fox

- 1982 Swidden Didn't Make All That Midden: The Search for Ancient Mayan Agronomies. *Journal of Anthropological Research* 38(2):179-193.
- Dunning, Nicholas P., and Timothy Beach  
1994 Soil Erosion, Slope Management, and Ancient Terracing in the Maya Lowlands. *Latin American Antiquity* 5(1):51-69.
- 2011 Farms and Forests: Spatial and Temporal Perspectives on Ancient Maya Landscapes. In *Landscapes and Societies*, Vol. 1, edited by I. P. Martini and W. Chesworth, pp. 369-389. Springer Science & Business Media B.V., Netherlands.
- Dunning, Nicholas, Timothy Beach, and David Rue  
1997 The Paleoecology and Ancient Settlement of the Petexbatun Region, Guatemala. *Ancient Mesoamerica* 8(2):255-266.
- Eberl, Markus, Marco Álvarez, and Richard E. Terry  
2012 Chemical Signatures of Middens at a Late Classic Maya Residential Complex, Guatemala. *Geoarchaeology* 27(5):426-440.
- Eidt, R. C.  
1973 A Rapid Chemical Field Test for Archaeological Site Surveying. *American Antiquity* 38:206-210.
- 1977 Detection and Examination of Anthrosols by Phosphate Analysis. *Science* 197(4311):1327-1333.
- 1984 *Advances in Abandoned Settlement Analysis: Application to Prehistoric Anthrosols in Columbia, South America*. University of Wisconsin-Milwaukee, Center for Latin America, Milwaukee, WI.
- 1985 Theoretical and Practical Considerations in the Analysis of Anthrosols. In *Archaeological Geology*, edited by G. Rapp and J. A. Gifford, pp. 155-190. Yale University Press, New Haven, CT.
- Eidt, R. C., and William I. Woods  
1974 *Abandoned Settlement Analysis: Theory and Practice*. Field Test Associates, Shorewood, WI.
- Fedick, Scott L.  
1996 Conclusion: Landscape Approaches to the Study of Ancient Maya Agriculture and Resource Use. In *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*, Vol. 1, edited by Scott L. Fedick, pp. 335-347. University of Utah Press, Salt Lake City, UT.



- 1994 Ancient Maya Agricultural Terracing in the Upper Belize River Area. *Ancient Mesoamerica* 5(01):107-127.
- 1995 Land Evaluation and Ancient Maya Land Use in the Upper Belize River Area, Belize, Central America. *Latin American Antiquity* 6(1):16-34.
- Fedick, Scott L., and Anabel Ford  
1990 The Prehistoric Agricultural Landscape of the Central Maya Lowlands: An Examination of Local Variability in a Regional Context. *World Archaeology* 22(1, Soils and Early Agriculture):18-33.
- Fedick, Scott L., and Bethany A. Morrison  
2004 Ancient use and Manipulation of Landscape in the Yalahau Region of the Northern Maya Lowlands. *Agriculture and Human Values* 21(2-3):207-219.
- Feigl, F.  
1958 *Spot Tests in Inorganic Chemistry*. Elsevier
- Fernandes, ECM, and PKR Nair  
1986 An Evaluation of the Structure and Function of Tropical Homegardens. *Agricultural Systems* 21:279-310.
- Flores-Delgadillo, Lourdes, Scott L. Fedick, Elizabeth Solleiro-Rebolledo, Sergio Palacios-Mayorga, Pilar Ortega-Larrocea, Sergey Sedov, and Esteban Osuna-Ceja  
2011 A sustainable system of a traditional precision agriculture in a Maya homegarden: Soil quality aspects. *Soil and Tillage Research* 113(2):112-120.
- Fuller, D., and E. Hildebrand  
2013 Domesticating Plants in Africa. In *The Oxford Handbook of African Archaeology*, edited by P. Mitchell and P. Land, pp. 507-525. Oxford University Press, Oxford, UK.
- Fuller, D., G. Willcox, and R. G. Allaby  
2011 Cultivation and Domestication Had Multiple Origins: Arguments Against the Core Area Hypothesis for the Origins of Agriculture in the Near East. *World Archaeology* 43:628-652.
- Glaser, Bruno, Wolfgang Zech, and William I. Woods  
2004 History, Current Knowledge and Future Perspectives of Geoecological Research Concerning the Origin of Amazonian Anthropogenic Dark Earths (Terra Preta). In *Amazonian Dark Earths: Explorations in Space and Time*, Vol. 1, edited by Bruno Glaser and William I. Woods, pp. 9-17. Springer-Verlag Berlin Heidelberg, Germany.
- Gómez-Pompa, Arturo  
1987 On Maya Sivilculture. *Mexican Studies* 3(1):2-9

- Gundlach, H.  
1961 Tüpfelmethode auf Phosphat, Angewandt in Prähistorischer Forschung (Als Feldmethode). *Mikrochimica Acta* 5:735-737.
- Gurney, D. A.  
1985 *Phosphate Analysis of Soils: A Guide for the Field Archaeologist*. Vol. Technical Paper 3, The Institute of Field Archaeologists, Birmingham, UK.
- Hammond, Norman  
1978 The Myth of the Milpa: Agricultural Expansion in the Maya Lowlands. In *Pre-Hispanic Maya Agriculture*, Vol. 1, edited by Peter D. Harrison and B. L. Turner, pp. 21-34. University of New Mexico Press, Albuquerque, NM.
- Hamond, F. W.  
1983 Phosphate Analysis of Archaeology Sediments. In *Landscape Archaeology in Ireland, BAR British Series*, Vol. 116, edited by T. Reeves-Smith and F.W. Hamond, pp. 47-80. Oxford University Press, Oxford, UK.
- Harris, David  
1990 Vavilov's Concept of Centres of Origin of Cultivated Plants: Its Genesis and its Influence on the Study of Agricultural Origins. *Biological Journal of the Ninnean Society* 39:7-16.
- Harrison, Peter D. and B. L. Turner  
1978 So the Seeds Shall Grow: Some Introductory Comments. In *Pre Hispanic Maya Agriculture*, Vol. 1, edited by Peter D. Harrison and B. L. Turner, pp. 11. University of New Mexico Press, Albuquerque, NM.
- Hassan, F. A.  
1981 Rapid Quantitative Determination of Phosphate in Archaeological Sediments. *Journal of Field Archaeology* 8:384-387.
- Healy, Paul F., Catrein van Waarden, and Thomas J. Anderson  
1980 Nueva Evidencia de Antiguas Terrazas Maya en Belice. *América Ingêgena* 40(4):773-796.
- Healy, Paul F., John D. H. Lambert, J. T. Arnason, and Richard J. Hebda  
1983 Caracol, Belize: Evidence of Ancient Maya Agricultural Terraces. *Journal of Field Archaeology* 10(4):397-410.
- Holliday, Vance T., and William G. Gartner  
2007 Methods of Soil P Analysis in Archaeology. *Journal of Archaeological Science* 34(2):301-333

- Hutson, Scott R., Travis W. Stanton, Aline Magnoni, Richard Terry, and Jason Craner  
2007 Beyond the Buildings: Formation Processes of Ancient Maya Houselots and Methods for the Study of Non-Architectural Space. *Journal of Anthropological Archaeology* 26(3):442-473.
- Hutson, Scott R., Aline Magnoni, Timothy Beach, Richard E. Terry, Bruce H. Dahlin, and Mary Jo Schabel  
2009 Phosphate Fractionation and Spatial Patterning in Ancient Ruins: A Case Study from Yucatan. *Catena* 78(3):260-269.
- Johnson, A. H.  
1956 Examination of Soil from Corrimony Chambered Cairn. *Proceedings of the Society of Antiquaries of Scotland* 88:200-207.
- Johnson, A. H., and D. Nicol  
1949 Analyses of Soil Samples from Old Ground Surface Under Cairn, Cairnholy I. *Proceedings of the Society of Antiquaries of Scotland* 83:161.
- Johnston, Kevin J.  
2003 The Intensification of Pre-Industrial Cereal Agriculture in the Tropics: Boserup, Cultivation Lengthening, and the Classic Maya. *Journal of Anthropological Archaeology* 22:126-161.
- Kamprath, E. J., and M. E. Watson  
1980 Conventional Soil and Tissue Tests for Assessing the Phosphorus Status of Soils. In *The Role of Phosphorus in Agriculture*, edited by F. E. Khasawneh, E. C. Sample and E. J. Kamprath, pp. 433-469. Soil Science Society of America, Madison, WI.
- Keeley, H. C. M.  
1981 Recent Work Using Soil Phosphorus Analysis in Archaeological Prospection. *Revue d'Archéométrie* 5:89-95.
- Killion, Thomas W.  
1992 *Gardens of Prehistory : The Archaeology of Settlement Agriculture in Greater Mesoamerica*. University of Alabama Press, Tuscaloosa, Ala.
- Killion, Thomas W., Jeremy A. Sabloff, Gair Tourtellot, and Nicholas P. Dunning  
1989 Intensive Surface Collection of Residential Clusters at Terminal Classic Sayil, Yucatan. *Journal of Field Archaeology* 16(3):273-294.
- Kumar, B. M., and Nair, P. K. R.  
2004 The Enigma of Tropical Homegardens. *Agroforestry Systems* 61(1-3):135-152.

- Langlie, BrieAnna S., Natalie G. Mueller, Robert N. Spengler, and Gayle J. Fritz  
2014 Agricultural Origins from the Ground Up: Archaeological Approaches to Plant Domestication. *American Journal of Botany* 101(10):1601-1617.
- Lehmann, Johannes, Carla Vabose Campose, Vasconcelos De Macedo, Jeferson Luiz, and Laura German  
2004 Sequential P Fractionation of Relict Anthropogenic Dark Earths of Amazonia. In *Amazonian Dark Earths: Explorations in Space and Time*, Vol. 1, edited by Bruno Glaser and William I. Woods, pp. 113-123. Springer-Verlag Berlin Heidelberg, Germany.
- Lentz, David L.  
1991 Maya Diets of the Rich and Poor: Paeleoethnobotanical Evidence from Copan. *Latin American Antiquity* 2(3):269-287.
- Leonardi, G., M. Miglavacca, and S. Nardi  
1999 Soil Phosphorus Analysis as an Integrative Tool for Recognizing Ancient Ploughsoils. *Journal of Archaeological Science* 26:343-357.
- Lohse, Jon C., and Patrick N. Findlay  
2000 A Classic Maya House-Lot Drainage System in Northwestern Belize. *Latin American Antiquity* 11(2):175-185.
- Lorch, Walter  
1940 Die Siedlungsgeographische Photsphatmethode. *Die Naturwissenschaften* 28:633-640.
- Lundell, Cyrus L.  
1940 The 1936 Michigan-Carnegie Botanical Expedition to British Honduras. *Botany of the Maya Area; Miscellaneous Papers*. 522:1-57.
- Lutz, H. J.  
1951 The Concentration of Certain Chemical Elements in the Soils of Alaskan Archaeological Sites. *American Journal of Science* 249:925-928.
- Macphail, R. I., G. Cruise, R. Engelmark, and J. Linderholm  
2000 Integrating Soil Micromorphology and Rapid Chemical Survey Methods: New Developments in Reconstructing Past Rurual Settlement and Landscape Organization. In *Interpreting Stratigraphy: Site Evaluation, Recording Procedures and Stratigraphic Analysis*, Vol. BAR International Series 910, edited by S. Roskams, pp. 71-80. Oxford, UK.
- Manzanilla, Linda (editor)  
1987 *Coba, Quintana Roo: Analisis de Dos Unidades Habitacionales Mayas*. Universidad Nacional Autonoma de Mexico, Mexico City, Mexico.

Manzanilla, Linda

1996 Soil Analyses to Identify Ancient Human Activities. *Canadian Journal of Soil Science* 76(2):107-108.

Maritsas, Constantinos

2013 *Origin of the Agriculture in the Context of the Evolutionary Theory*. <http://eds.b.ebscohost.com.ezproxy.net.ucf.edu/eds/pdfviewer/pdfviewer?vid=12&sid=c4a6ac64-d289-49c3-a8a6-8208ee5b5092%40sessionmgr110&hid=117> ed. Vol. 4, Biomirror, Sofia University, Bulgaria.

Mattingly, G., and R. Williams

1962 A Note on the Chemical Analysis of a Soil Buried Since Roman Times. *Journal of Soil Science* 13:254-258.

McKee, Brian R.

1999 Household Archaeology and Cultural Formation Processes: Examples from the Ceren Site, El Salvador. In *The Archaeology of Household Activities*, edited by Penelope Allison, pp. 30-42. Routledge, London.

McLean, W.

1936 The Determination of Phosphorus in Soils. *Journal of Agricultural Science* 6:331-336.

Montagnini, Florencia

2006 Homegardens of Mesoamerica: biodiversity, food security, and nutrient management. In *Tropical Homegardens*, edited by B. M. Kumar and P. K. R. Nair, pp. 61-84. Springer, Netherlands.

Neulinger, Korinna, Christian R. Vogl, and Josè A. Alayón-Gamboa

2013 Plant Species and Their Uses in Homegardens of Migrant Maya and Mestizo Smallholder Farmers in Calakmul, Campeche, Mexico. *Journal of Ethnobiology* 33(1):105-124.

Nigh, Ronald, and Stewart A. Diamond

2013 The Maya Milpa: Fire and the Legacy of Living Soil. *Frontiers in Ecology and the Environment* 11(1):e45-e54.

Niñez, Vera

1987 Household gardens: Theoretical and policy considerations. *Agricultural Systems* 23(3):167-186.

Olsen, S. R., and L. E. Sommers

- 1982 Phosphorus. In *Methods of Soil Analysis, Part 2- Chemical and Microbiological Properties, second ed.* Vol. 9, edited by A.L. Page, R.H. Miller and D.R. Keeney, pp. 403-430. American Society of Agronomy, Madison, WI.
- Ower, Leslie  
1927 Features of British Honduras. *The Geographical Journal* 70(4):372-386.
- Parnell, J. J., Richard E. Terry, and Zachary Nelson  
2002a Soil chemical analysis applied as an interpretive tool for ancient human activities in Piedras Negras, Guatemala. *Journal of Archaeological Science* 29(4):379-404.
- Parnell, J. J., Richard E. Terry, and Payson Sheets  
2002b Soil Chemical Analysis of Ancient Activities in Cerén, El Salvador: A Case Study of a Rapidly Abandoned Site. *Latin American Antiquity* 13(3):331-342.
- Pohl, Mary, and Lawrence H. Feldman  
1982 The Traditional Role of Women and Animals in Lowland Maya Economy. In *Maya Subsistence: Studies in Memory of Dennis E. Puleston*, edited by Kent V. Flannery, pp. 295-311. Academic Press, Inc., New York, NY.
- Proudfoot, B.  
1976 The Analysis and Interpretation of Soil Phosphorus in Archaeological Contexts. In *Geoarchaeology: Earth, Science, and the Past*, edited by D. A. Davidson and M. L. Shackley, pp. 93-113. Duckworth, London.
- Provan, Donald M. J.  
1971 Soil Phosphate Analysis as a Tool in Archaeology. *Norwegian Archaeological Review* 4(1):37-50.
- Puleston, Dennis E.  
1978 Terracing, Raised Fields, and Tree Cropping in the Maya Lowlands: a New Perspective on the Geography of Power. In *Pre-Hispanic Maya Agriculture*, Vol. 1, edited by Peter D. Harrison and B. L. Turner, pp. 225-245. University of New Mexico Press, Albuquerque, NM.
- Riehl, S., M. Zeidi, and N. J. Conard  
2013 Emergence of Agriculture in the Foothills of the Zagros Mountains of Iran. *Science* 341:65-67.
- Robin, Cynthia  
1999 *Towards an Archaeology of Everyday Life: Maya Farmers of Chan Nòohol and Dos Chombitos Cik'in, Belize*. Ph.D. ed. University of Pennsylvania, Philadelphia, PE.
- Sánchez, A., M. L. Cañabate, and R. Lizcano

- 1996 Phosphorus Analysis at Archaeological Sites: An Optimization of the Method and Interpretation of the Results. *Archaeometry* 31(1):151-164.
- Sanders, William, and Thomas Killion  
1992 Factors Affecting Settlement Agriculture in the Ethnographic and Historic Record of Mesoamerica. *In Gardens of Prehistory: The Archaeology of Settlement Agriculture in Greater Mesoamerica*. Thomas Killion, ed. Pp. 14-32. Tuscaloosa, AL: The University of Alabama Press.
- Schiffer, Michael B.  
1987 *Formation Processes of the Archaeological Record*. 1st ed. Vol. 1, University of New Mexico Press, Albuquerque, NM.
- Sharer, Robert J., and Loa P. Traxler  
2006 *The Ancient Maya*. 6th ed. Stanford University Press, Stanford, California.
- Sheets, Payson, and Michelle Woodward  
2002 Cultivating Biodiversity: Milpas, Gardens, and the Classic Period Landscape. Before the Volcano Erupted: The Ancient Cerén Village in Central America:184-191.
- Shiple, B. N., and J. C. C. Romans  
1962 the Excavation of Two Circular Enclosures at Dalnagar, Perthshire. *Proceedings of the Society of Antiquaries of Scotland* 95:134-159.
- Siemens, Alfred, and Dennis Puleston  
1972 Ridged Fields and Associated Features in Southern Campeche: New Perspectives on the Lowland Maya. *American Antiquity* 37(2):228-239.
- Sjöberg, A.  
1976 Phosphate Analysis of Anthropoc Soils. *Journal of Field Archaeology* 3:447-454.
- Skinner, S. M.  
1986 Phosphorus as an Anthrosol Indicator. *Midcontinental Journal of Archaeology* 11:51-78.
- Smyth, Michael P., C. C. Dore, and Nicholas P. Dunning  
1995 Interpreting Prehistoric Settlement Patterns: Lessons from the Maya Center of Sayil, Yucatan. *Journal of Field Archaeology* 22:321-347.
- Sokoloff, V., and G. Carter  
1952 Time and Trace Elements in Archaeological Sites. *Science* 116:1-5.
- Tanno, K., and G. Willcox

- 2006 The Origins of Cultivation of *Cicer arietinum* L. and *Vicia faba* L.: Early Finds from Tell el-Kerkh, Northwest Syria, Late 10th Millennium B.P. *Vegetation History and Archaeobotany* 15:197-204.
- Terry, Richard E., Sheldon D. Nelson, Jared Carr, Jacob Parnell, Perry J. Hardin, Mark W. Jackson, and Stephen D. Houston  
2000 Quantitative Phosphorus Measurement: A Field Test Procedure for Archaeological Site Analysis at Piedras Negras, Guatemala. *Geoarchaeology* 15(2):151-166.
- Terry, Richard E., Fabian G. Fernández, J. J. Parnell, and Takeshi Inomata  
2004 The story in the floors: chemical signatures of ancient and modern Maya activities at Aguateca, Guatemala. *Journal of Archaeological Science* 31(9):1237-1250.
- Thompson, J. E. S.  
1931 Archaeological Investigations in the Southern Cayo District, British Honduras. In *Anthropological Series*, Vol. 17, Field Museum of Natural History, Chicago, IL.
- Tourtellot, Gair  
1988 Mapping Community Patterns at Sayil, Yucatan, Mexico: The 1985 Season. *Journal of New World Archaeology* 7:1-24.
- Turner, B. L.  
1978 The Development and Demise of the Swidden Thesis of Maya Agriculture. In *Pre-Hispanic Maya Agriculture*, edited by Peter D. Harrison and B. L. Turner, pp. 13-22. University of New Mexico Press, Albuquerque, NM.  
  
1983 *Once Beneath the Forest: Prehistoric Terracing in the Rio Bec Region of the Maya Lowlands*, Vol. 1. Westview Press, Boulder, CO.
- Turner, B. L., and Peter D. Harrison  
1981 Prehistoric Raised-Field Agriculture in the Maya Lowlands. *Science* 213(4506):399-405.  
  
2000 *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize*. 2nd ed. Vol. 1, University of Utah Press, Salt Lake City, UT.
- Vavilov, N. I.  
1926 The Origin of Cultivated Plants. *Proceedings Of The International Congress Of Plant Sciences* 1:167-169.
- Webb, Elizabeth A., Henry P. Schwarcz, and Paul F. Healy  
2004 Detection of ancient maize in lowland Maya soils using stable carbon isotopes: evidence from Caracol, Belize. *Journal of Archaeological Science* 31(8):1039-1052.



- Webster, David, Nancy Gonlin, and Payson Sheets  
 1997 Copan and Ceren: Two Perspectives on Ancient Mesoamerican Households. *Ancient Mesoamerica* 8(1):43-61.
- Wells, E. C., and Richard E. Terry  
 2007 Introduction. *Geoarchaeology* 22(3):285-290.
- Wells, E. Christian, Richard E. Terry, J. Jacob Parnell, Perry J. Hardin, Mark W. Jackson, and Stephen D. Houston  
 2000 Chemical Analyses of Ancient Anthrosols in Residential Areas at Piedras Negras, Guatemala. *Journal of Archaeological Science* 27(5):449-462.
- Wilk, Richard R.  
 1991 Land Tenure and Crops. In *Household Ecology: Economic Change and Domestic Life Among the Kekchi Maya in Belize*, Vol. 1, edited by Richard R. Wilk, pp. 85-141. University of Arizona Press, Tucson, AZ.
- Wilken, Gene C.  
 1971 Food-Producing Systems Available to the Ancient Maya. *American Antiquity* 36(4):432-448.
- Willey, Gordon R.  
 1965 Problems Concerning Prehistoric Settlement Patterns in the Maya Lowlands. In *Prehistoric Settlement Patterns in the New World*, pp. 107-114. Viking Fund Publications, New York.
- Wilson, Clare A., Donald A. Davidson, and Malcolm S. Cresser  
 2008 Multi-element Soil Analysis: An Assessment of its Potential as an Aid to Archaeological Interpretation. *Journal of Archaeological Science* 35(2):412-424
- Winklerprins, AMGA  
 2009 Sweep and Char and the Creation of Amazonian Dark Earths in Homegardens. In *Amazonian Dark Earths: Will Sombroek's Vision*, Vol. 1, edited by William I. Woods, Wenceslau G. Teizeira, Johannes Lehmann, Christoph Steiner, Antoinette M. G. A. WinklerPrins and Lilian Rebellato, pp. 205-211. Springer Science,
- Wood, Raymond W., and Donald L. Johnson  
 1978 A Survey of Disturbance Processes in Archaeological Site Formation. *Advances in Archaeological Method and Theory* 1:315-381.
- Woods, William I.  
 1977 The Quantitative Analysis of Soil Phosphate. *American Antiquity* 42:248-252.
- Woods, William I.

1975 The Analysis of Abandoned Settlements by a New Phosphate Field Test Method,  
The Chesopiean. *A Journal of North American Archaeology* 13:1-45.

Wright, A. C. S., D. H. Romney, R. H. Arbuckle, and V. E. Vial  
1959 *Land in British Honduras: Report of the British Honduras Land Use Survey Team*.  
Vol. 24, Her Majesty's Stationary Office, London.

Zizumbo-Villarreal, Daniel, Alondra Flores-Silva, and Patricia Colunga-Garcia Marin  
2012 The Archaic Diet in Mesoamerica: Incentive for Milpa Development and Species  
Domestication. *Economic Botany* 66(4):328-343.