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A Dynamic Model of Stability and Change in Mississippian Agricultural Systems

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To the Graduate Council:

I am submitting herewith a dissertation written by William W. Baden entitled "A Dynamic Model of Stability and Change in Mississippian Agricultural Systems." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Anthropology.

Gerald F. Schroedl, Major Professor

We have read this dissertation and recommend its acceptance:

Paul A. Delcourt, Richard Jantz, Charles Faulkner

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A DYNAMIC MODEL OF STABILITY AND CHANGE IN MISSISSIPPIAN AGRICULTURAL SYSTEMS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

William W. Baden
August 1987

DEDICATION

To all the generations of farmers in my family
for whom all of this is self-evident.

ACKNOWLEDGMENTS

I would like to thank the members of my committee: Drs. Gerald Schroedl, Richard Jantz, Charles Faulkner, and Paul Delcourt for their support and advice in this research endeavor. I would especially like to thank Dr. Schroedl for our many discussions on Cherokee origins, as seen from a systems perspective, that ultimately led to this project. I would also like to thank Dr. William Bass and the Department of Anthropology for their support during my years as a graduate student.

Much of this project grew out of my exposure to the research endeavors of the Tellico Archaeological Project. I would like to thank Dr. Jefferson Chapman for his support and encouragement which made the numerous projects I worked on not only intellectually stimulating, but also fun. Of the many people I worked with, four can be singled out for their contributions to this study. I would like to thank Dr. Clifford Boyd and his wife Donna for their friendship and willingness to send me data after I left Knoxville. I want to thank Dr. Patricia Cridlebaugh for undertaking the difficult palynological research that helped provide the data that inspired and helped validate this model. Finally, I must thank Brett Riggs for our discussions that, in the early stages of formulation, help provide the central focus of this model.

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ABSTRACT

An argument in support of applying Stability Theory concepts to southeastern Mississippian agricultural systems is presented. By redefining such a system in terms of a finite set of variables, a characteristic definition can be developed that predicts system response to varying conditions. In particular, an attempt is made to determine periods of instability during the development of Mississippian Culture in the Little Tennessee River Valley of East Tennessee and correlate these periods with the timing of phase transitions. The system is divided into sets of (a) control (climatic and ecological) and ($\mathbf{x}$) behavioral (technological and social) variables. The rules that define the behavioral limits form a potential function, $V(a,\mathbf{x})$. For an agricultural system this function represents the total non-depleted, arable land reservoir. Stability is defined when $dV/d\mathbf{x} = 0$.

An extensive examination of the ethnohistoric record was used to produce a behavioral model of precontact aboriginal agriculture. Fields were cleared using fire. Plant densities were on the order of 10,000 plants per acre. No recognized method of soil fertilization was practiced. Cultivation was limited to two hoeings. Harvesting was divided between the green corn (milky stage) harvest in midsummer and one final harvest in the fall. Historical estimates of yield range between 10 and 20 bu/acre (6.3 to 12.6 quintals/ha). Field sizes varied between 0.3 and 1.5 acres/person (0.12 to 0.6 ha/person).

Using region specific agricultural, pedological, and archaeological data; system parameters of yield potential, population growth, and minimum consumption are defined as functions of time. Predicted times of system failure are produced for a range of input parameters. Periods of instability are delimited based on the generalized, best case response curve for the total remaining land reservoir. The results suggest that Mississippian I (Martin Farm - A.D. 900-1000) and middle Mississippian III (Dallas - A.D. 1300-1400) were unstable phases. Mississippian II (Hiwassee Island - A.D. 1000-1200) and late or post Mississippian III (Mouse Creek or Cherokee - after A.D. 1400) represent stable adjustments. This result is in agreement with the archaeological and palynological record, demonstrating the applicability of this approach to anthropological research.

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CHAPTER I

INTRODUCTION

Background

Non-coastal Mississippian Period cultures (A.D. 900 to 1700?) have traditionally been thought to be ranked societies supported by intensive maize agriculture (Brose and Percy 1978; Brown et al. 1978; Fowler 1969; Gibson 1974; Griffin 1967; Larson 1972; Overstreet 1978; Peebles 1978; Smith 1978; Ward 1965; and others). While considerable research has produced lengthy statements on the proposed sociopolitical aspects of these precontact populations (Autry 1983; Brown 1971; Goldstein 1980; Larson 1971; Peebles 1971, 1983; Peebles and Kus 1977; and others), little attention has been focused on generating models of the economic system which served to support these societies. Yet, some archaeologists associate changes in the prehistoric record with cultural adjustments precipitated by intensive agricultural practices:

> The settlement pattern of Mississippian populations in some floodplain situations might also change through time if soil depletion necessitated shifting the location of homesteads, and perhaps even local centers [Smith 1978],

> The reasons for the abandonment of hamlets were probably varied but may have centered on both the depletion of natural food resources and on soil fatigue by unrestricted crop-growing [Harn 1978].

Such concerns are warranted given the ethnohistoric accounts of the shifting nature of aboriginal agricultural systems :

> As the Indians never manure their ground and do not even let it lie fallow, it is soon exhausted (and worn out). Then they are forced to move their villages elsewhere and make new fields in new lands [Lafitau 1977:69-70],

> The land, as they do not cultivate it, produces for only ten or twelve years at most; and when the ten years have expired, they are obliged to remove their village to another place [Thwaites 1896-1901:15:153],
>
> . . .on the 7th of November, 1715, Monsieur Begon wrote that Father Cholenec, the missionary of these savages, represented in 1714 to Monsieur The Marquis de Vaudreuil and to him that these savages could no longer remain in their village, because the soil was exhausted and the woods too far away; and that it was absolutely necessary for them to settle elsewhere [Thwaites 1896-1901:67:25].

Recognition of the effects of agrarian practices on cultural systems is not new. Cowgill's (1961, 1962; Cowgill and Hutchinson 1963) Mayan research examined various aspects of Guatemalan soil productivity, concluding that soil depletion did not account for the Mayan collapse in the region (cf. Reina 1967; Street 1969). Heidenreich (1971:159-198) produced a preliminary examination of the Huron's soil needs which suggested that by the early seventeenth century this Lower Great Lakes population was living close to its maximum carrying capacity. A detailed study by Parry (1975, 1978) examined the drastic effect of soil depletion and climatic change on land tenure in medieval Scotland. Additional studies and reviews substantiate the importance of measuring the cultural effects of man's interaction with the environment in an agricultural setting (Bennett 1973; Green 1980a, 1980b; Hosler et al. 1977; Meadows and Meadows 1973; Moylan 1973; among others).

This study is an extension of the current trend towards redefining the relationships of theory and methodology. Its purpose is to augment the current format of archaeological inquiry while delineating the structure, stability, and changes in prehistoric agricultural systems for the Mississippian Period (A.D. 900 to 1700?) in eastern North America. This will be accomplished by presenting a model of Mississippian agricultural productivity potential based on the recognized boundary conditions of such systems as defined by Stability Theory (Nicolis and Prigogine 1977:71). By attempting to model culture change as a byproduct of dynamic systems, I will address whether we have the ability to associate the observed fluctuations in Mississippian cultures with a steady decrease in agricultural potential; not as a singular cause and effect relationship but as one component of an overall system instability requiring social and cultural adjustment. In so doing, I explore potential weaknesses in the current empirical approach to data recovery and examine the explanatory power of well-defined models developed from concepts of stability theory.

Recent discussions (Friedman 1975, 1982; Friedman and Rowlands 1977; Peebles 1978; and Renfrew 1979) provide us with several theoretical relationships, some of which Schroedl (1986) suggests may be capable of qualitatively describing change in terms of a systemic reaction to nonspecific fluctuating conditions. Are there ways to take what we know about specific cultural phase states and use this information to predict trajectories in phase space (i.e. the topological coordinate system mapping cultural characteristics against time)? My goal is to model the dynamic relationships incorporated in shifting agricultural systems, creating a methodology suitable for quantitatively testing the effects of one set of specific fluctuations (agricultural impacts) on the stability of Mississippian systems. It will differ from the purely theoretical discussions by presenting the model in actual Mississippian phase space. That is, the model will predict Mississippian trajectories along a real time line; not solely in terms of abstract relationships. I will not try to "predict" that Mississippian cultures will fail. We know that to be the case. I will show one reason why the failure occurred and, more importantly, reproduce its rate of occurrence.

A global or regionally independent definition of Mississippian variability recognizes growth in social complexity and elaboration through various discrete stages beginning with an emergent phase that transcends to a climax followed by a precontact decline into historic societies (Peebles 1983). For Mississippian studies the historical precedent has been the presentation of distinctive associations of elaborate material and structural remains as indicators of changing, complex social organization along a space-time continuum. Current systemic approaches focus on the boundary conditions of the system as an "... adaptation to a specific habitat situation" with "a particular level of sociocultural integration" (Smith 1978:480). The resulting abstract models are derived from optimization theories for resource allocation and redistribution of prestige goods. Such a paradigm makes agriculture an unbounded resource, important only in terms of its labor (i.e. organizational) requirements. Such a perspective never requires a detailed study of agriculture's long term impact on influencing Mississippian cultural evolution (cf. Peebles 1978). Agriculture has been ignored in favor of the more observable aspects of the archaeological record. Nevertheless, as an integral part of the total subsistence base it must be included in any examination of overall system structure.

This examination starts with the premise that the response of any agricultural system will fluctuate over time. How will these fluctuations affect the stability of the parent cultural system? Traditional approaches to archaeological inquiry leave this question unanswered. This serves as the initial impetus for this study, but it also leads to another more basic question. How can we measure or observe stability? To interpret Mississippian phase shifts (morphogenesis), we must develop some means to address this problem. At this point in the discussion only a general definition of stability is needed. After developing the model, a more lengthy examination will be appropriate.

All systems can be defined by a finite set of interacting variables. If a characteristic definition is developed that expresses this interaction in a way that facilitates predicting system response, then the fluctuating conditions can be isolated. In terms of macroscopic detail, stable systems maintain (within finite limits) their initial reference state despite changes in the values of internal variables. This is referred to as *structural stability* (Nicolis and Prigogine 1977:69). As demonstrated from evolutionary theory, stability is maintained within environmental and behavioral limits (Rindos 1984:264). Their respective parameters constitute the system's control ($\mathbf{a}$) and behavior ($\mathbf{x}$) spaces. The rules that define the behavioral limits form a potential, $V(\mathbf{a},\mathbf{x})$. Stability is defined when the rate of change in potential is zero (i.e. $dV/d\mathbf{x} = 0$). Stability Theory concentrates on identifying these absolute limits.

As a simple example, the response of an agricultural system may be defined to be energy production per unit catchment area (quintals per hectare) and the potential to be the amount of available arable land (ha). The system itself is composed of four internal parts ($\mathbf{x}$): botanical resources, an extractive technology, some level of horticultural knowledge, and a work force. Externally, it is affected by weather conditions and the nutrient level of the soil (a). In the absence of optimal stability, a system will respond to errors (e.g. insufficient production levels) by changing internal behavioral parameters in ways that minimize undesirable effects. At some point the system's response may not be maintainable because these internal adjustments trigger an eventual system collapse necessitating a redefinition of the operating rules ($dV/d\mathbf{x} \neq 0$). This "triggering" is caused by the forced acceptance of behavioral rules, like planting larger fields, that are outside the current behavioral limits which preserve stability. We view the occurrence of such a change as a shift in phase space or, archaeologically speaking, a Mississippian transition.

Following Green's (1980b:337) approach the agricultural process is necessarily an interaction between cultural and environmental systems. This linkage involves management, impact, response, and feedback mechanisms. Horticultural practices, the primary behavioral input, form the management portion of the process. The initial effects of these decisions produce an environmental impact on the ecosystem. The ecosystem's response to the impact, varying from one environment to another, provides feedback to the behavioral system. It is the interaction of these two systems, cultural and biological, that define the larger agricultural process.

Given such interactions, does the response of the system in this simple example remain constant over time? The historical record documents change in such systems. To demonstrate this, the internal and external variables must be examined by mapping the fluctuations in agricultural response over time and defining the parameter space appropriately to account for established agricultural processes. In dealing only with agricultural subsistence strategies, the questions related to the origin of agriculture can be effectively ignored. These topics are best left to other approaches concerned with adaptive potentials and not the kind of stability questions examined here (Rindos 1984:275). Given that the agricultural choice has been made by Woodland and Mississippian populations, then, it is necessary to measure the impact of that choice.

How does this conceptualization of the problem differ from that of the past and promote alternative trends in analysis? Addressing the complex question of stability requires a certain theoretical understanding of systems interpretation and data acquisition techniques. Our interpretation of archaeological cultures can tend to be overly simplistic from an explanatory perspective. We are often content to isolate singular cause and effect relationships to explain transformations without quantifying their rate functions. This concentration on certain avenues to the exclusion of others is largely a result of the developmental process of enhancing archaeological science.

At any point in time a discipline consists of a finite set of approaches, some of which may compete with others for supremacy (e.g.

Binford 1985; Gould 1985). Archaeology concentrates on describing, defining, and explaining changing residual patterns in cultural refuse using varying techniques of observation and generalization to link the patterns with hypothesized behavioral models. By the 1960's recognition of the archaeological implications of culture as a dynamic, if unobservable, phenomenon led to the replacement of the more static material dependent theories of culture change with what has become known as the processual approach (Willey and Sabloff 1974:209).

Although this New Archaeology has been characterized as a methodological binge (Moore and Keene 1983), its earliest application depended more on qualitatively invoking an unobservable Processual Being as the ultimate explanation of most material patterns in the archaeological record. As a complex adaptive guidance system, "process" was seen as the underlying causation for the morphogenesis of one discrete archaeological unit into another. Methodologies were selected that presented artifact patterns in ways that were assumed to be quantitatively scientific and logically valid in hopes of extracting process from static assemblages. Yet, strong arguments linking the process with the patterns could not be made largely because the methodologies were not adequately linked to an archaeological theory relating objects, context, and morphogenesis to a single system. In the end, culture was reduced to a byproduct of the Processual Being who, like Laplace's all-knowing Demon (Prigogine and Stengers 1984:75-77), orchestrates the dynamics without revealing any of the mechanics.

This initial failure to fully explain culture process resulted from an inability to recognize that, while thinking we were explaining change, we were really addressing philosophical problems of system identification (see Maciejowski 1978:19). After developing some analytical sophistication, we have begun to challenge the unobservable nature of the Being, realizing that process and context must at least be described, if not explained, as archaeological systems. We should be able to assign these systems operational parameters and recognize boundary conditions that trigger change. We recognize that to define process effectively, we need to develop new tools of observation and analysis that are derived from archaeological theory and capable of relating qualitative expectations with quantifiable data. Whether we call this theory Middle Range (Binford 1977) or not (Moore and Keene 1983), its development is beginning to replace the strictly methodological emphasis of earlier studies. The research presented here serves as an extension to this trend.

Most examinations into the workings of agricultural systems have failed to adequately address Green's (1980b:337) four mechanisms cited above. In particular, carrying capacity measurements have ignored the effect of environmental degradation caused by agricultural practices. This is largely because most studies begin by assuming that their focus is on a stable process (see Street 1969). It is a mistake to assume that the ethnographic present results from stable conditions. Similarly, we should not assume that archaeological phases are associated with stability. Indeed, processual instabilities direct cultural trajectories. Modeling the entire agricultural system (aspects of management, impact, response, and feedback) produces a more useful representation of cultural dynamics that recognizes inherent fluctuations. But more importantly, when done in the manner described here, such models display the ability to predict archaeological phenomena, such as the timing of phase shifts. This is what makes this study unique and important.

Modeling

Clarke's (1972) presentation and volume (1972, edited) on the subject of modeling demonstrates that modeling has been accepted as a valid analytical approach. Archaeologists interpret their observations on the basis of a set of conceptual models (paradigms) of one sort or another. However, the degree to which our conclusions are testable is dependent on some measure of the explicitness or refutability, in Popper's (1959:86) sense, of our constructs. Here modeling deals with predicting system behavior under specified conditions based on observed, past behavior (Maciejowski 1978:12). Because they require rigid specification of relationships, such abstract summaries serve as the most specific, manipulative framework for organizing observations along integrative and interpretive lines. In this sense they can become powerful tools of analysis and description.

In exchange for precision, modeling requires an acceptance of approximation. Any real phenomenon being analyzed must be defined under some rule of closure whereby the interrelationships within a finite set of essential parameters (i.e. sufficient to approximate observed responses) are examined (Bellman 1968:7). We cannot expect to account for all the interactions or all the variables. Despite this limitation, quantitative models do provide a means of addressing questions that expose the continuum of processual dynamics, otherwise unapproachable by conventional methods.

Our applications have, however, often ignored the conceptual differences between model identification and realization in Maciejowski's sense (1978:1-22). The identification of the system involves coming to terms with the larger philosophical questions surrounding the nature of the scientific method. How is it that we observe and interpret the archaeological record? Is there a singularly "scientific" way this should be done? What should be observed? These questions were partially addressed during the development of the New Archaeology, although not explicitly in terms of modeling. System identification involves placing experimental observations within a larger conceptual framework which serves as an abstract summary of the data. Archaeologists have assumed this involves the almost impossible task of taking static material observations and reconstructing cultural processes. In retrospect, this was the cause of the New Archaeology's analytical failure (Binford 1982). Today's Middle Range applications try to reverse the order by observing cultural processes in an attempt to define the resultant archaeological record. By restructuring our concepts of scientific archaeology in this way, we are in a better position to construct refutable models of the archaeological record.

For this study the identification process involves developing a way to quantify aboriginal behaviors in terms of their ecological impact. We must duplicate the rules governing Mississippian agriculture by extrapolating modern analogues from historical records which describe Mississippian-like lifeways. Given these behavioral options, we can use observations from agronomy to predict the ecological response to Mississippian conditions.

System realization involves generating the means by which input-output relationships can be calculated. Selection of a model, whether statistical or dynamic, is largely based on one's assumptions about the structure of the phenomena under study. To accomplish both one must first present a system definition based on observed relationships specified under well defined research restraints. To improve accuracy, the observations used to construct the model should not exhaust those available for testing its validity. In other words, a model which only reiterates its initializing observations lacks predictive credibility. Using data independent of the specific archaeological application or choosing a different set of situations to test a model is the only appropriate way to utilize the modeling approach free of tautologies.

Our level of resolution is largely dependent on our goals. Detailed specificity in model design sacrifices the global application of the results. For example, a model designed around a single site loses its general validity at the coarser scaled regional level. Likewise, the more general and theoretical the model the less useful it is in addressing specific micro-level variability. A model's application must be clearly presented in terms of some level of specificity and is constrained at a particular level of resolution in terms of space and time. Just as the modeler must not overstate the conclusions, the reader must be cautious not to misapply the results to an unsuitable situation (or at a scale inappropriate for the model's assumptions and parameters).

The problem orientation of this research is somewhat complex, having been derived from several studies on the nature and effects of change during and after the Mississippian period. Any model used to examine a critical part of such a system should produce equally discontinuous responses at equivalent intervals along a temporal dimension. These intervals make up the frequency of change for the system.

Recent studies (Autry 1983; Peebles 1983; Schroedl 1986; among others) have benefited from theoretical discussions of culture as an information processing system (Johnson 1978, 1982), a means of social reproduction (Friedman 1975, 1982; Friedman and Rowlands 1977), and a topological manifestation (Renfrew 1978, 1979; Renfrew and Poston 1979; Poston and Stewart 1978:412-413; Zeeman 1982). Each of these theoretical approaches offers a processual perspective suitable for addressing Mississippian change. Unfortunately, initial applications have been limited to qualitative discussions of their processual elegance (in an explanatory sense) and not directed towards quantification of the frequency of change. This has largely been due to the difficulties inherent in quantifying information, social reproduction, and relevant topological parameters along a time line.

This study recognizes the usefulness of these approaches as a first step towards realigning theory with observation and methodology. My conclusions are not intended to replace the intuitive elegance of their arguments. But, to add substance (i.e. a level of refutability) to the application of theories such as these, they should be restated in terms that are directly testable and that facilitate dynamic modeling of specific situations. That is, it is necessary to identify, through observations on working systems, the parameters that serve to influence the direction of change and create a computational model to plot the fluctuations of relevant response variables over time.

My intent is to supplement their intuitive conclusions with such an analysis of the, as yet unexplored, agricultural subsystem of the Mississippian Period. The subsystem is worth studying because of the historical references to its instability, its assumed importance in the literature, and the lack of any substantive description of its prehistoric form.

The Hypothesis

Because the focus of this study is on the agricultural limitations of Mississippian cultures, the model's definition of crop production should be in terms of the needs and capabilities of the practitioners. This involves determining what is grown, how it is grown, and how much is produced within a specific cultural context. This observational stage involves comparing similar populations in like environmental and technical settings. Unfortunately, finding extant data on maize agriculturalists lacking domesticated livestock and living in temperate climates is difficult (see Nye and Greenland 1960). Therefore, these parameters must be extracted from ethnohistoric accounts of contact groups in North America.

Resorting to analogy by enumeration assumes that the observed situations in the sixteenth through eighteenth centuries approximate those of the previous 700 years. Although the specifics will change over this time period, the maximum technological knowledge should approach that of the contact period. The material technology of hoe agriculture prior to the introduction of European tools can be safely assumed to be a constant. Maize varieties, if grossly different between A.D. 900 and 1700, will certainly be more productive at the end of the period. Thus, inaccuracies will tend towards understating the negative effects of aboriginal agriculture over the entire period. The minimum caloric needs of each individual will be a constant even though surplus requirements may vary. Given the discipline's use of ethnographic analogy, data extracted from ethnohistoric accounts should be acceptable as a basis for describing the macroscopic behavior of hoe agriculturalists.

The observational base will provide the structural framework of the system in terms of behavioral and technological inputs and their resultant productive output. By identifying the options available to traditional aboriginal cultures, we can address the long term maintenance implications of such a man-plant-soil relationship. This involves understanding the physiological needs of maize and the productive response of the agrarian ecosystem to nutrient extraction and replenishment. Such independent empirical information is readily available from botanical, agricultural, and ecological sources. Understanding the agrarian ecosystem makes it possible to select computational models of specific responses to traditional practices. These responses will be compared to the dynamic fluctuations indirectly observable in the actual archaeological systems.

Once a model is constructed on the basis of a set of observed system responses, its application must be archaeologically tested. As this study represents an initial attempt to model such a system within an archaeological context, its application must be at a level of specificity suitable for data acquisition and presentation. This would involve a single catchment area with well defined environmental and cultural data. I have selected data from the lower Little Tennessee River valley of east Tennessee as the subject of the study. The geographical boundaries include the counties of Monroe, Blount, and Loudon (see Figure 1). These arbitrary limits serve to contain the agricultural catchment around known sites in the Little Tennessee and Tellico River Valleys and provide manageable soil data relevant to this study.

The availability of extensive archaeological data produced by late nineteenth century investigations, the Works Progress Administration period of Southeastern archaeology, and the recent Tellico Archaeological Project (Riggs and Chapman 1983) provide sufficient cultural data for model testing. Ethnohistoric accounts of the Overhill Cherokee settlements in east Tennessee (see Baden 1983; Schroedl and Russ 1986) contribute regionally specific estimates of model parameters. The region also benefits from palynological research (Cridlebaugh 1984) and published soils data relevant to agricultural modeling. The combination of model identification, realization, and testing following the guidelines discussed above should provide a suitable demonstration of the power of system modeling for archaeological applications.

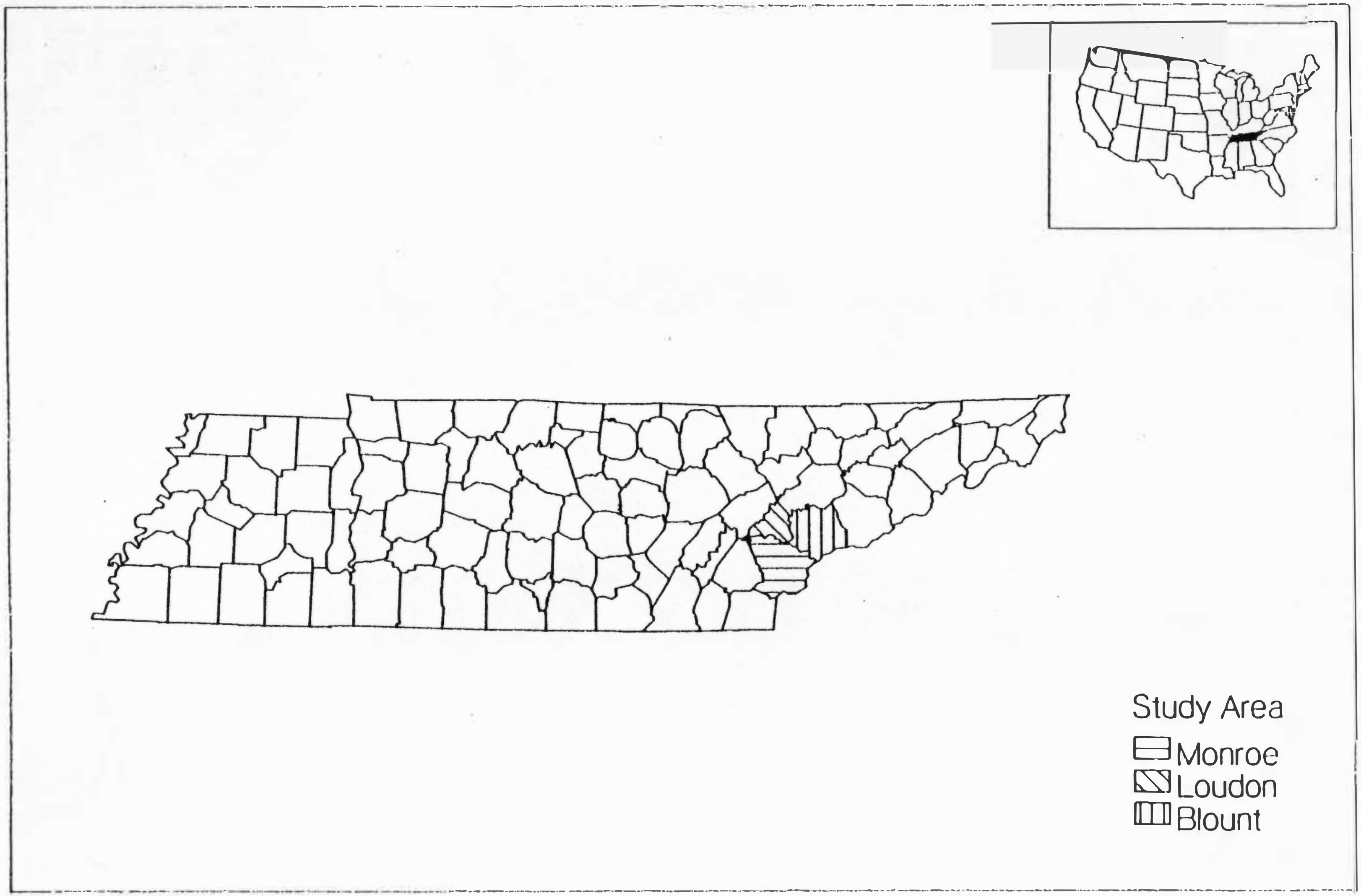

Figure 1. Study area.

CHAPTER II

ETHNOHISTORIC EVIDENCE OF PREHISTORIC AGRICULTURAL SYSTEMS

Ethnohistoric Accounts

The following section examines the historic record of aboriginal contact with western chroniclers as it pertains to agricultural practices in the temperate climates of North America. The goal is a recreation of the earliest known planting practices in the Great Lakes, Plains, and Southeast. The evidence is in the form of firsthand (primary) accounts and secondary examinations by scholars that display sufficient knowledge about maize horticulture or aboriginal lifeways. Of particular interest are statements describing the importance of maize, field preparation, planting, cultivation, and harvesting.

The primary sources include the accounts of the French Jesuits and Recollects in New France during the seventeenth and eighteenth centuries. Of the nearly 400 references to corn in Thwaites' (1896-1901) volumes, the relations of Le June (ca. 1635-6), du Peron (ca. 1639), and Rale (ca. 1723) were found to be the most useful. The more detailed accounts of Sagard (1939), Lafitau (1977), Le Clercq (1968), and Lescarbot (1968) were also used. The writings of Bartram (1853, 1928) and Adair (1930) serve as major sources for the Southeast.

First hand observations of aboriginal agriculture are seldom lengthy, even when made by a botanist like Bartram. The accounts need to be supplemented with secondary sources devoted more exclusively to summarizing subsistence activities. The data summaries of Will and Hyde

(1917), Herndon (1967), Parker (1968), and Holder (1970) serve such a purpose. When combined, the historic record provides a pattern of early agricultural practices sufficiently detailed for our purposes. In addition, the observations noted in this chapter are supported by the specific examinations of others (Baker 1974; Ceci 1975; Day 1953; Heidenreich 1971; Minnis 1985; Rutman 1967).

The Importance of Maize

The origins of agriculture, though important, need not be examined here. Anthropologists have concentrated on discovering the earliest evidence of agriculture to such an extent that they often lose sight of the more important issue of agricultural productivity. For this study the question is, "What did agriculture provide its practitioners" and not "Why did they take up agriculture?" We know that by Mississippian times maize farming was an important aspect of the aboriginal economic system. I would argue that to understand its importance we must look at early accounts of Indian lifeways and, following Harner (1975:125), discard the substantivists' assumption of abundant food resources in North America.

Aboriginal groups suffered from severe food shortages in the winter. Without the capability of long term food preservation, the bounty of the spring and fall seasons could not be utilized when food sources were less accessible in January and February. Parker (1968:64) reports that the Iroquois appetites were small and that they consumed only two meals a day to prepare them for the lean winter months. Le Clercq (1968:110) notes that the Gaspesians did not plant crops being ". . .

convinced that fifteen to twenty lumps of meat, or of fish dried or cured in the smoke, are more than enough to support them for the space of five to six months." He adds that they often were left "fasting" in January and February.

The Seneca referred to their agricultural products as "these that sustain us" (Parker 1968:27). This is because plant foods are easier to store for long periods and, if kept dry, grains could last through the winter and into the summer.

As to the singular importance of maize, Le June (Thwaites 1896-1901:10:139,163) observed that an early frost killed the corn leading to famine and a hard winter. He alluded to a function of the Green Corn Harvest when he noted that ". . . the children will cause the ears to be roasted when they are green" (Thwaites 1896-1901:10:163). Adair (1930: 436) referred to corn as "their chief produce, and main dependence". Herndon (1967) recognized that "[corn] was the main dependence of all tribes south of the St. Lawrence River and east of the Mississippi". Bennett (1955:395) estimates that maize constituted 65% of the total caloric intake of southeastern New England groups with meat and fish supplying less than 20%. The number of dishes incorporating maize (Parker 1968) further suggests that maize far outweighs beans and squash as a food resource. As such, we are justified in making the production of maize the essential system to be studied here.

Field Preparation

Field preparation involves the removal of all primary growth prior to initial planting of new ground and the clearing of annual plant debris from older fields. Most, if not all, trees must be removed and all brush burned prior to planting. Parker (1968:21) describes the process as involving girdling the trees in the spring with the brush being burned the following spring before planting. Any trees left standing at that time would be burned down. Lafitau's (1977:70) 1724 discussion suggests that this process precedes the initial planting by "some years". Adair substantiates that this basic clearing practice was followed in the Southeast:

> Now, in the first clearing of their plantations, they only bark the large timber, cut down the saplings and underwood, and burn them in heaps; as the suckers shoot up, they chop them off close by the stump, of which they make fires to deaden the roots, till in time they decay [1930:435].

Similar practices were followed by Plains agriculturalists such as the Arikara, Mandan, Pawnee, and Hidatsa (Will and Hyde 1917:77).

To what extent the horticultural value of burning was understood, is difficult to ascertain. Most observers were struck by the absence of any form of fertilizing. Reverend Gilbert Wilson believed the Hidatsa recognized the value of ashes when they burned the plant debris while noting that they would also remove all horse dung from the fields because "weeds always came up where the dung lay" (cited in Will and Hyde 1917:84). Will and Hyde (1917:79) relate that the practice of spreading brush over the fields prior to burning was only seen as making the ground easier to dig. Sagard (1939:103) notes that the women clear the fields of everything before planting. Thomas Heriot, in 1587, writes that the coastal Indians of Virginia never used "muck, dung, or any thing" to "fatten" the soil (cited in Parker 1968:25). He further notes that all dried debris was piled in heaps to be burned with the ashes seldom spread unless their volume required it.

Planting

In those accounts offering information about labor, the post-clearing stages of maize agriculture was carried out by the women of the village (Parker 1968:23; Sagard 1939:103; Will and Hyde 1917:79; Williams 1963:123). The process generally began with the production (on new land) or clearing away of "hillocks" (Lafitau 1977:54). These hills were the result of mounding actions around growing plants to help secure them in the soil (Parker 1968:26). Will and Hyde (1917:79) relate that along the Upper Missouri the hills were dug up and pulverized before planting. Sagard (1939:103) saw them place the seeds in round holes, not hills, a pace apart. Other accounts indicate the seeds were placed directly into hills (Lafitau 1977:54; Lescarbot 1968:195-196).

The number of seeds planted in each hill ranged from three to ten (Lafitau 1977:54; Lescarbot 1968:248-249; Parker 1968:17,25-26; Sagard 1939:92; Thwaites 1896-1901:66:142-143; Will and Hyde 1917:81). The hills were a foot or more in diameter and generally described as being two to three feet apart (Lafitau 1977:54; Lescarbot 1968:248-249; Parker 1968:25; Sagard 1939:103; Will and Hyde 1917:79,81). Each row was separated by an area five to six feet wide (Parker 1968:26). In one case the plantings were described as being more densely packed:

> [the Indians] plant the corn-hills so close, as to thereby choak up the field. They plant their corn in straight rows, putting five or six grains into one hole, about two inches distant. They cover them with clay in the form of a small hill. Each row is a yard asunder, and in the vacant ground they plant pumpkins, water-melons, marsh-

> mallows, sunflowers, and sundry sorts of beans and peas, at least two of which yield a large increase [Adair 1930:439].

Champlain (ca. 1605) notes that three to four bean seeds were placed in each hill (cited in Parker 1968:17). Parker (1968:27) says the Seneca planted squash and beans in every seventh hill. Among the Omaha, Fletcher and La Flesche (1911:269) relate that hills alternated between squash and corn. Generally, however, additional plots or the area between rows were planted with squash, pumpkins (citruels), and melons (Adair 1930:436; Parker 1968:89-92). Parker (1968:89-92) notes that the Iroquois planted fourteen types of beans and five types of squash in addition to various varieties of melons.

Along the Upper Missouri River Valley, the Indians recognized that various maize varieties would cross pollinate, so plots of common seed were separated by 60 to 100 yards (Will and Hyde 1917:291). Will and Hyde (1917:69) describe three basic types of maize grown in this region: flint (8, 10, 12 row), flour (8, 10, 12 row), and sweet. Adair (1930: 436) notes three types of corn grown in the Southeast early in the eighteenth century: flint ("hommony-corn"), bread-corn, and a smaller, unidentified variety.

Planting was begun when the danger of a late frost was minimized. This could occur as early as April in Florida (Lescarbot 1968:195-196) and as late as May as far north as Quebec (Parker 1968:17). Most planting seems to have been done in May, although Parker (1968:26) cites Harris on the practice of also planting some in April and June to produce (weather permitting) both early and late harvests. The Iroquois and the Southeastern Indians planted small, personal plots near their dwelling structures prior to planting the larger, communal fields (Adair 1930:435; Bartram 1928:284; Parker 1968:29).

The popularized (Bennett 1955:375) practice of fertilizing each hill with fish (the Squanto legend) was partially substantiated only once in all the accounts examined. Lescarbot (1968:248-249) speaks of the Armouchiquois, living in the area of modern Boston, using shellfish as fertilizer. Ceci (1975), on the other hand, clearly rejects the notion that this technique was aboriginal in origin (see also Rosthund 1957). She argues that Squanto learned the value of fertilizing during his visits to New World settlements and (ca. 1614) the Old World. Indeed, as she points out, the quantity of fish required at a time of year when food was most needed would have logically been wasteful.

Cultivating

Parker (1968:23) cites Heckewelder as claiming women worked six weeks a year in the fields. Considering that planting and harvesting could take up to two weeks each (Will and Hyde 1917:129) this means that very little time was spent cultivating the fields. For the Iroquois (Parker 1968:29) and Plains farmers (Will and Hyde 1917:82), cultivation involved two hoeings. Parker relates that the first hoeing occurred when the plants were a "span" high. The second, called "hilling up", took place when the plants were knee high. Similarly Arikara, Hidatsa, Mandan, and Pawnee performed their second hoeing when the plants were roughly one foot high and just before abandoning the villages for the summer hunt.

Herndon (1967) concludes that only the hills were weeded. Sagard (1939:104) noted that the land was not tilled, only "cleansed of noxious weeds" such that he often got lost in the maze of paths running through the fields. Parker cites Harris on the Iroquois weeding "from time to time" (Parker 1968:26). With the exception of trying to keep rodents and deer from destroying the crop (Lescarbot 1968:248-249), the fields were largely left without additional maintenance.

Harvesting

Generally, the maize harvest was divided into two stages. The first was the Green Corn Harvest of flint and flour maize varieties in early August (Will and Hyde 1971:115). Unripe ears (kernels in the milky stage) would be picked and boiled before being eaten or sun dried (the only way these kernels can be stored). Will and Hyde (1917:143) first recognized that this harvest served as a precaution against total crop destruction later in the year by insects, birds, drought, and raiding parties. By harvesting a portion of the crop early, villages were guaranteed a minimal supply of maize. The remainder of the crop would be harvested later in the fall or continuously as the need arose.

Witnessing this early harvest often confused western observers into thinking the growing season was shorter than it really was. They often state that the crop ripened in two months or early in August (Adair 1930:435; Lescarbot 1968:195-196; Parker 1968:26; Thwaites 1896-1901:67: 142-143). However, the crop required three to four months to ripen (Parker 1968:17; Sagard 1939:104;) with the second stage of the harvest occurring in September and October.

The most detailed description of the harvest is provided by Parker (1917:31-35). The Iroquois would remove the ears from the field for later husking. In some cases the entire plant was taken to the village for processing. The corn was then husked and the ears braided together and hung from the house roofs and centerpost to dry. This braiding technique was also performed by the Huron (Sagard 1939:104) and Plains groups (Will and Hyde 1917:133). Shelled grain was stored in dry, bark casks or in elevated granaries (Parker 1968:31-33). Although in dry areas corn was stored in pits dug along slopes or mounds (Bennett 1955:376; Cutright 1969:98; Lescarbot 1968:195-196), storage pits were more likely to be used to keep melons and squash (Parker 1968:31-35). Frost-prone melons could even be transplanted into baskets for later harvest (Parker 1968:92).

The harvest was often divided between communal and individual tasks (Bartram 1928:400; Parker 1968:29). As noted above, each village would collectively plant a communal field explicitly divided into family plots. Each family also had the option of growing a small garden which could be harvested at any time (Herndon 1967). The familial plots in the communal field were harvested together as a village-wide activity. Bartram (1928:401) speaks of the Creek practice of providing the King's crib with a portion of each family's harvest. Such a surplus was used for unexpected needs such as depletion of a family's stores, the needs of another village, warparties, and visitors.

Crop Yields and Field Size

Potential crop yields and field size are two very important variables in modeling aboriginal agriculture. Few accounts, however, provide detailed measures of either. In southwestern Ontario, Sagard (1939:103) speaks of the Huron growing two to three years supply of maize for consumption and trade with their northern, Algonkin neighbors. Lescarbot (1968:195-196) suggests that Florida harvests lasted six months. Denonville (cited in Parker 1968:18) writes that an attack on four Seneca villages destroyed, perhaps overestimating, 1,200,000 bushels of old and unharvested corn. Le June's Relation (Thwaites 1896-1901:8:95) claims one Indian had two bins containing 100 to 120 bushels of corn.

Yield potential is related to ear production, field size, and plant density under varying climatic conditions. Will and Hyde (1917:71-74) identified a wide variety of forms within each maize race conducive to differing environmental conditions. Hayden (cited in Will and Hyde 1917:71-72) states that Upper Missouri corn was three to six feet tall with an average height of 4 to 4.5 feet. Ears were generally produced close to the ground with two or more growing further up. Pawnee varieties, growing further south, tended to be taller. Good climate and soil conditions could double the size of Mandan corn over that grown under less than optimal situations.

Specific figures on actual maize yields are more difficult to obtain. Sagard (1939:104) speaks of each plant producing two or three ears with each ear containing from 100 to over 400 grains. Roger Williams (1963:124) estimated that each Indian woman produced 24 to 60 bushels of corn per year. Using Rutnam's (1967:43) yield estimate of 18 bushels per acre for seventeenth century America, we have 1.3 to 3.3 acres planted by each family.

The only specific data on field size comes from the work of Will and Hyde. The Mandan used a unit of area called a nupka (Will and Hyde 1917:99). It consisted of seven rows of corn with "rows of beans between each two rows of corn, and with no fixed length". They claim the average size was 0.25 acres. Although some fields may have been as large as ten, on average each mature women had a garden of three to four nupkas. Additionally, they (1917:65) cite Dunbar's observation that up to three acres were planted per family, with a mean closer to one. They conclude that Upper Missouri field size ranged between 0.33 and 1.0 acre per person, depending on the population's level of agricultural dependence. Cutright (1969:98) suggests that Arikara plots ranged in size between 0.5 and 2.0 acres depending on the number of wives in the family.

Various census reports provide crude estimates of per capita field size. Will and Hyde's (1917:106) data from the 1878 census of Iowas suggests a mean of 1.4 acres/person. Seven bands of Osage in 1872 had a combined average field size of only 0.3 acres/person (Will and Hyde 1917:107). An eighth band consisting, in part, of "half breeds" used 3.0 acres/person. In 1666, the Puquot Indians in Connecticut were removed to a new area and reimbursed for their land. Records of corn field size for nine individuals showed a range of 0.15 to 2.5

acres/family, averaging 0.85 acres/family (Thomas 1976:11). Prior to their removal, data on agricultural production of eastern Cherokees was compiled into the 1835 census (Bureau of Indian Affairs 1835). Using only those families (n = 36) which indicated no corn was raised as a cash crop, mean estimates of yield per acre (11.4 bu, sd = 8.19), field size (6.6 acres, sd = 4.26), harvest per person (20.1 bu, sd = 18.54), and field size per person (1.25 acres, sd = 2.08) were calculated. Schoolcraft's (1847:32-38) census of the nine Iroquois Reservations produces estimates of an average yield of 21.3 bu/acre (sd = 5.95) and 9.8 bu/person (sd = 4.07) for a society devoting only 39.2% of its fields to maize.

In comparison, English farms in twelfth century Peterborough generally consisted of less than three modern acres (Will and Hyde 1917:109). The French botanist, F. A. Michaux, observed eight to ten acres planted by large American families along the Ohio River in 1802 (cited in Will and Hyde 1917:108). Rutman (1967:61) reports that, although each Plymouth farmer was capable of cultivating as much as twenty-five acres, few ever did. In each case, these farmers made use of draft animals and plows.

Discussion

The 1952 survey by the UNESCO Commission on World Land-Use classified <u>shifting cultivation</u> as that type which involves settlement movement rather than merely periodic field changes (i. e. field rotation) (Nye and Greenland 1960:5). Shifting cultivation always involves burning forest or grassland prior to cultivation. Such burned areas have been referred to by the Old English term of swidden with the process being called slash and burn. However, the transient nature of the process is more accurately represented by the term shifting cultivation or by regional terms like *milpa* (Central America), *chena* (Shri Lanka), *kaingin* (Phillipines), *coamile* (Mexico), *ray* (Laos), *conuco* (Venezuela), and *masole* (lower Congo) (Nye and Greenland 1960:6, Symons 1978:172). It is my contention that the agricultural cultures living in the temperate climates of North America practiced shifting cultivation. If true, the implications for settlement interpretation would be far reaching (see White 1963).

To support this characterization, note that ethnohistoric accounts substantiate the use of fire to clear fields prior to planting. Secondly, although most accounts are not precise concerning all details of maize production, they often are most explicit about its impact on settlement systems. Soil depletion and firewood exhaustion are clearly seen as causes for village movements.

Sagard, ca. 1632, on the Huron states:

> The chief town formerly contained two hundred large lodges, each filled with many households; but of late, on account of lack of wood and because the land began to be exhausted, it has been reduced in size, divided in two, and rebuilt in another more convenient locality . . . . There are certain districts where they move their towns and villages every ten, fifteen, or thirty years, more or less, and they do so only when they find themselves too far away from wood . . . . They move their town or village [also] when in course of time the land is so exhausted that their corn can no longer be grown on it in the usual perfection for lack of manure; because they do not understand cultivating the ground nor putting the seed anywhere else than in the usual holes [Sagard 1939:92-93].

Francois du Peron, ca. 1639, writes of the Huron:

> The land, as they do not cultivate it, produces for only ten or twelve years at most; and when the ten years have expired, they are obliged to remove their village to another place [Thwaites 1896-1901:15:153].

In the "Decrees of the Council of Marne respecting the Christian Savages in Canada, April 1, 1716":

> . . . on the 7th of November, 1715, Monsieur Begon wrote that Father Cholenec, the missionary of these savages, represented in 1714 to Monsieur The Marquis de Vaudreuil and to him that these savages could no longer remain in their village, because the soil was exhausted and the woods too far away; and that it was absolutely necessary for them to settle elsewhere [Thwaites 1896-1901:67:25].

In 1724 Lafitau, after ten years in Canada, writes:

> As the Indians never manure their ground and do not even let it lie fallow, it is soon exhausted (and worn out). Then they are forced to move their villages elsewhere and make new fields in new lands. They are also reduced to this necessity, at least in North American and cold countries, by another more pressing reason for, as the women have to carry firewood to their lodges every day, the longer a village stays in the same place, the farther the distant the wood is so that, after a certain number of years, they can no longer keep up the work of carrying the wood on their shoulders from so far [1977:69-70].

Bartram, ca. 1773, received this answer from a trader in the Creek town of Apalachucha when asked why the Indians "frequently" broke up their towns and settled new ones:

> . . . the necessity they were under of having fresh or new strong land for their plantations, and new, convenient and extensive range or hunting ground, which unavoidably forces them into contentions and wars with their confederates and neighboring tribes; to avoid which they had rather move and seek a plentiful and peaceable retreat, even at a distance, than contend with friends and relatives or embroil themselves in destructive wars with their neighbors . . . [1928:315].

As further evidence, Ceci's (1975) examination of northeastern agriculture cites Roger Williams' (1963:119) record of two Indian terms for "planting fields", one meant "worne out" and the other "new ground". She further notes Morgan's contention that the Huron and Iroquois moved their villages every eight to twelve years. Herndon (1967) states that the Indians ". . . practiced a rotation of fields rather than a rotation of crops". In the Plains, Holder recognizes:

> The physical size of a village appears to have been limited by the available arable land and wood supplies in the river bottoms. As these resources were depleted the location of the village shifted, following a slow cycle of some fifteen to thirty years [1970:35].

All of this supports the utilization of a shifting agricultural model for aboriginal agriculture (cf. Bennett 1955:373-374) and the necessity of incorporating it into our definition of the Mississippian system.

Summarizing, the Eastern North American Indian's agricultural tradition involved the following generalized practices:

1. Fields were cleared using fire one or more years in advance of the first planting;
2. Fire was also used to clear old fields prior to planting;
3. Planting was undertaken after the first sufficient thaw;
4. Three to ten kernels were placed in hills spaced two to three feet apart in rows up to six feet apart;
5. No recognized soil fertilization procedure was practiced;
6. Cultivation involved two minimal hoeings when the plants were roughly six inches and two feet high, respectively;
7. Harvesting was undertaken in two phases: the first in middle-to-late summer when the kernels were in the milky stage and the

last in the fall after the grain had completely ripened;

8. Yield estimates ranged between 10 and 20 bu/acre;

9. Field sizes ranged between 0.3 and 1.5 acres/person.

The data presented in this chapter serve as the observational basis for defining specific model parameters. The next step involves generalizing the range of procedures used in land preparation, planting, and harvesting in a way suitable for defining the behavioral boundary conditions of the system. At that point, we can specify the essential parameters that directly contribute to defining the production potential of the system and arrive at a dynamic model of system change.

CHAPTER III

SPECIFICATION OF MODEL PARAMETERS

To create a quantitative model based on the ethnohistoric evidence, we must identify the essential parameters which would induce the observed decline in soil fertility over a period of time. Ultimately the derivation must be reformulated into mathematical terms. If we start with a population of size p which requires n units of maize per person per unit time then we estimate that $(np)/y$ units of land will be required, where y is the average yield potential per unit area. Our problem involves predicting what these values will be at some time, t, recognizing that p and y (and later, n)are changing functions of time expressed as $P(t)$ and $Y(t)$, respectively.

Assuming, for the moment, that per capita maize requirements remain essentially constant, the land requirement, l, at time t is:

$$l = nP(t)/Y(t) \qquad (3.1)$$

Population, under normal conditions, will be expected to be nondecreasing. Because we know from observation that soil used under aboriginal conditions becomes depleted, we can infer that $Y(t)$ is a decreasing function of time. It follows that l can be defined as a nondecreasing function, $L(t)$. If $L(t)$ reaches some threshold value related to the maximum amount of land available or the maximum amount of land that can be worked under technological and manpower restraints, the society must make adjustments to reduce the subsistence stress. Because their technological system precludes the implementation of soil improvement practices, aboriginal options were limited to population controls such as migration (fissioning of villages), adjustments in biological response (e.g. reduction in body size), or decreasing the intrinsic rate of growth (such as infanticide and war). The purpose of modeling aboriginal agriculture is to define when such stresses would occur so that we can anticipate the impact on the archaeological record.

Recreating the dynamics of Mississippian agriculture means being able to approximate the form of P(t) and Y(t) as well as estimate the value of **n** and the threshold values of L(t). Our estimates must be accurate within the same order of magnitude of the actual, but unobservable, values during the Mississippian. For archaeological applications such accuracy is reasonable and sufficient. This chapter provides arguments for the acceptance of certain functions and parameter values which answer these needs.

This involves defining population dynamics, yield potentials, yield reduction, and per capita consumption as physical processes bounded by a range of potential values. The structure of Mississippian agriculture is composed of a set of production options and limitations. By understanding the interactions, we can construct a viable model that can be applied to a specific archaeological context (Chapter IV).

Population Dynamics

The growth rate function is modeled in terms of some range of initial population densities over the entire Mississippian Period. To do this, population parameters must be developed to reflect prehistoric conditions as revealed by paleodemographies (and constrained by the inherent limitations of such data).

The approach of paleodemographic studies primarily incorporates life table methods, assuming a stationary population (i.e. no significant increase in size) as presented by Acsadi and Nemeskeri (1970) and Ubelaker (1974). Although such a model provides some useful information (Hall 1978), I do not believe it is acceptable to assume stationary conditions existed during the entire span of the Mississippian Period simply to facilitate the use of life table data. Howell (1973) and Weiss (1973,1975) argue that we should use models developed from large populations over time in the study of prehistoric demographics. The established Coale-Demeny models (Coale et al. 1983) serve this purpose.

Their models were derived from 326 male and female life tables taken from populations recorded over the last century or more. They include samples from Africa (15), North America (18), Latin America (33), Asia (32), Europe (206), and Oceania (22). The results (see Coale et al. 1983:1-36 for the methodology) were categorized into four families (North, South, East, and West) of tables each with 25 mortality levels for each sex. Given certain empirical data, such as estimates of life expectancy and the gross reproductive rate for females, models can be selected from which the underlying parameters of the population can be derived. The advantage of this approach lies in its allowance for interpolation between "real" data instead of relying on the extrapolation of unobserved information from incomplete archaeological material (see Angel 1969).

Instead of assuming a stationary condition, one can recognize the underlying stability which all populations tend to reflect and use it to generate an alternative representation. Such stable populations display a constant rate of increase derived from a prolonged "prevalence of an unchanging fertility schedule" (Coale et al. 1983:7). The original concept of stability was defined by Lotka (1907) as a population whose age distribution was:

$c(x) = bP(x)\exp(-rx)$ where : $c(x)$ is the proportion of individuals at age x

b is the birth rate

r is the annual rate of increase

$P(x)$ is the proportion surviving to age x.

Every life table tabulation and its computed r value implies a "determinate age composition, with an associated birth rate and death rate" (Coale et al. 1983:7). Stability is defined in terms of this unchanging age distribution.

The selection of appropriate mortality schedules for each sex requires that we make some basic assumptions about the characteristics of late prehistoric demographics. Generalized knowledge (Hassan 1975: 43; Angel 1975) of early population dynamics would indicate that we should expect:

1. a high infant mortality rate, probably around 50%,
2. a life expectancy at birth of 20 years,
3. a low average maternity schedule ($\mathbf{m}$), probably around 23 years, and
4. a large female gross reproductive rate for $\mathbf{m}$ [GRR($\mathbf{m}$)] in the range of 4.0 to 5.0 female children.

Given a high infant mortality rate and a low life expectancy, West level 1 mortality models are the most suitable. Some of the basic population statistics adjusted for a GRR(23) range of 2.0 to 4.5 for these models are presented in Tables 1 and 2 (higher GRR values cannot be interpolated from the original tables when m is as low as 23 years). The Net Reproductive Rate (NRR) represents the average number of daughters that reach adulthood born to each woman. The Dependency Ratio is the proportion of individuals of each sex less than 15 and over 60 years of age to the rest of the population. The Generation Length is calculated following Pollard (1973:35) for those situations where the growth rate is greater than zero. It represents the number of years required to increase the birth rate by a factor of NRR times its original value. The mean number of male and female offspring that must be born to each adult woman if her cohort is to be replaced prior to reaching menopause is the Average Family Size (Weiss 1973:39).

Life expectancy at birth for the female tables is 20.0 years. For the males it is 17.4 years. The growth rates range from -0.014933 when GRR(23) equals 2.0 to 0.022205 for a GRR(23) of 4.5. Hassan's (1975:42) estimate of 0.007 to 0.017 maximum potential annual growth for hunter/gatherers suggests the validity of using the GRR(23) value of 4.0 (r = 0.016690). However, this implies an average gross family size of over eight children, well beyond Angel's (1975:183) 4.7 estimate used by Hassan (1975:43). This would mean that either Angel's (1969:432) method of using pubic changes to estimate the average number of births per woman is invalid or these stable models are inappropriate for our use. In the absence of more reasonable data, we will assume that our

Table 1. West Level 1 female statistics.

Parameter	GRR(23.0) 2.0	2.8	3.0	4.0	4.5
Birth rate	0.032801	0.050416	0.054341	0.073211	0.081591
Death rate	0.047734	0.050416	0.051014	0.056521	0.059386
Growth rate	-0.014933	0.0	0.003327	0.016690	0.022205
NRR	0.656	1.017	1.097	1.586	1.845
Average age	31.126	25.589	24.355	20.249	18.788
Percent 15-44	46.793	46.05	45.887	42.715	40.983
Dependency ratio	0.560	0.719	0.754	0.992	1.117
DR over age 1	0.036606	0.033249	0.032501	0.031520	0.031512
DR over age 5	0.033211	0.027541	0.026278	0.022814	0.021714
Avg age at dth	30.605	20.338	18.050	11.793	9.947
Avg age dth >5	48.137	41.586	40.127	34.449	32.290
Generation length	-	-	27.8	27.6	27.6
Avg family size	3.4	5.2	5.6	8.1	9.4

NRR = net reproductive rate DR = death rate Avg = average dth = death

Table 2. West Level 1 male statistics.

Parameter	GRR(23.0) 2.0	2.8	3.0	4.0	4.5
Birth rate	0.037075	0.055883	0.060073	0.080109	0.089022
Death rate	0.052009	0.055883	0.056746	0.063429	0.066819
Growth rate	-0.014933	0.0	0.003327	0.016690	0.022205
Average age	29.597	24.550	23.425	19.661	18.315
Percent 15-44	49.263	47.660	47.303	43.633	41.753
Dependency ratio	0.533	0.705	0.743	0.985	1.110
DR over age 1	37.381	33.780	32.978	31.678	31.530
DR over age 5	33.965	28.108	26.803	23.062	21.839
Avg age at dth	27.645	18.358	16.289	10.666	9.000
Avg age dth >5	46.488	40.828	39.567	34.622	32.693

DR = death rate Avg = average dth = death population parameters based on the West level 1 model are usable. Based on all the data, we will adopt a range of growth between 0.003 and 0.017 corresponding to GRR(23) values of 3.0 and 4.0, respectively. Such rates should be appropriate for Mississippian development beginning around A.D. 900. The average family size, allowing for infant mortality, would probably lie between four and five individuals at any one time.

To estimate future population size at some time, t, we will use :

$$P_t = P_0 e^{rt} \tag{3.2}$$

where P_0 is the initial population size, r is the intrinsic growth rate, and t is time in years (Weiss 1973:73). As populations cannot grow exponentially indefinitely, anticipated adjustments to the population size can be modeled in a number of ways. The growth rate could be seen as a function inversely related to some static maximum population size.

$$r_t = 1 - \frac{P_t}{K} \quad \text{where: } K = \text{maximum population size} \tag{3.3}$$

Hassan (1978:70) discusses such a damped growth function. However, use of such a logistic model for growth has not been shown to be reflective of human response to such stress (Pollard 1973:23) (cf. Harpending and Bertram 1975).

Instead of adjusting the value of r in this manner, we could recognize that stable populations maintain relatively consistent growth patterns until such time as they exceed some viable population size. This maximum size can be related to the abstract notion of fluctuating carrying capacity. Although it is an extremely difficult task to calculate this value (see Brush 1975 and Street 1969), we can accept its existence as an index of a culture's capacity to exist under specific environmental, technological, and societal limits. For agricultural systems such as those of interest here, this will involve relating productive needs against productive capabilities. When the limits are reached, however they are measured, society will restructure the conditions as best it can to reduce the associated stress. In the absence of technological shifts and social adjustments, this can involve adopting instantaneous population reduction measures, such as infanticide and war, or encouraging migration to reduce the population density in one area. We will calculate the frequency of such stresses as they relate to agricultural dependence and examine the consequences of proposed Mississippian solutions to the problem.

Estimating Yield Potential

Anthropological and botanical research into the development and use of early forms of *Zea mays* L. has almost exclusively been directed towards describing their origins and evolution rather than their productive capabilities (Galinat 1977; MacNeish 1964; Mangelsdorf 1974; Mangelsdorf et al. 1964,1967). This study requires specific botanical data on yield potentials and cultivation requirements for pre-contact varieties given the farming technology of the period. Pending publication of such information (e.g. Cutler and Blake n.d. cited in Brown and Goodman 1977:75), we must investigate the possibility that documented pre-hybrid varieties were sufficiently similar to their earlier ancestors to justify extracting physiological data from historical records. This is reasonable given the antiquity of the various forms of maize and the slow rate of genetic change prior to intensive and systematic hybridization in the early 1920s. With such information we can evaluate the effects of early farming practices on long term productivity, Y(t).

To bracket yields per unit area over time, we must separate genotypic variability from environmental effects. As a result of microadaptations to specific conditions, each variety of maize has a certain maximum yield potential that can be achieved under optimal conditions. Such a value is independent of geographical locale and serves as a baseline about which we can judge the cultural and environmental influences on yield. Fortunately, maize adaptability to specific conditions allows us to ignore geographical influences when considering yield as a function of time. Maturation periods will vary with latitude but production potential under single cropping will be essentially constant within each variety. This section will examine the varietal influences on yield and attempt to estimate the prehistoric yields of early forms of maize.

Races of Maize

Anderson and Cutler (1942) developed the concept of maize "races" to classify forms that shared "enough" characteristics to make them recognizable as a single group. Brown and Goodman (1977:49-52) have outlined the development of the race concept noting the extensive efforts made to isolate racially important characters. Early emphasis was placed on obvious tassle, ear, and kernel variability. Today, chromosome knobs are used to help delineate specific movements of racial groups between geographic areas. Unfortunately only a few of these attributes are observable in an archaeological setting, resulting in a limited level of discriminatory resolution.

Archaeological samples from the eastern Woodlands tend to be placed into one of two general groups: Basketmaker or Eastern Complex (Yarnell 1964:107-120). The Basketmaker race is derived from the Southwest and represents the earliest (Middle Woodland) recognized "race" of maize in the East. Its form persists into the Mississippian period at Cahokia, west central Illinois. Basketmaker cobs have an elliptical cross section, small shanks, and tapered ends. The number of rows is usually 12 or 14 (here denoted 12/14) (Yarnell 1964:111-112). The Eastern Complex (sometimes just called Eastern) is characterized by 8/10/12 row ears with observable row pairing that produces square, pentagonal, or hexagonal cross sections. The kernels are usually crescent shaped with a height generally less than their width. These flint and flour forms appear in the East as secondary elements among Basketmaker-like samples dated as early as A.D. 1000 (Yarnell 1964:107).

Most research (Goodman and Bird 1977a,1977b) into early maize development concentrates on Latin American complexes largely because only nine of the recognized 169 races of modern maize are found outside the region (Galinat 1977:19; Brown and Goodman 1977:72-73). In their non-archaeological survey of maize races, Brown and Goodman (1977:72) acknowledge that very little is known about the extent of pre-hybrid varieties in the United States. Ignoring pop and sweet forms of maize, the modern races found north of the Rio Grande are :

1. Northern Flints,
2. Great Plains Flints and Flours,
3. Pima-Papago,
4. Southwestern Semidents,
5. Southwestern 12 Row,
6. Southern Dents,
7. Derived Southern Dents,
8. Southeastern Flints, and
9. Corn Belt Dents (Brown and Goodman 1977:72-73).

Based upon Brown and Goodman's (1977:73-79) overview, it appears that, on the basis of origin and antiquity, the races of Northern Flints, Great Plains Flints and Flours, and Southern Dents encompass the contact varieties relevant to this study. Additionally, the Pima-Papago race may be important due to its hypothesized relationship to the earliest forms (Basketmaker) found in the East (Brown and Goodman 1977:75; Yarnell 1964:111).

Most of the maize grown north of Georgia and east of the Mississippi River during the pre-Colonial period can be classified as Northern Flint. Its origin has been traced to either the Harinoso de Ocho of Mexico or the San Marceno and Serrano races of highland Guatemala. The many races found in the Great Plains often appear to be the product of crosses between Southwestern varieties and Northern Flints. Such mixing has been observed in ethnobotanical remains from fifteenth century sites in South Dakota. The complex of floury Southern Dents was extensively grown during the Colonial period as far north as Maryland. Many varieties seem to be northern adaptations of the Tuxpeno, Pepitilla, Tabloncillo, and Olotillo races of central Mexico (Brown and Anderson 1947,1948; Brown and Goodman 1977:73-77).

The relatively short stalked Northern Flints characteristically produce two, 8/10 row, ears per plant. Like their eastern relatives, the more variable Plains races tend to display 8/10 rows although 12/14 rows are not uncommon. The plants also tend to be shorter than the Northern Flints. The Southern Dents produce the tallest plants of all the races found in the United States. The number of rows per ear range from 8/10 (var. Hickory King) to 24/26 (var. Gourdseed) (Brown and Anderson 1947,1948; Brown and Goodman 1977:73-77).

At what time, then, do these gross morphological types of maize first appear prehistorically? Although it is difficult to generate a one-to-one correspondence between archaeological and modern samples, ethnobotanical research confirms a relatively great antiquity for many of the modern races. Some forms (Tuxpeno and Olotillo) linked to Southern Dents have been dated to the seventh century A.D. (Mangelsdorf et al. 1967:197), making them potentially available to spread northward into the Southeast by Mississippian times. A form of the Southwestern Pima-Papago race is considered to have been transported to the upper Mississippi Valley by A.D. 100 and to the coast of Georgia even earlier (Brown and Goodman 1977:75). The assumed Northern Flint ancestor, Maiz de Ocho, is recognized in the Southwest as early as A.D. 700 (Mangelsdorf 1974:113). As already noted, 8/10 row flint varieties begin to appear archaeologically in the East around A.D. 1000 (Brown and Anderson 1947:10).

Over the last 7000 years, the only fundamental change in the botanical characteristics of maize has been an increase in cob and kernel size (Mangelsdorf et al. 1967:200). Mangelsdorf notes:

> . . . it is true that in the hands of Indian cultivators maize had reached a high state of development when America was discovered. All of the principle commercial types of corn recognized today: dent, flint, flour, pop, and sweet, were already in existence when the white man appeared on the scene and, until hybrid corn was developed, the modern corn breeder, for all his rigorous selection, had made little progress in improving the productiveness over the better Indian varieties [1974:207].

Therefore, it is highly probable that most of the Mississippian varieties were similar enough to the flint and flour types grown by the early settlers that their production characteristics can be extrapolated from pre-hybrid historical records as well as data from hypothesized parental components in the Southwest, Mexico, and Guatemala.

Yield as a Function of Race

Approximating the yield of various races of prehistoric maize is difficult from two perspectives. First, our concept of archaeologically recognizable races does not carry with it quantitative values related to productivity. At best we can infer certain value ranges based on supposed connections with extant races, if these links are not too far removed temporally. For example, Yarnell's Eastern varieties consist of both flint and flour forms whose descendents are the modern, but no longer commercially viable, Northern Flints. To estimate the yield potential of these Northern Flints we could either conduct experiments with existing seed stored at various seed banks or examine the production records of the early nineteenth century. The first approach would be useful but beyond the scope of this project. Using historical records provides an upper bound for late contact maize production but does not give us specific information about earlier forms, such as the Basketmaker complex. This brings us to the second obstacle.

Our knowledge of the earliest forms of Mississippian maize is limited to fragmentary morphological characteristics of kernels and cobs. Although useful in terms of developing a classification system (see Nickerson 1953), they provide little insight into actual yields. We are left with the dilemma of not being able to directly measure the changes in crop yields related to varietal improvements. We must develop some method of accounting for such improvements, given the observed morphological trend of decreasing row number (Cutler 1956) and increasing cob size through time.

One way to approach this problem is to isolate the relative characteristics of the earliest forms and compare them to the later races. Using Nickerson's (1953) data we can begin to construct such a measure. Of the samples he documents, Iroquois Sacred Flour, Northern Flint, and Basketmaker are the most relevant to this study. Table 3 lists the average values (Nickerson 1953:88) of the standard morphological characteristics of each racial group. The Iroquois Sacred Flour sample represents one form of the latest Northern Flint descendent. It is described as having ear lengths of 20 to 28 cm. The Northern Flint collection is a composite grouping of both Northeastern and upper Great Plains varieties. No range for cob length is provided. The Basketmaker cobs were taken from sites in northern Arizona. Their length ranged between 6 and 12 cm.

Table 3. The average values of four morphological characteristics of maize cobs.

Sample	Cupule Width (mm)	Shank Diameter (mm)	Kernel Thickness (mm)	Glume Width (mm)
Iroquois Sacred Flour	11.5	22	3.7	8.7
Northern Flint	9.5	16	4.4	7.0
Basketmaker	6.0	9	4.0	4.4

Although kernel thickness remains fairly constant, all other characters increase by a factor of two from earliest to latest. We can, therefore, expect a twofold increase in potential productive capability from the earliest introduction to the colonial period. This increase is solely defined on the basis of racial differences and not on improvements within a variety. Such varietal enhancements would only become quantitatively important when two distinctively different races are crossed. For example, the ancestors of modern Corn Belt Dents were formed by crossing Northern Flints with Southern Dents (Brown and Anderson 1947,1948). The earliest date for such mixing is probably around A.D. 1840, because it was at this time that we find evidence of 40 maize varieties of various racial origins (Bowman and Crossley 1911:3). This represents an eightfold increase in variability over the five varieties (four flints and one dent) known to have existed in 1814 (Bowman and Crossley 1911:3).

There is no indication archaeologically or ethnohistorically that significant crossbreeding between races occurred at such a level during the late prehistoric period. Further, recent carbon isotope research on skeletal remains (Lynott et al. 1986) suggests that at least some Emergent Mississippian (A.D. 900 to 1000) cultures did not rely heavily on maize. During this period we would expect to find the Basketmaker varieties being grown in garden situations. Heavier dependence on maize would seem to be correlated with the acceptance of the more productive flint varieties ca. A.D. 1000 to 1200.

The earliest introduction of dents into the Southeast is unclear. Brown and Anderson (1948:256) note that Beverly's history of Virginia discusses dented corn in 1705. They divide the dents into Old and Derived which separates Mexican-like dented types from colonial flint-flour-dent crosses. Two of the most common Old varieties are Hickory King and Gourdseed/Shoepeg (Brown and Anderson 1948:263-264). Hickory King appears to be one of the oldest dents with several flint-like characteristics such as 8/10 rows, row pairing, narrow cylindrical ears, and wide kernels. Gourdseed and Shoepeg are more typical of the dents with longer kernels, prominent denting, and large row numbers (greater than 16). Despite their assumed late prehistoric arrival into the eastern United States, the lack of supporting archaeological data would indicate that they were either not heavily used until the colonial period or were not yet recognizably different (like var. Hickory King) from the various flint varieties. Given either the absence or similarity argument, our model can deal strictly with the productive capability of the Northern Flint form for most of the Mississippian Period.

What can we expect the yield per unit area to have been for these varieties? Yield is the product of environmental, physiological, and technological influences. For the moment we will ignore the first two factors and concentrate on the technological or behavioral effects of aboriginal agriculture. Given a particular variety of maize, its yield will be dependent on the density of plants per unit area. Modern Corn Belt varieties produce a maximum yield when the plant densities range between 40,000 and over 100,000 plants per hectare (pph) (Larson and Hanway 1977:645). Row widths of 40 to 100 cm and corresponding ranges of plant spacings of 62 to 10 cm would be needed to achieve such densities for modern drilled corn. The success of different plant densities will largely be dependent on soil conditions, climate, and the ability to optimize the leaf area index relating upper leaf area to ground surface (Bowman and Crossley 1911:172-174; Larson and Hanway 1977:645).

Based on the ethnohistoric evidence, aboriginal planting consisted of widely spaced (three to six feet) hills with several plants per hill. Such a practice is very similar to that used in the Corn Belt prior to the self-propelled mechanization of agriculture in the mid-twentieth century. The traditional checked planting rate was set at three seeds per hill with 3.5 ft (1.07 m) between hills and rows (Bowman and Crossley 1911:102). This would result in 3556 hills per acre (hpa) (8788 hills per hectare [hph]) and up to 10,668 plants per acre (ppa) (26,364 pph). Four or five plants per hill were possible without a loss in yield if the climatic and soil conditions were optimal. On poorer soil, it was recommended that fewer seeds be planted per hill and the hills be spaced up to six feet apart resulting in more than a 66% reduction in plant density and yield.

The average pph for four Corn Belt states (Indiana, Iowa, Illinois, and Minnesota) in 1973 was 47,400 (Larson and Hanway 1977:645). Thus, traditional densities were slightly more than half that of today. The average yields in the United States for the years 1850, 1910, 1945, and 1973 were 16.0 quintals/ha (25.5 bu/acre), 21.0 quintals/ha (33.5 bu/acre), 17.8 quintals/ha (28.4 bu/acre), and 58.9 quintals/ha (93.8 bu/acre), respectively (Bowman and Crossley 1911:14; Larson and Hanway 1977:625). (Appendix A contains definitions of the units of measure used in this study). The 1880 average yield in Tennessee was 21.6 bu/acre (13.6 quintals/ha) (Hawkins 1882:64). Clearly, pre-hybrid yields were relatively consistent and slightly greater than the estimates of 18 bu/acre (11.3 quintals/ha) made by Rutman (1967:43) for the Plymouth farmers and the calculated 11.4 bu/acre (7.2 quintals/ha) average for 1835 Eastern Cherokee Reservees (Bureau of Indian Affairs 1835). Modern varieties are at least twice as productive as the best of the Northern Flints and plant densities are similarly twice that of aboriginal systems. We should, therefore, be able to reasonably expect the average upper productive limit of aboriginal agriculture on the best soils and under optimal patterns to be between 11.3 and 18.8 quintals/ha (18 and 30 bu/acre) for Northern Flints and probably a fourth of that for Basketmaker varieties for a range in maximum possible yield of 4.7 to 18.8 quintals/ha (7.5 to 30 bu/acre) for the Mississippian Period. Actual or average yields will be dependent on differing environmental constraints such as soil type, soil condition, and weather conditions.

To address the real potential for maize agriculture we must examine the factors that annually limit yields.

Factors Influencing Reduced Yields

So far we have concentrated on the static production potential of specific races of maize available to late prehistoric populations holding all other variables constant. We know from observation that these yields vary as a decreasing function of time. Several external factors, such as weather, pests, disease, and nutritional deficiencies, tend to limit production in various ways. Considerable research has examined the process of soil depletion in terms of Anglo-American farming practices since the Colonial Period (Bonner 1964; Craven 1926; Hall 1905, 1917). Craven (1926) notes that the tobacco plantation system practiced a form of shifting agriculture much the same as that outlined in Chapter II. In the long leaf pine zones of the cotton states, first to third year corn production could drop from 25 to less than 10 bu/acre. Soil in short leaf pine environs could be exhausted in five to seven years. Under oak-hickory conditions soil might produce for up to 12 years. If we could empirically measure the response curves of the most important factors as functions of time, it would be possible to reconstruct agricultural potential under aboriginal conditions.

To estimate the rate, dy/dt, of such a process we must examine the external factors that influence yields in conjunction with the effects of aboriginal practices. Nye and Greenland (1960:75) outline six causes for the documented decline in production of shifting agricultural systems:

1. "Deterioration in the nutrient status of the soil
2. Deterioration in the physical condition of the soil
3. Erosion of the top soil
4. Changes in the numbers and composition of the soil fauna and flora
5. Increase of weeds
6. Multiplication of pests and diseases."

All of these are consequences of agricultural practices. Weather and climatic trends can be added as a seventh stochastic factor independent of technology. From a modeling perspective, by examining the causal agents of soil depletion we can better isolate the essential dynamic elements as functions of time.

Soil Depletion

The deterioration of nutrients and the physical condition of the soil, top soil erosion, and loss of soil fauna and flora combine to reduce the viability of the growing medium. Nitrogen (N), phosphorous (P), and potassium (K) are the three critical elements absorbed from the soil by maize (Larson and Hanway 1977:634). Deficiencies in these elements generally lead to a decreased growth rate and stunting. Nitrogen deficiency results in barren ears and stunted kernels. Phosphorus deficiency can minimize successful pollination by delaying silking. Potassium-deficient plants tend to produce small and poorly filled ears as well as weak stalks succeptable to rot (Larson and Hanway 1977:635-636).

Absorption of N is dependent on the processes of oxidation (NO_3) and reduction (NH_4) largely as a result of nitrifying bacteria (Gardner et al. 1985:110). Because these are biological processes, they are easily affected by temperature, moisture, and soil pH. Nitrification is minimal during the cold, wet months of winter and spring and optimal in well aerated soils when the temperature exceeds 25° C. Denitrification becomes a problem under warm, waterlogged conditions and during leaching when the soil is well aerated. Late-successional vegetation tends to produce nitrification inhibitors (tannins and phenols) which are slowly removed by leaching during cultivation.

Phosphorus is represented in both organic and inorganic portions of the soil matrix. Most P absorption is dependent on the element being in solution, which accounts for the smallest share of soil P. Although the concentration of soluble P can be extremely low, root action results in plant levels up to 1000 times that of the surrounding soil. Thus, plants can quickly incorporate most of the available P (Gardner et al. 1985:115-116).

Potassium is primarily derived from minerals, especially clay minerals (such as montmorillonite). Although only about 1% to 3% of the total K in soil is available through exchange or solution, most soils are sufficiently buffered to sustain constant levels from year to year. Like N, potassium absorption is optimal at 25° C (Gardner et al. 1985: 117-118).

Rates of nutrient uptake vary according to the growth stage of the plant. Potassium absorption usually is complete by the time of silking, while N and P continue to be incorporated until the plant is almost mature. Through the process of translocation, N and P are largely (66.7% to 75%) concentrated in the grain by harvest time. Potassium, on the other hand, tends (75%) to remain in the leaves and stalk (Larson and Hanway 1977:634-635). Using a standardized 100 quintals/ha (159.3 bu/acre) we can expect 200 kg of N, 36 kg of P, and 190 kg of K to be deposited in the grain and stover (bulk plant remains) of modern corn belt varieties (Larson and Hanway 1977:634-635).

Erosion of exposed top soil is another side effect of agricultural development. Our concern is with its increased rate over that under late-successional vegetation (Nye and Greenland 1960:85). Its effect is influenced by clearing practices, slope, and cultivation techniques. The practice of ridging or hilling the soil produces a "cap" which promotes runoff and impedes oxygen absorption (Nye and Greenland 1960:82). Every doubling of slope will result in 2.5 times the erosion per unit area (Symons 1978:55). Today's mechanized farming practices are optimal on surfaces with a 0.5 to 3.0 degree slope (less than a 5% gradient).

An increase in the proportion of weeds found in fields and the proliferation of pests and diseases are encouraged by monoculture practices. The long term agricultural experiments at Rothamsted, England (Hall 1917:154) demonstrated that continuous cropping of unfertilized fields resulted in an increase in the proportion of weedy plants over grasses and clovers. Such competition from plants adapted to poor soil conditions would further restrict the flow of soil nutrients to cultivated plants.

Maize damage by soil insects (rootworms, cutworms, wireworms, and billbugs) and surface insects (earworms, aphids, borers, grasshoppers, and beetles) can be extensive (Dicke 1977). Non-chemical inhibitors of such pests include deep plowing, short rotations, good drainage, early planting, and clean cultivation. Storage pests, with their capacity to survive southeastern winters, can extend the period of grain destruction beyond the harvest.

Disease-induced losses of 2% to 7% are considered normal today (Ullstrup 1977). Occasional widespread epidemics, however, can destroy significant portions of a crop. They include rots (seed, stalk, ear, and root), blights (leaves), wilts, mildews, smuts, rusts, viral and mycoplasma diseases, among others. The spread of disease is regulated by temperature, moisture, host resistance, and the form of the agent (fungal, bacterial, or viral). Traditional options to control the outbreak of maize diseases include maintenance of soil fertility (minimizing stalk rots), plant rotation (periodic removal of the host), and field sanitation (removal of host debris) (Bowman and Crossley 1911).

Of the various practices outlined in Chapter II, three directly affect productive potential of the system:

1. land was cleared using fire to burn off all plant debris,
2. cultivation consisted of only two spot hoeings, and
3. no form of fertilizer was added to the fields.

The use of fire to remove plant debris following the initial clearing and field preparation in subsequent years influences the nutrient balance in both positive and negative ways. On the positive side, the ash, if incorporated into the soil, will serve to raise the pH. This would be beneficial towards the growth of nitrogen fixing bacteria. It would also return some non-volatile elements to the soil. However, unless the ash is plowed into the soil most will be washed away during subsequent rainstorms. Fire would also help sanitize the field minimizing future outbreaks of insect infestations and disease. Negatively, fire releases approximately 96% of the volatile nitrogen and 54% of the potassium stored in plant remains (Arianoutsou and Margaris 1981). Approximately 1.97 kgN/ha will be stored in every quintal/ha of produced maize (Gardner et al. 1985:107). The heat from the fire will also destroy nitrogen fixing organisms in the upper layers of the soil. The combined effect of this process and the removal of most of the plant's stored nitrogen (located in the grain) at harvest would result in a decrease in N availability.

Cultivation practices would also affect the maintenance of yield levels. The minimal hoeing schedule would result in a weed cover which would minimize the erosional effects. The increased competition between plants for water and nutrients would, however, increase. These plants serve as nutrient sinks capable of holding between 36 and 73 kgN/ha and up to 40 kgK/ha (Arianoutsou and Margaris 1981:345). Burning these plant residues would effectively remove two or more times the nutrients stored in the maize alone. Weed growth would also be conducive to insect propagation. The end result is, as Butzer (1982:148) notes, that spot hoeing lowers yield.

The failure to replenish soil nutrients under the aboriginal system is perhaps the most far reaching of all the cultural factors. Sustained cropping is a non-renewable process. Harvesting just the grain removes most of the nitrogen and phosphorus absorbed during the growing period. If we also remove or burn the stover and weeds, more than two times the nutrients are taken out of the cycle. Destruction of nitrogen fixing bacteria within the upper soil zones decreases the ability of the field to replenish this deficit. We noted little or no support for either the use of manures or systematic fallowing during the contact period. Corrective measures suitable for extending the productive life of the soil appear to have been extremely limited for prehistoric cultures.

In this regard, the mistaken belief that legumes were used to supply nitrogen to growing maize plants needs to be corrected. These plants have the capability to develop a symbiotic relationship between their root systems and nitrogen fixing bacteria present in the soil. The bacteria concentrate in root nodules and provide nitrogen to their hosts. This frees the beans and clovers from absorbing the nutrient from the soil. Unless the plant is incorporated into the soil while green (as a so-called green manure) the nitrogen will be lost to the harvest and subsequent burning. The fact that the soil's surplus N is not used by these plants allows them to be planted among other N consumers. The aboriginal practice of sowing beans with maize was adaptive because it minimized field size and provided a support (the maize stalk) for the climbing legume. The practice does not provide any nutrient value to the maize plants (Gardner et al. 1985:133; Russell 1973:359). Conversely, it has been shown (Bowman and Crossley 1911:97) that growing cow peas between the rows can reduce corn yields by as much as eight to ten bu/acre.

Similarly, the widespread assumption that the use-life of low river terrace soils is replenished by flooding ignores three points. First, waterlogged conditions encourage denitrification processes. Second, deposited silts, although highly tillable under hoe technology, will not necessarily be nitrogen rich. Finally, spring floods will tend to occur after the maize has been planted, therefore increasing the local risk of crop failure.

What are the essential parameters affecting soil degradation? The foremost is obviously nitrogen depletion. Weed and insect increases, along with disease epidemics, will tend to exacerbate reduced yields at the end of the viable life span of a field largely as a result of nutrient deficiencies. In the absence of systematic rotation, fields would produce until some point when their yield per unit labor is insufficient to support their needs and field abandonment would occur. For modeling purposes, the use-life of a field can therefore be directly related to the nutrient depletion curve. The quantification of this process is developed later.

Climate

The seventh influencing factor, weather, is external to the behavioral options. Varying weather patterns would significantly alter agricultural potential if their long term trends (climatic changes) substantially changed the probability of crop failure. Crop failures become archaeologically significant only when they occur frequently. Therefore our consideration of climatic effects is in terms of the fluctuating probability of crop failure over time.

The two most important climatic variables for maize production are water infiltration and temperature (Symons 1978:21-22). Moisture requirements for maize vary with the growth stage. During the first two months, growth occurs at a slow pace and moisture needs are minimal. Roughly between the middle of June and the middle of July the rate of growth is greatest (±15 days from tasseling). Approximately two weeks before the milky stage is reached, the plant will obtain its maximum weight. From that point on the plant will slowly decrease in weight. The need for moisture is therefore greatest during the 30 days of rapid growth (Azzi 1956:58-59; Larson and Hanway 1977:629).

Temperature plays a vital role in determining the growth rate of maize. Under low temperatures above the critical temperature (9° C for maize), growth is slow (Symons 1978:27). The optimal range for growth is 18° to 25° C. A study (Palmer 1973) of seven Mexican races demonstrated that the lower the minimum temperature, the longer it took for plants to flower. Grain weight was shown to increase with earlier plantings given a sufficiently high minimum temperature. As a result, May 21 plantings produced better yields than those planted 30 days earlier and later.

We lack sufficient climatic data to incorporate the effect of the "little Ice Age" on Mississippian development (cf. Parry 1975), yet the potential for increased crop failure probabilities late in the period cannot be dismissed. Although very little climatic data exist for the late Holocene in the Southeast, preliminary attempts (e.g Hall 1982; Swain 1978) to characterize climatic conditions elsewhere during this period do suggest long term, gross fluctuations in moisture potentials. Knowing that conditions varied substantially in the Southwest, the Southern Plains, and the Northeast would mean that similar climatic influences could have affected Mississippian agriculture in the Southeast. If there was a deterioration below that of the so-called "little optimum" of A.D. 1000-1200 (Butzer 1982:24), it probably occurred after A.D. 1400. Following Parry (1975), this could have resulted in an increased frequency of crop failure from 0.05 in A.D. 1200 to 0.3-0.4 by A.D. 1600.

The following discussion will formulate a functional representation of nutrient depletion in conjunction with stochastic crop failure potentials.

Yield as a Function of Time

Specific maize yields for any given year are dependent on soil quality, climate, and cultivation practices. Cultivation options can be empirically isolated and used to predict yield potentials. Climate is a stochastic variable that may produce trends in crop failure frequencies at different time periods during the Mississippian. We have observed that soil quality, or its ability to maintain a nutrient base suitable for agriculture, decreases over time. To model this decrease as a function of time requires data on the rate at which it occurs. Studies were carried out late in the nineteenth century by various agricultural research organizations that provide data suitable for addressing this question.

The Rothamsted Experiments (Hall 1917) began in 1843 using half acre plots to test the effects of various cultivation practices over long periods of time. Although maize was not included in this English study of farming practices, many of their observations are useful here. First, they demonstrated that continuous cropping does significantly reduce yields over a 20 to 30 year period. They also documented that the characteristics of each plant species differentially affects the rate of this decrease. Barley, with a short root system, depleted soil faster than wheat with its longer roots (Hall 1917:72). (Maize root systems can extend two meters, although most of the system is concentrated near the surface). Plant rotation and manuring was shown to help prevent the depletion process, especially if legumes (clovers, beans, and peas) were used once every four to seven years (Hall 1917:133). Finally, their data indicate that yields tend to stabilize at some minimum level rather than plunging to zero.

One study of maize and its effect on soil quality involved a three year examination of nitrogen depletion in soils from Kansas, Virginia, and California (Wright 1920) (the Virginia data appear to contain typographical errors for the second year and have not been used in this analysis). Continuous cropping in buckets showed that the ratio of dry plant weights annually decreased along the lines of 1.0:0.54:0.35 for the Kansas soil and 1.0:0.81:0.5 for the soil from California over the three year period. Measurement of nitrate content each year revealed that nitrogen reduction was proportional to the amount of plant growth the previous year.

These examinations qualitatively describe the effects of soil depletion on plant growth. The most useful quantitative data available comes from studies of actual field plots where maize was continuously grown under various conditions for several years. Such a study was carried out on a silt loam in Wooster, Ohio between the years 1893 and 1913 (Weir 1926). The purpose of the experiment was to demonstrate the value of a five year rotation of corn, oats, wheat, clover, and timothy. Thirty 0.1 acre plots were planted under various cultivation circumstances. Our interest is in those plots where maize was continuously cropped with (n=6) and without (n=4) fertilizer. If we assume that the yields from the fertilized plots represent the maximum potential yield each year under variable environmental restraints, then we can estimate that the expected yield for the unfertilized plots should be equally proportional to the first year's yield. That is, the expected yield of the unfertilized plots in year t [U_t] should be:

$$U_t = \frac{F_t}{F_0} U_0 \tag{3.4}$$

where F_t is the fertilized yield for year t. The difference between the observed unfertilized yields and the expected value should be approximately equal to the effect of soil depletion on the crop. These data are presented in Table 4. The mean yield over 20 years for the fertilized plots was 37.439 bu/acre (sd = 12.414) (23.5/7.8 quintals/ha) and for the unfertilized test units it was 18.136 bu/acre (sd = 11.431) (11.4/7.2 quintals/ha).

In all but the second year, the unfertilized plots consistently produced below the expected. The cumulative ratio represents the reduction of yield from that expected over a 20 year period. The cumulative ratio of unfertilized to expected yields shows a gradual asymptotic leveling off at just under 60% of the expected accumulated yield.

At some point during this period, the decreasing yield would reach a level unsuitable for further exploitation. If, for example, the minimum requirement is 18 bu/acre for a given technology with some

Table 4. Continuous cropping data from Wooster, Ohio (adapted from Weir 1926:32).

Year	Fertilized (bu)	Unfertilized (bu)	Expected (bu)	Cumulative Ratio
1894	22.16	18.41	18.41	1.0000
1895	37.09	32.26	30.81	1.0294
1896	70.57	52.05	58.63	0.9524
1897	26.23	11.91	21.79	0.8842
1898	52.61	30.56	43.71	0.8376
1899	40.32	20.95	33.50	0.8032
1900	48.06	26.38	39.93	0.7802
1901	49.82	26.46	41.39	0.7599
1902	45.40	14.86	37.72	0.7176
1903	32.14	8.02	26.70	0.6860
1904	24.21	4.24	20.11	0.6603
1905	45.57	20.73	37.86	0.6499
1906	41.69	21.59	34.63	0.6479
1907	26.83	6.22	22.29	0.6303
1908	27.97	12.66	23.24	0.6262
1909	30.61	10.23	25.43	0.6152
1910	20.75	6.26	17.24	0.6071
1911	41.00	15.80	34.06	0.5985
1912	37.02	12.60	30.75	0.5888
1913	28.73	10.52	23.87	0.5831

maximum allowable field size then 11 out of 20 years would have been considered failures. The failure rate for the first 13 years was 0.31 and for the last seven years it was total. If we apply the same rule to the fertilized plots, even with negative climatic impacts, there would not be any crop failures. Clearly, soil depletion is the primary limiting factor for sustained land use.

Denitrification is a complex process (Burford et al. 1978), but for our purposes a simple model can be developed that allows us to predict the use-life of fields, if we accept certain basic assumptions. First we must accept the data in Table 4 as representative of the process. We recognize that there are measurement errors inherent in the results reflecting various external impacts (e.g. germination rates, insect damage, disease, etc.) but these are real factors equally pertinent to our study. We also realize that yield is correlated with the previous production of a field. Thus a poor yield in year t could be followed by a proportionally larger than expected yield in year t+1 simply because the demands during year t were minimal (see years 1907 and 1908 in Table 4). However, such an effect will tend to develop after the field has exceeded its practical use-life. Its impact would therefore not be quantitatively significant under an aboriginal system where the field would have been abandoned earlier. If we accept these conditions we can estimate Y(t)'s contribution to (3.1).

We begin by noting that the expected value of the cumulative ratio fits the curve:

$$f_t = 1.066t^{-.1989} \qquad t > 0 \qquad (3.5)$$

shown in Figure 2. If we simulate expected yields [E_x] dependent on annual weather conditions we can estimate depleted yields [Y'_t] as:

$$Y'_t = f_t \sum_{0}^{t} E_x - \sum_{0}^{t-1} Y'_x \quad \text{(bu/acre)} \qquad (3.6)$$

Thus a stochastically varying yield pattern can be generated reflecting both fluctuating climatic influences and soil degradation.

As an example of the usefulness of (3.6), if the expected yield was a constant 30 bu/acre (no climatic variation) the depleted yield would reach 18 bu/acre after six years (Figure 3). This function can be approximated by:

$$Y_t = 27.78t^{-.2249} \quad \text{(bu/acre)} \quad t > 0 \qquad (3.7)$$

$$Y_t = 30.0 \quad \text{(bu/acre)} \quad t = 0$$

Soil depletion lowers the maximum potential yield, exacerbating the effects of climatic perturbations. Restated, if the maximum possible yield is 30 bu/acre then (3.7) represents the maximum possible yield under continuous cropping. Fluctuating external constraints would result in an average yield below this curve.

If we accept the fertilized yields of Table 4 as representative of reasonable ranges of yield variability excluding soil depletion influences, it is possible to use these data to estimate average undepleted yields under aboriginal conditions. The highest yield was 70.57 bu/acre in 1896. By reducing each value by a factor of 30.0/70.57 (0.4251) we can transform Table 4 to approximate aboriginal yields. The resultant average yield [E_t] would have been 15.92 bu/acre (sd = 5.28) (10.0/3.3 quintals/ha). Therefore, we can be reasonably certain that mean aboriginal yields would have been on the order of 16 bu/acre (10 quintals/ha)

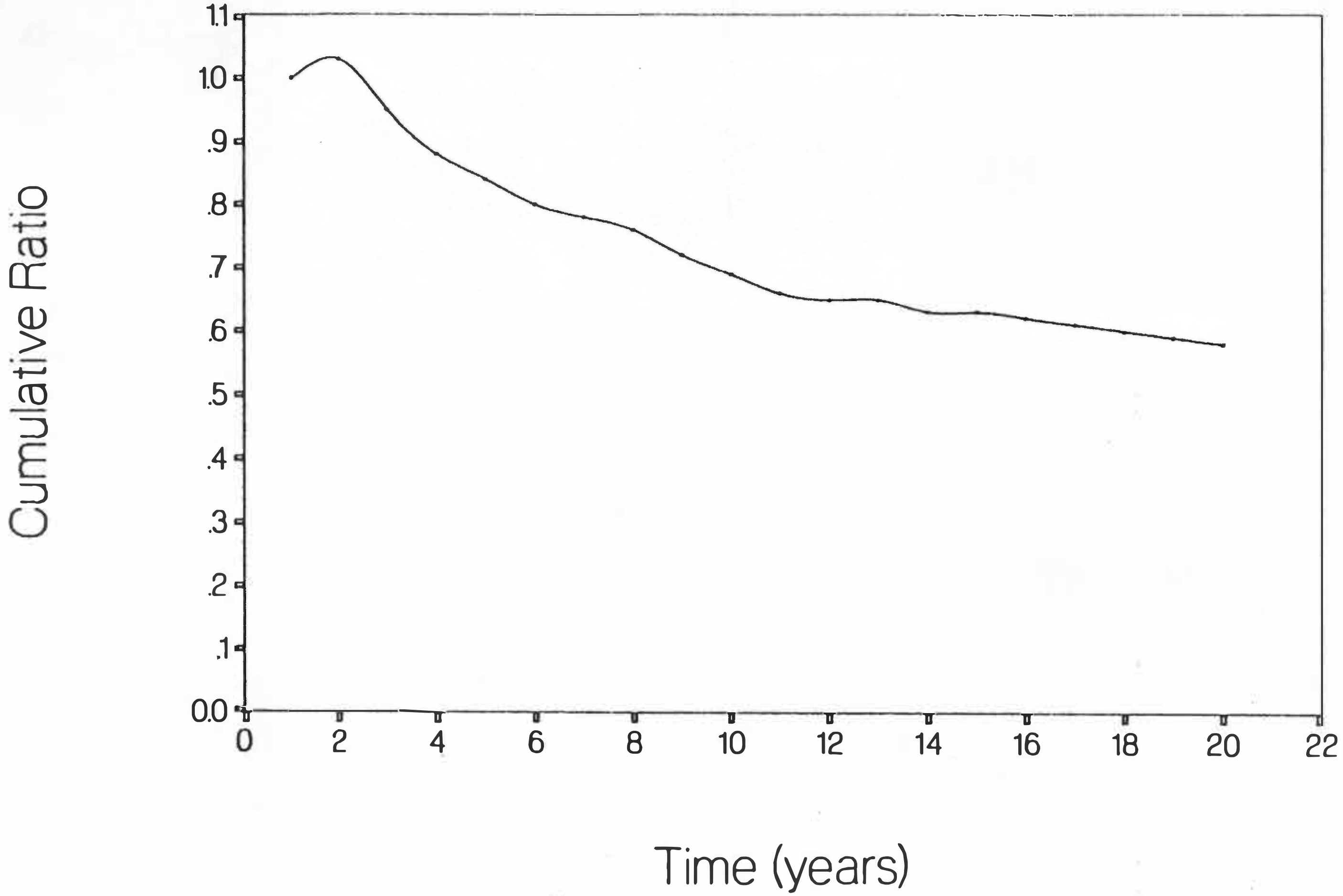

Figure 2. Cumulative ratio of depleted to undepleted yields.

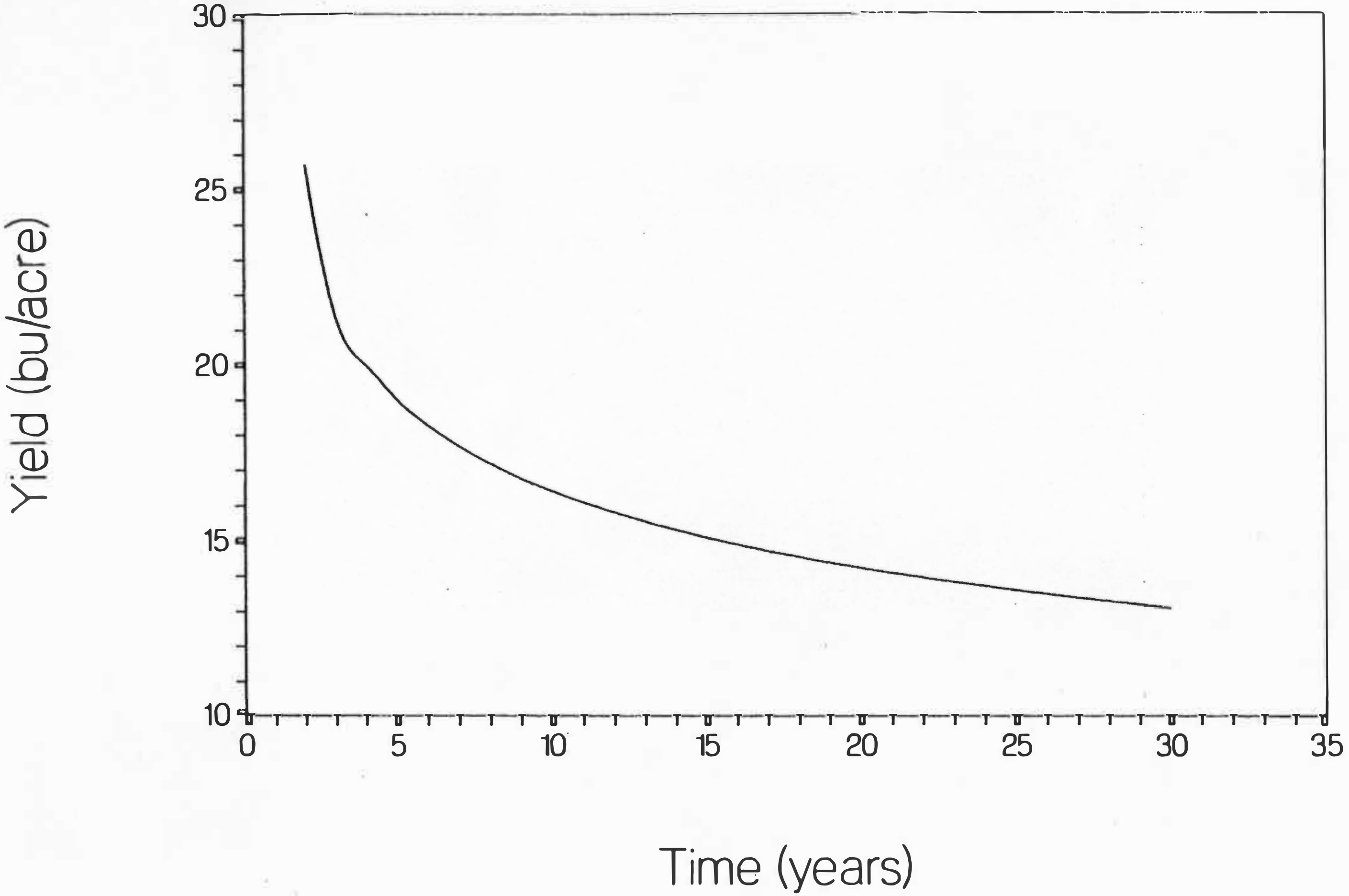

Figure 3. Depleted yield curve.

under environmental conditions similar to those of the early twentieth century. Soil depletion effects would lower this value each year according to:

$$E_t = \frac{15.92}{30.0} Y_t \qquad \text{(bu/acre)} \quad t \geq 0 \qquad (3.8)$$

with a standard deviation of:

$$s_t = \frac{5.28}{30.0} Y_t \qquad \text{(bu/acre)} \quad t \geq 0 \qquad (3.9)$$

This technique can be extended to adjust for different soil types by rescaling the curves to correspond with the specific maximum potential yield.

These equations assume cultivated conditions. The Mississippian practices of allowing fields to become overgrown and burning all residues force us to consider the effect of weed growth on the depletion curve. As noted above, two to three times as much nitrogen may be stored in the weeds and maize compared with that found just in the maize. Conservatively, this is equivalent to doubling the impact of maize production. To approximate this effect, we can adjust (3.8) and (3.9) by substituting 2t for t (or by multiplying each by 0.8557). This will double the rate of depletion and more accurately account for this specific impact.

Modeling the process of soil recovery under temperate conditions following intensive agricultural use is a more difficult problem. Heidenreich (1971:190) estimated that over 60 years would be required on sandy soils. Sandy loams were expected to replenish themselves after 35 years. Green (1980a:224) expects a 60 to 85 year period would be required to return an agriculturally disturbed area to a mature secondary stand. His estimate is based on Liken's (1978) research. However, the Rothamsted experiments suggest that "old arable soils" would require between 100 and 150 years to raise the nitrogen level from a nearly depleted 0.11% to a grassland level of 0.25% (Russell 1973:324). Such plots were referred to as "old fields" by the Cherokee and were distinguished by plants adapted to depleted conditions (especially wild strawberries [Adair 1930:439]). Based on these observations, a 125 year recovery period or "fallow" would seem reasonable for temperate forest environments, after which the land could be reused.

Per Capita Consumption

Estimating the average annual consumption per individual, n, involves contrasting the amount of land that can be farmed under finite yield potentials against the amount of maize required. The ethnohistoric accounts indicate the average individual would utilize 0.33 to 1.5 acres and a family would plant from 1.0 to 4.0 acres (0.4 to 1.6 ha) of maize.

The required amount of maize is largely dependent upon its importance in the diet. Most researchers (Bennett 1956; Minnis 1985; Thomas 1976; and others) base their estimates of maize consumption on the average caloric needs of an individual per day. This assumes that no chronic periods of nutritional deprivation occurred and that we know the relative contribution of maize to the diet. Faced with these limitations, it would be more appropriate to use such approximations as upper limits of maize consumption and contrast these values with expected yields from observed field sizes. Bennett (1956:392) and Thomas (1976:14) suggest that roughly 65% of the eastern aboriginal diet consisted of maize and that the average individual required 2500 calories/day. This relative importance figure is well within the upper bounds of Lynott et al.'s (1986:61) Mississippian estimate of a 35% to 72% cline after A.D. 1000 based on isotopic data from human skeletal remains.

Minnis (1985:11) states that maize contains 3600 calories/kg. This means that each individual would require, for consumption purposes, roughly 6.47 bu/year or 1.64 quintals/year (for 65% of their caloric needs or 0.025 quintals/percentage dependence). Using the yield range of 7.5 to 30 bu/acre (4.7 to 18.8 quintals/ha), this would mean 0.21 to 0.87 acres (0.08 to 0.35 ha) would be needed per person per year. Based on 1848 data (United States Commissioner of Patents 1848:130) a standard acre planted following the 3.5 ft spacing with three kernels/hill would require 5.33 qt (0.17 bu or 0.04 quintals) of seed, which would add a minimal amount to the production needs. Therefore a family of five would be expected to need approximately 1.1 to 4.4 acres (0.45 to 1.78 ha) to produce one year's consumption assuming no spoilage. These independently derived values are in line with those given in the ethnohistoric accounts.

Given the low production capacity of Basketmaker maize, it is not surprising that Emergent Mississippian consumption was measured at 35%. With optimal yields of only 7.5 bu/acre, 0.87 acres/person (4.7 quintals/ha and 0.35 ha/person) would be the minimum field size needed to provide 65% of an individual's caloric needs. Historically, it is unlikely that more than one acre per person could have been cultivated. Yet, expected average yields below 7.5 bu/acre would require field sizes to exceed this limit. A 35% dependence on maize would lower the minimal field size to 0.47 acres/person (0.19 ha/person). The importance of maize would obviously increase as productivity per unit area improved; probably around A.D. 1000 when Northern Flint varieties appeared.

To translate consumption (quintals/person/year) into a nondecreasing function of time, an equation such as:

$$C_t = 0.3326\tan^{-1}\{\pi(0.005t - 6.498)\} + 1.3385 \qquad (3.10)$$

where t c [900,1700] can be used. The percentage dependence will be:

$$D_t = \frac{C_t}{0.025} \qquad t \in [900,1700] \quad (3.11)$$

The plot of this curve (Figure 4) shows a slow rise in dependence both early (A.D. 900 to 1100) and late (A.D. 1500 to 1700) with a sharp increase ca. A.D. 1250. This is a reasonable reproduction of the observed skeletal data (Lynott et al. 1986).

Beyond the annual consumption requirements, we must consider the possibility that there was a need to generate surpluses which, in turn, would require increased planting. To store an extra year's worth of grain the land requirement would have to double. Yet, based on the above calculations a single year's supply of grain already approaches what the accounts have generally indicated to be the yield from fields of maximum size. However, it has always been assumed that accounts describing large amounts of stored grain indicated such a surplus existed. It is difficult to adequately estimate the size of such a

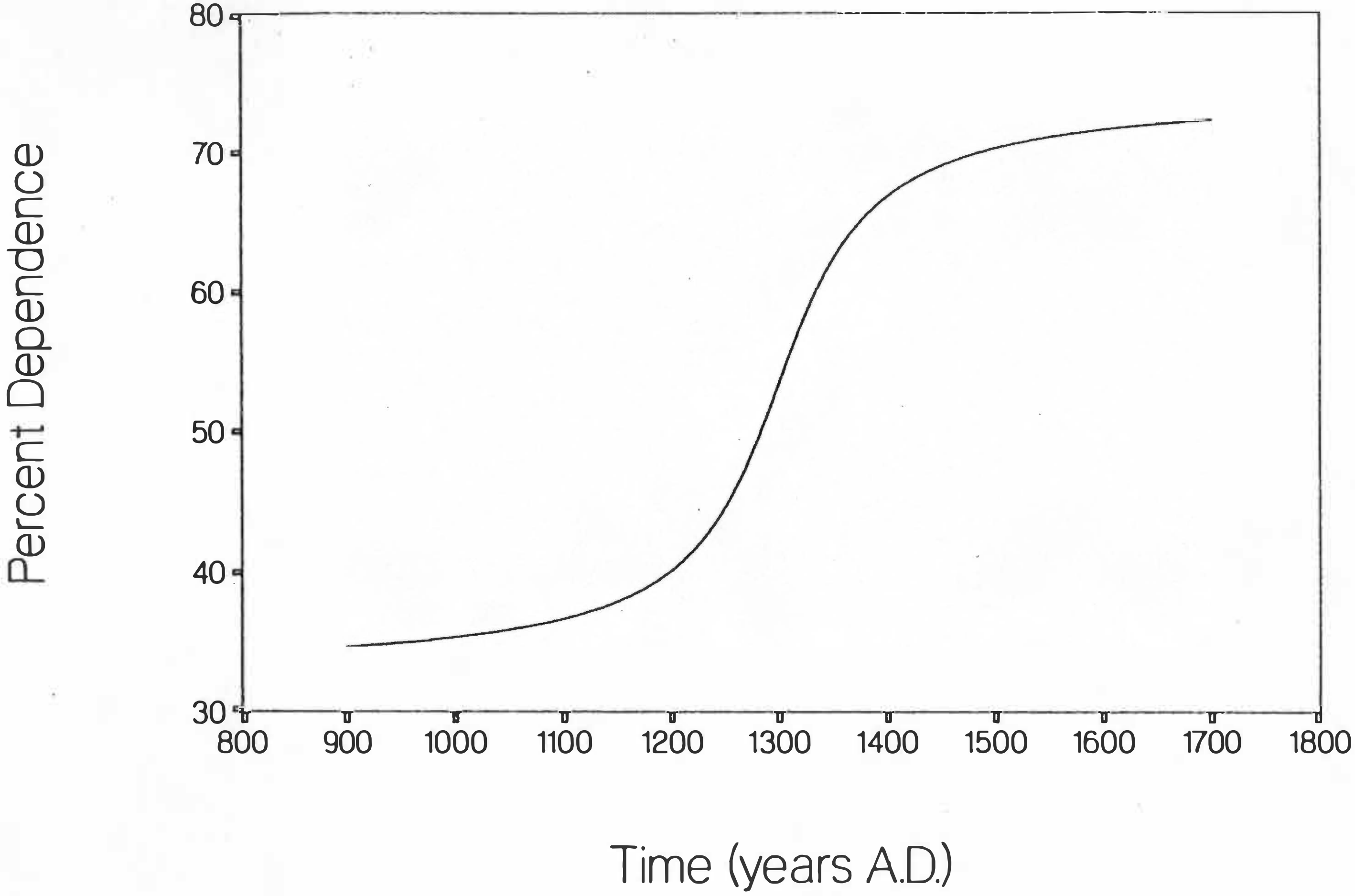

Figure 4. Percentage dependence on maize as a function of time.

surplus strictly in terms of need. An alternative approach would be to consider the ability of aboriginal technology to store maize for extended periods. Inability to store the product would necessarily preclude the value of producing it.

To maintain the integrity of a maize crop under storage conditions one must stay within certain well-defined environmental limits. Optimally, maize should be stored at average temperature and humidity with sufficient air circulation (Bowmen and Crossley 1911:106-115). Specifically, shelled seed corn must be maintained below 10° C (50° F). at 45% to 55% relative humidity to maintain germination viability (Craig 1977:710-711). Seed moisture levels greater than 21% are considered high and at temperatures below freezing can reduce germination rates 40% to 70% (Bowman and Crossley 1911:116). Today such moisture levels require artificial drying. Maize at 17% to 22% moisture can be stored in bins with air circulation if the temperature is less than 10° C. Under warm summer conditions, the grain would have to maintain moisture levels of less than 13% or 14% in order to minimize spoilage due to molds and insect infestations (Dicke 1977:561; Larson and Hanway 1977:662; Ullstrup 1977:420). Shelled maize, when kept confined, will have a tendency to "heat", reducing the germination rate and leading to rapid spoilage. Once such destruction starts, it will tend to spread quickly. Spoilage results in loss of seed, lowered nutritional values, and the potential production of mycotoxins (Ullstrup 1977:420). In light of aboriginal storage technology we cannot expect large amounts of grain to have been kept for periods in excess of one year.

The practice of drying ears over the winter in the rafters of structures would be optimal in a Mississippian setting but the amount of space required for surplus yields would seem to exceed that which would be available. A family of five, with a harvest of 6.47 bu/person (1.64 quintals/person), would need 1.14 cubic meters (1140 l) of storage space for shelled grain. If a bushel of maize in 1846 contained approximately 64,000 seeds (United States Commissioner of Patents 1847:130) and an ear produced roughly 100 to 400 grains (following some accounts), this family would have from 160 to 640 ears to store. If the grain were stored in cribs little would be expected to survive the following hot, humid, southeastern summer. Storage pits could not be ventilated and moisture levels would be too high for long term confinement.

It would seem unlikely that production levels beyond those defined above would ultimately be usable over a long period by a Mississippian population. If surpluses were produced they would have to be short term, i.e. to be used between the fall harvest and the following summer. Such a surplus, like that placed in the "king's crib", could be redistributed to other areas experiencing crop failures the same year. Excess grain could also be traded to non-agriculturalists, as was the case with the Huron of southwestern Ontario. But it is highly unlikely the grain could have been kept to mitigate the effects of some future crop failure.

Discussion

At this point it is important to restate the above results as boundary conditions for Mississippian agricultural systems:

1. Population will be expected to increase at a rate between 0.003 and 0.017 per year.
2. Individual maize consumption per year is expected to be on the order of 0.025 quintals (0.1 bu) per percent dependence, e.g. an average 65% dependence implies a 1.63 quintals/year (6.5 bu/year) requirement per person. As a function of time, consumption for the Mississippian Period will approximately follow (3.10).
3. Maximum potential yield under optimal conditions is not expected to greatly exceed 18.8 quintals/ha (30 bu/acre) during the period. Emergent Mississippian yields would not be expected to exceed 4.7 quintals/ha (7.5 bu/acre).
4. Maximum labor output will not exceed 0.4 ha (1.0 acre) per person.
5. The expected non-depleted average yield will be 9.99 quintals/ha (sd = 3.31) (15.92/5.28 bu/acre).
6. Yields are expected to be annually reduced according to equation (3.6).
7. Allowing for depletion, maximum potential yield is expected to follow equation (3.7).
8. Time dependent expected yields and their standard deviations, taking into account environmental fluctuations and soil depletion, will follow (3.8) and (3.9), respectively, with the substitution of 2t for t.
9. The recovery or fallow period will be on the order of 100 to 150 years.

With these parameters, we can produce a quantitative model of agricultural stability for specific archaeological contexts. Up to this point we have not used any East Tennessee archaeological data (i.e. Mississippian observations) to define any aspect of the model. This is in keeping with the necessary constraint of separating observational data from testing situations. We are now ready to test the model by applying it to an archaeological study area. Before developing the proposed East Tennessee example, it would be useful to present a simplified demonstration of the model's use on a less complex set of data. Muller (1978:287-288) provides an appropriate description of the agricultural setting at the Kincaid site in southern Illinois.

Muller's analysis concludes that Kincaid was composed of 400 individuals each requiring 0.4 ha of arable land from an available, total reservoir (R_0) of 621 ha. He concludes that 1500 people could be supported at this Mississippian site. Assuming climatic effects follow a $n(E_t, s_t)$ distribution, we can produce probability measures of yearly yields. Thus, if $\mathbf{n}$ is 1.64 quintals/person (6.47 bu/person) and no more than 0.4 ha per person are planted per year the probability of "crop failure" will be:

$$p(Y_t < \mathbf{x} \mid t) = \frac{1}{s_t\sqrt{2\pi}} \exp(- \frac{[\mathbf{x} - E_t]}{2s_t^2}) \quad t > 0 \qquad (3.12)$$

where $\mathbf{x}$ is $\mathbf{n}$/(maximum field size per person), the minimum required yield. This curve is shown in Figure 5 for $\mathbf{x}$ equaling 4.06 quintals/ha (6.47 bu/acre). Given a population of 400 individuals at t=0 and 621 ha of land, we can perform a discrete simulation of a 300 year period in the following manner:

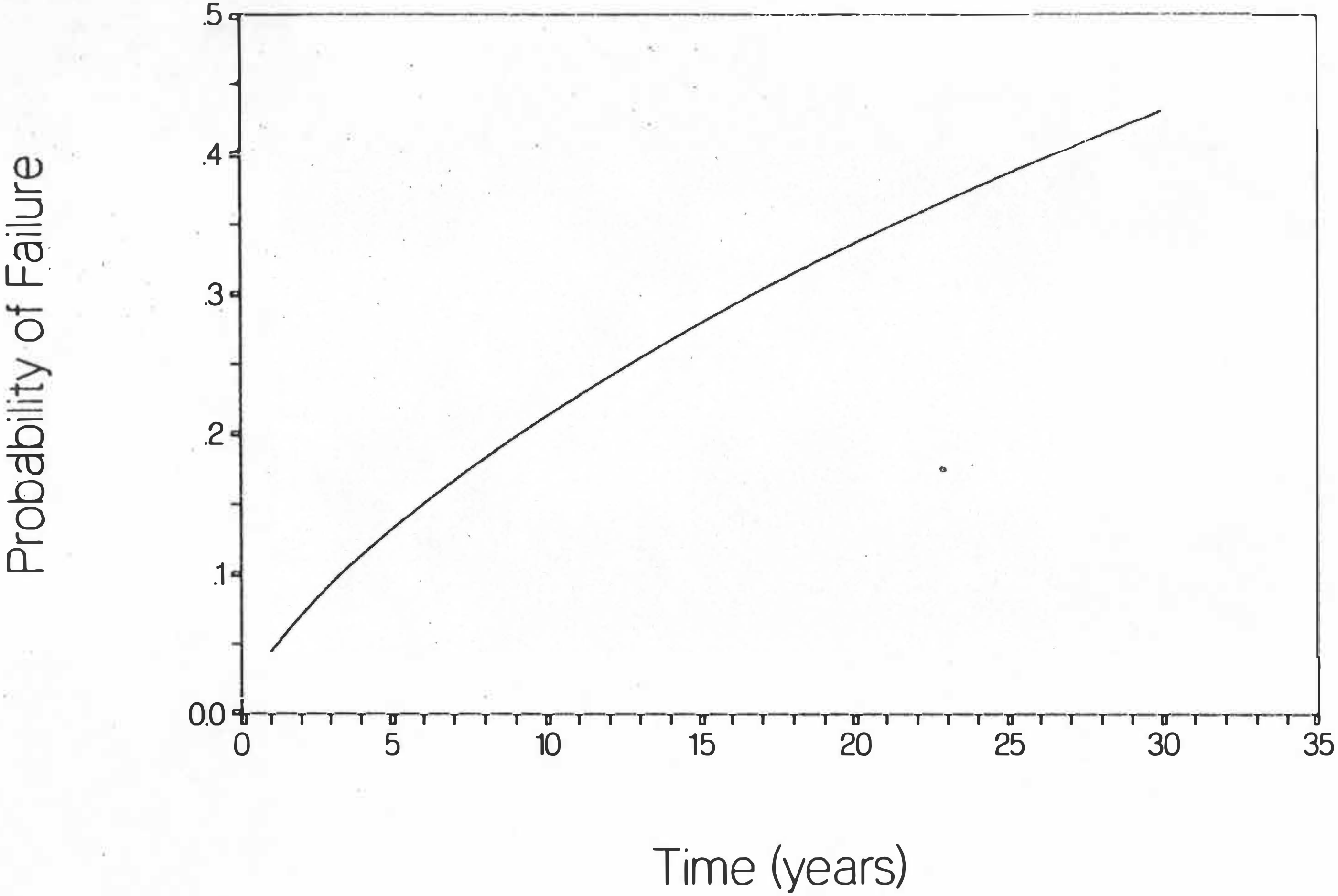

Figure 5. Probability of crop failure over time.

1. Set:
   a. $n = 1.64$ quintals/person
   b. maximum field size = 0.4 ha/person
   c. $\mathbf{x} = 4.1$ quintals/ha
   d. soil recovery period = 125 years
2. Define each year's conditions:
   a. determine the expected yield based on (3.8) adjusted for quintals/ha
   b. use enough land to produce $\mathbf{n}$ quintals/person
   c. simulate random fluctuations in yield following (3.12)
   d. arbitrarily remove the field from use after the third crop failure (harvest $< \mathbf{x}$) (return it after 125 years)
   e. if the amount of land available for new fields is less than $\mathbf{n}P(t)$ then reduce the population (e.g. through migration) to $R_t/\mathbf{n}$
   f. if no land is available abandon the site for 125 years at which time conditions can return to that of $t=0$
   g. use $r = 0.01$ with (3.2) to simulate population growth
3. Repeat step 2 for a period of 300 years
4. Chart the following variables over time:
   a. Population (Figure 6)
   b. Harvest (Figure 7)
   c. Proportion of land used to total land available (Figure 8)

After 51 years all available land would be in a depleted state. At $t = 176$ the site could be repopulated (in this case by 400 people). Because of the periodic nature of site repopulation, total depletion

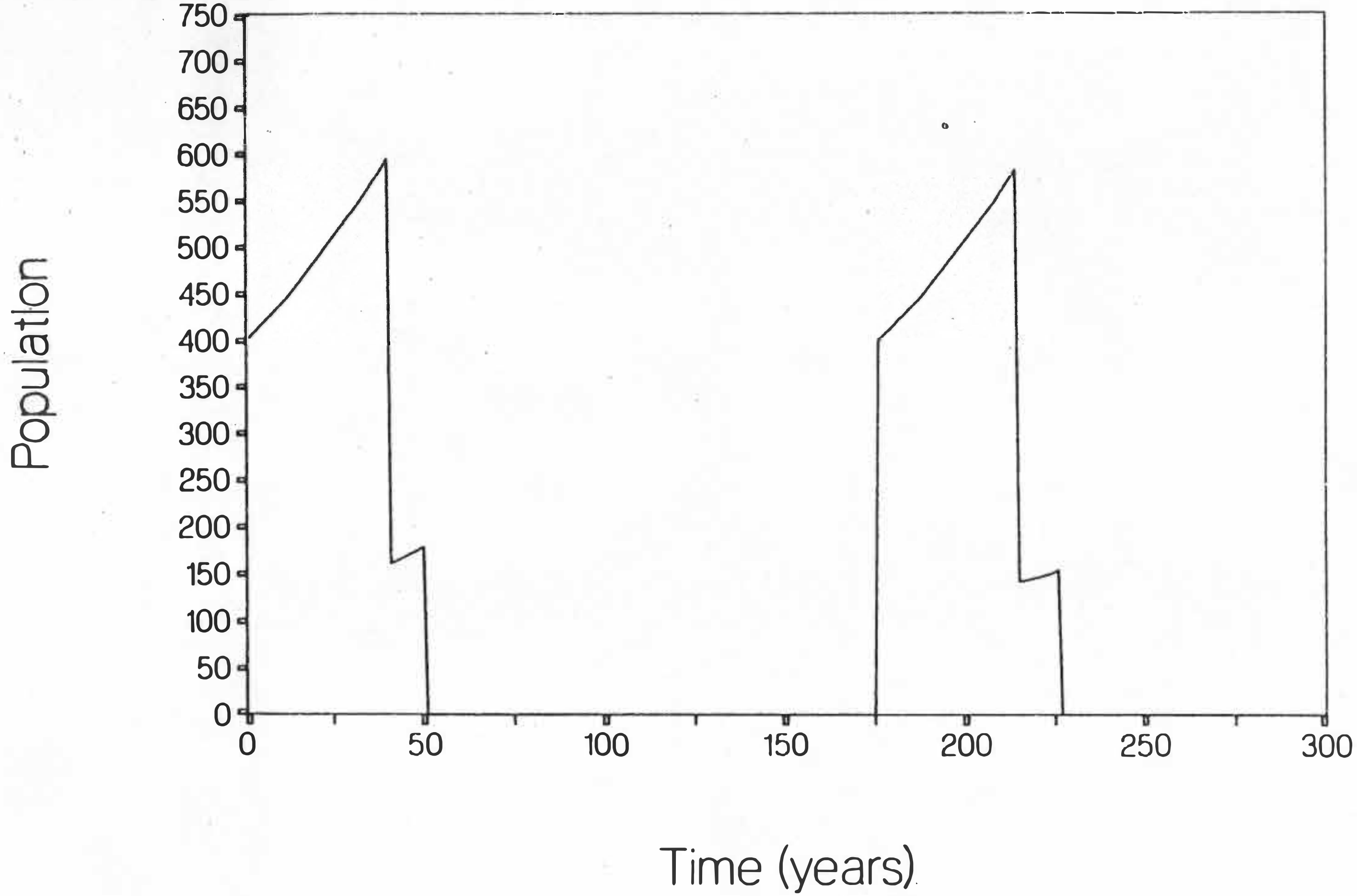

Figure 6. Predicted population curve for Kincaid.

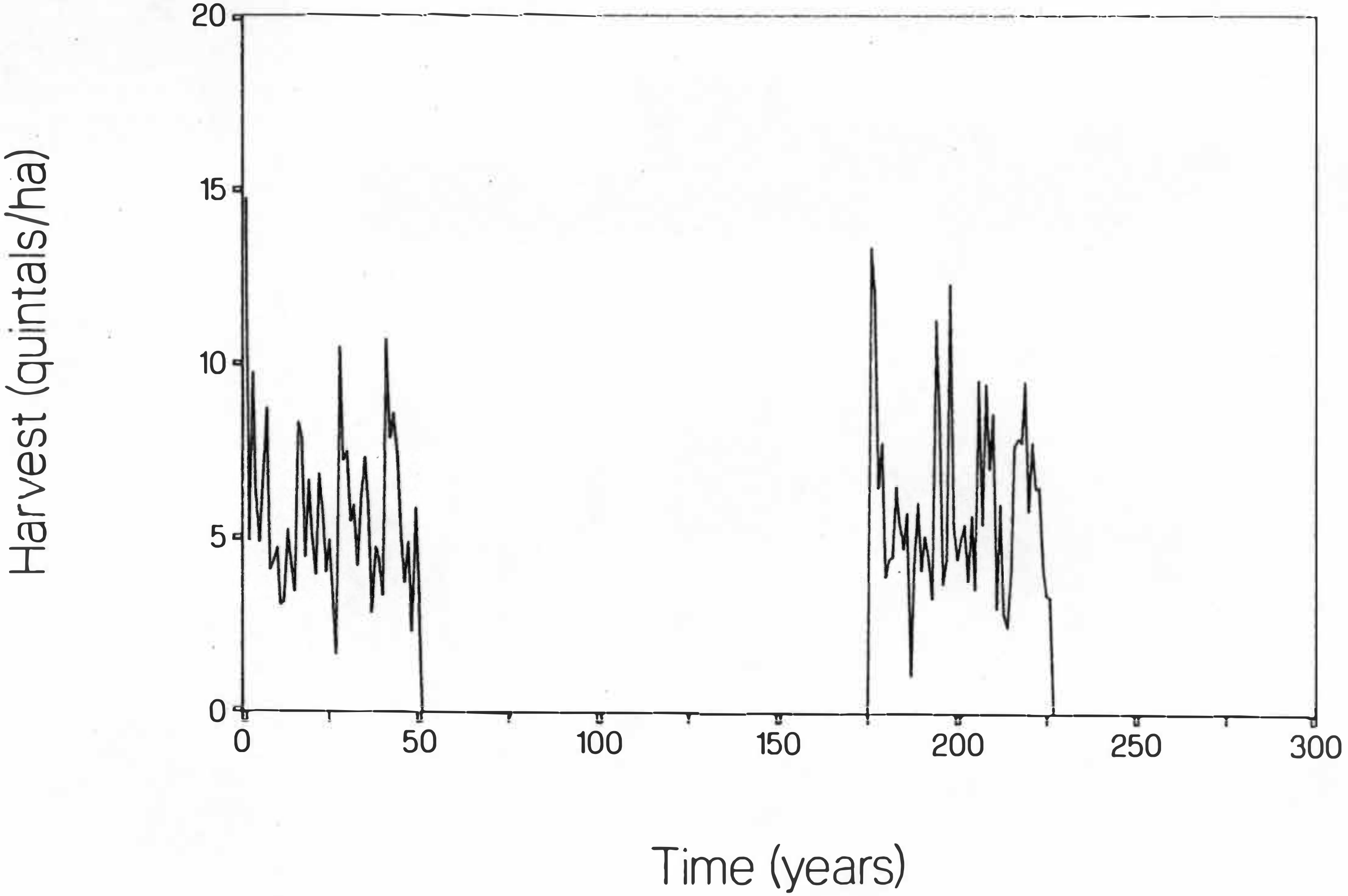

Figure 7. Predicted harvest curve for Kincaid.

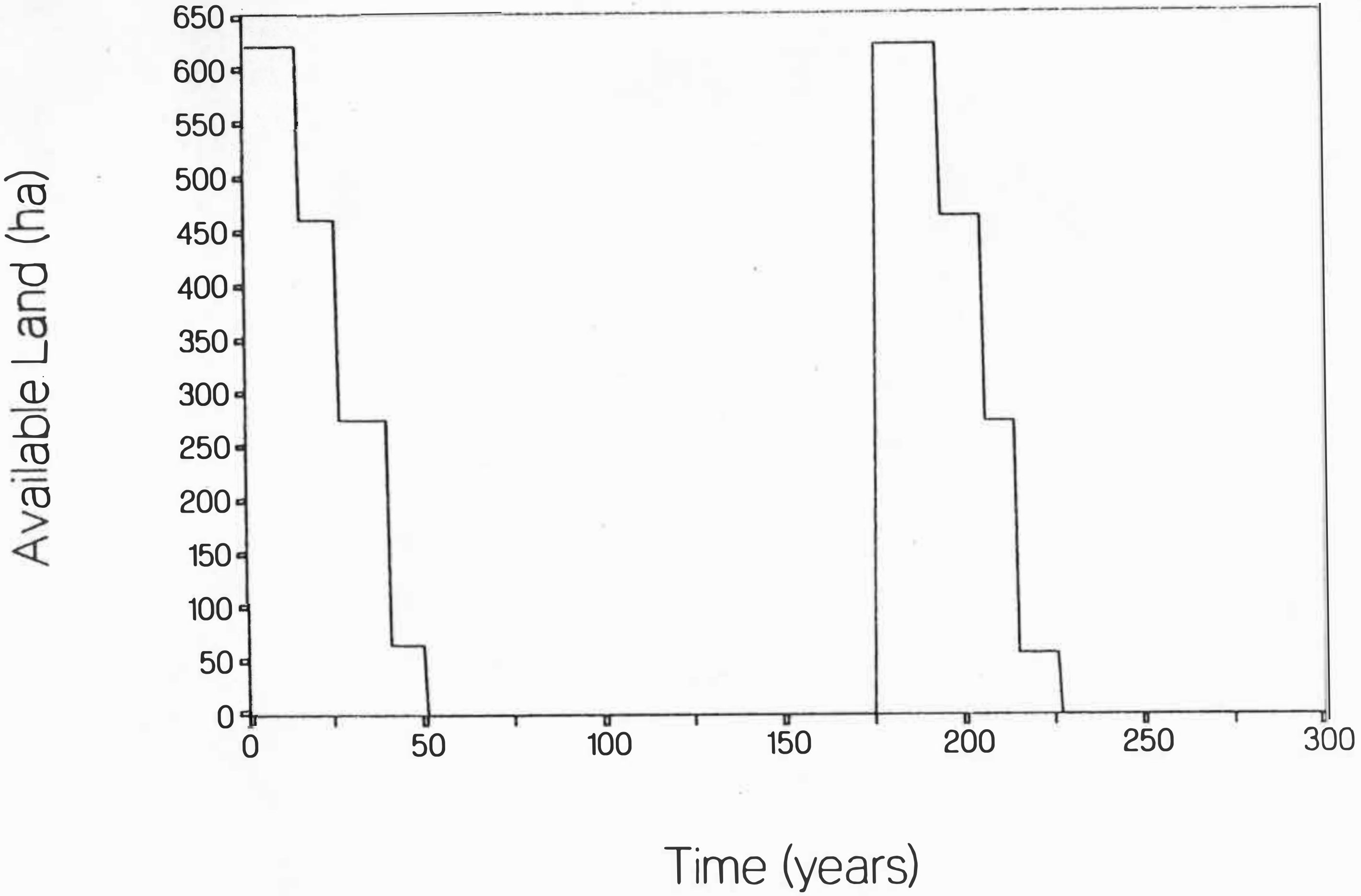

Figure 8. Total amount of available land at Kincaid.

would again occur at t = 227 (a cycle of 51 years). Population adjustments occurred at t = 41 and 215. During the 300 year period the average planting duration was 12.6 years per field. The average surplus per person was 0.72 quintals.

Although highly generalized, this example demonstrates that soil depletion would seriously inhibit growth at Kincaid under Muller's terms. Such a level of population density could not be supported for more than a few generations without major adjustments.

Carneiro (1960:82) would argue that the maximum sustainable population (carrying capacity) of such a site should be :

$$\frac{\frac{621\ \text{ha}}{(125 + 12.6)\ \text{yr}}\ 12.6\ \text{yr}}{0.4\ \text{ha/person}} = 142.2\ \text{people} \qquad (3.13)$$

If we re-simulate the above conditions without using (3.2), maintaining a zero population growth at $P_0 = 142$, the fluctuating amount of available land (R_t) is shown in Figure 9. Because of soil depletion, population reductions would occur at t = 126 (P_t drops to 133). Total abandonment would occur at t = 134. This demonstrates that failure to recognize the negative effects of agriculture invalidates the usefulness of (3.13).

We can now turn to a more detailed application. Using the system definition outlined above, the potential of East Tennessee's Little Tennessee River Valley will be calculated and compared to the archaeological record. Specific input parameters like soil variability, population levels, and culture changes will be used to specify the appropriate model parameters for this setting.

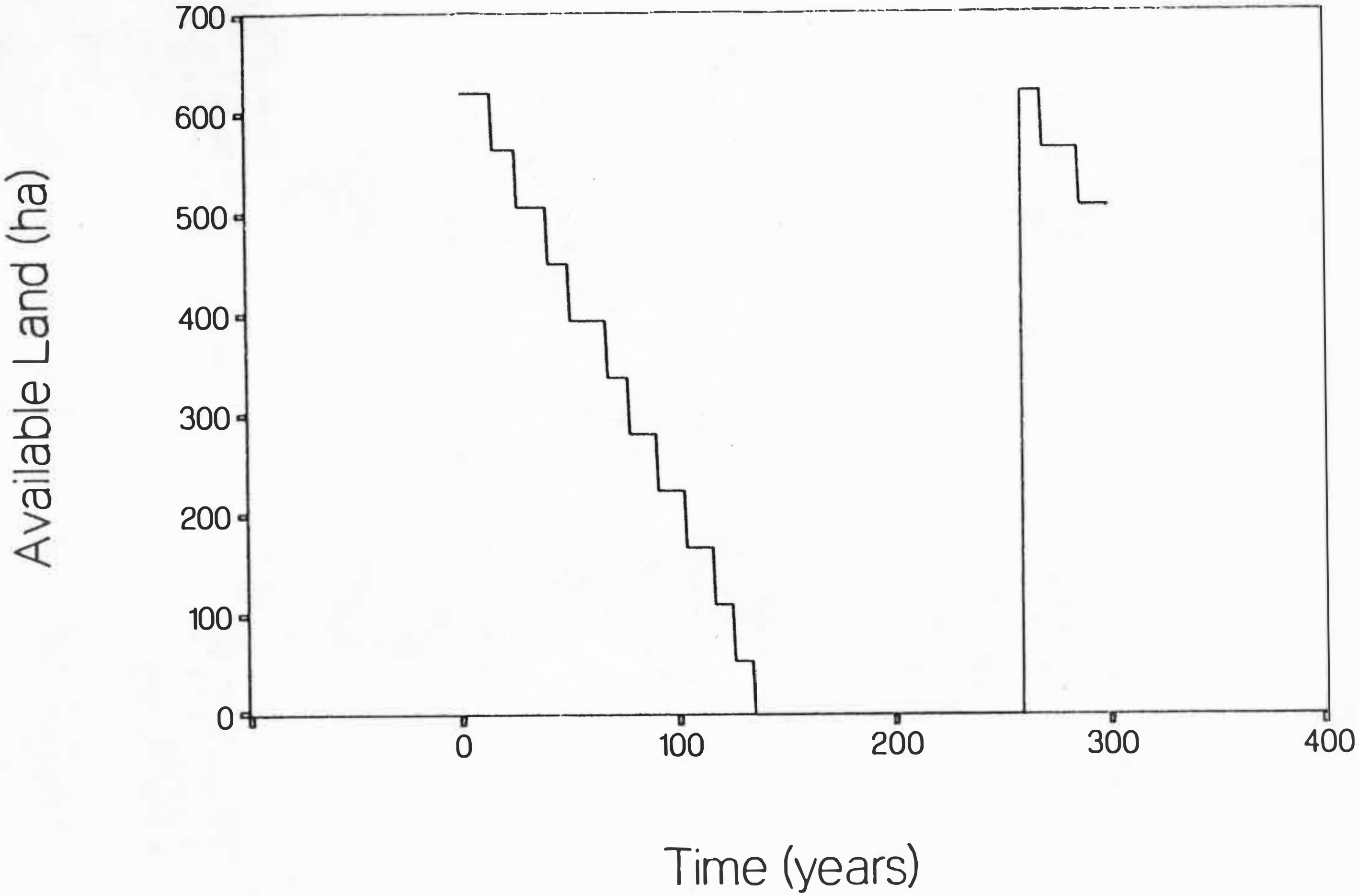

Figure 9. Total amount of available land at Kincaid for a stationary population of 142.

CHAPTER IV

THE APPLICATION

Background

The Little Tennessee River flows from its headwaters in the Blue Ridge Physiographic Province of northern Georgia to its mouth on the Tennessee River. Most of the study region lies along the lower Little Tennessee and Tellico Rivers in the Ridge and Valley Physiographic Province of East Tennessee. Several archaeological endeavors have documented the geographic characteristics (Cridlebaugh 1984:9-14; Kimball 1985:88-120; Davis et al. 1982:8-36) and cultural sequence (Kimball 1985: and Davis et al. 1982:333-411) of the Valley. Applying the model to this setting requires calibrating population and soil productivity in terms of this information.

The region's late prehistoric/early historic period has been divided into four sequential manifestations: Martin Farm (A.D. 900 to 1000), Hiwassee Island (A.D. 1000 to 1300), Dallas and Mouse Creek (A.D. 1300 to 1600?), and Overhill Cherokee (A.D. 1700? to 1819) following, in part, Lewis and Kneberg (1946) and Kimball (1985). In this study these periods will be designated Mississippian I-IV, respectively, on the basis of ceramic continuity (Kimball and Baden 1985).

Regional Mississippian research has primarily been restricted to salvage operations resulting from Tennessee Valley Authority reservoir construction (1934 to 1979). These include the Norris (Webb 1938), Chickamauga (Lewis and Kneberg 1941, 1946), Chilhowee, and Tellico Reservoir projects. Reports produced by the Tellico Archaeological

Project (1967 to 1982) serve as the modern basis for understanding the Mississippian sequence in the study region. Particular emphasis is placed on the excavations at the sites of Bat Creek (Schroedl 1975), Toqua (Polhemus 1984), Citico (Salo 1969; Chapman 1979), and Martin Farm (Schroedl et al. 1985). The unexcavated site of Great Tellico (40MR12), located on the upper Tellico River, also served as a major Mississippian center. In addition, because the Valley was the homeland of the Overhill Cherokees (A.D. 1700? to 1836), the historically recognized (Timberlake 1927) towns of Chota/Tanasee (Schroedl 1986, edited), Tomotley (Baden 1983; Guthe and Bistline 1978), Citico (Chapman 1979), and Mialoquo (Russ and Chapman 1983) play an important role in understanding the region's late Mississippian Period. The most significant Mississippian and Cherokee sites are shown in Figures 10 and 11.

Environmental data pertinent to quantifying the area's soil productivity are available in the soil survey reports for Blount (United States Department of Agriculture 1953), Loudon (United States Department of Agriculture 1961), and Monroe (United States Department of Agriculture 1981) counties. Interpretation of resource utilization patterns depend on the results of two research projects which examine the region's cultural sequence: Cridlebaugh's (1984) palynological/paleobotanical study and the 1982 probabilistic survey of cultural resources (Davis et al. 1982; Baden 1985). Combined, the available data for this region are highly suitable for testing the applicability of the preceding model.

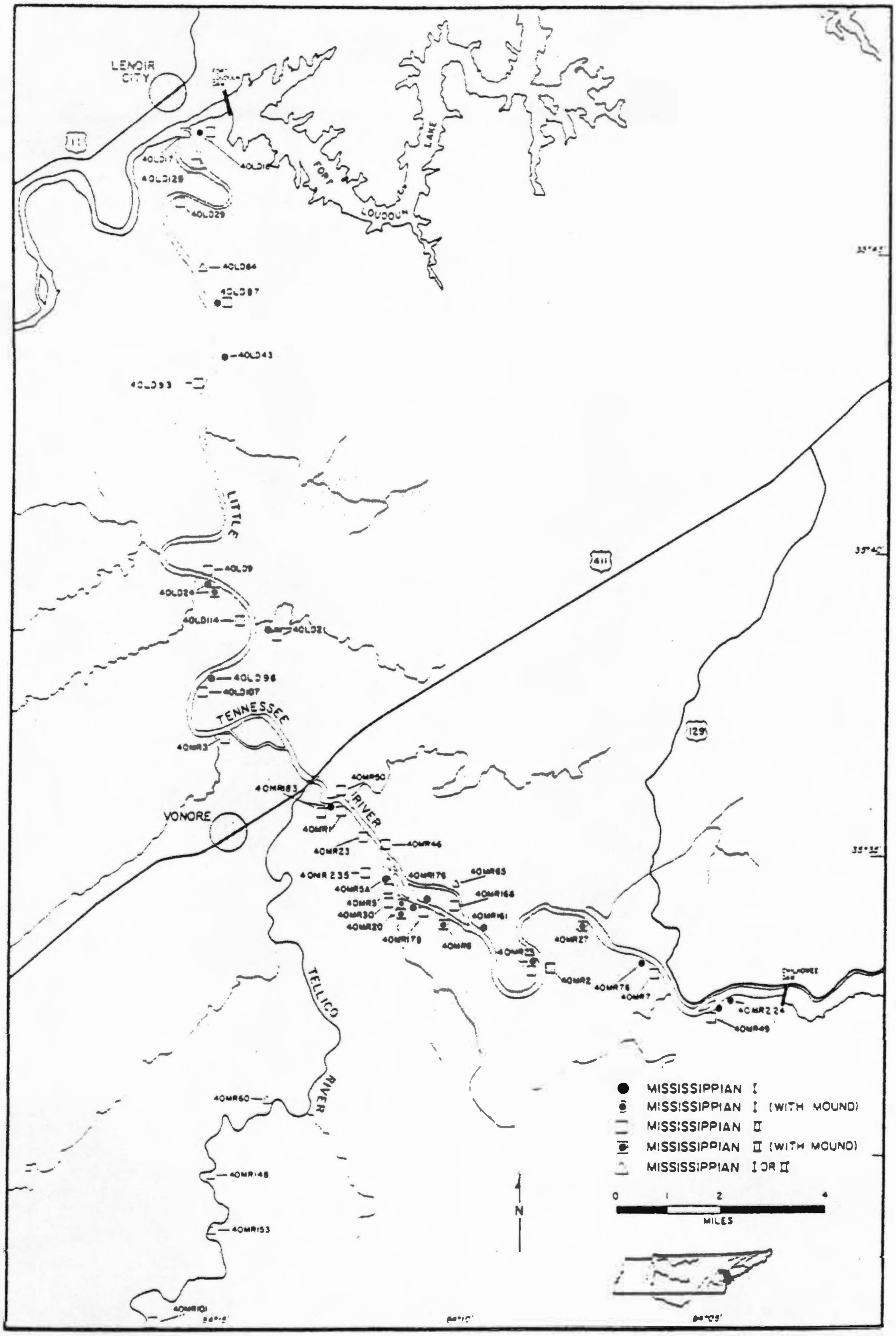

Figure 10. Distribution of Mississippian sites along the Little Tennessee River Valley (Schroedl et al. n.d.).

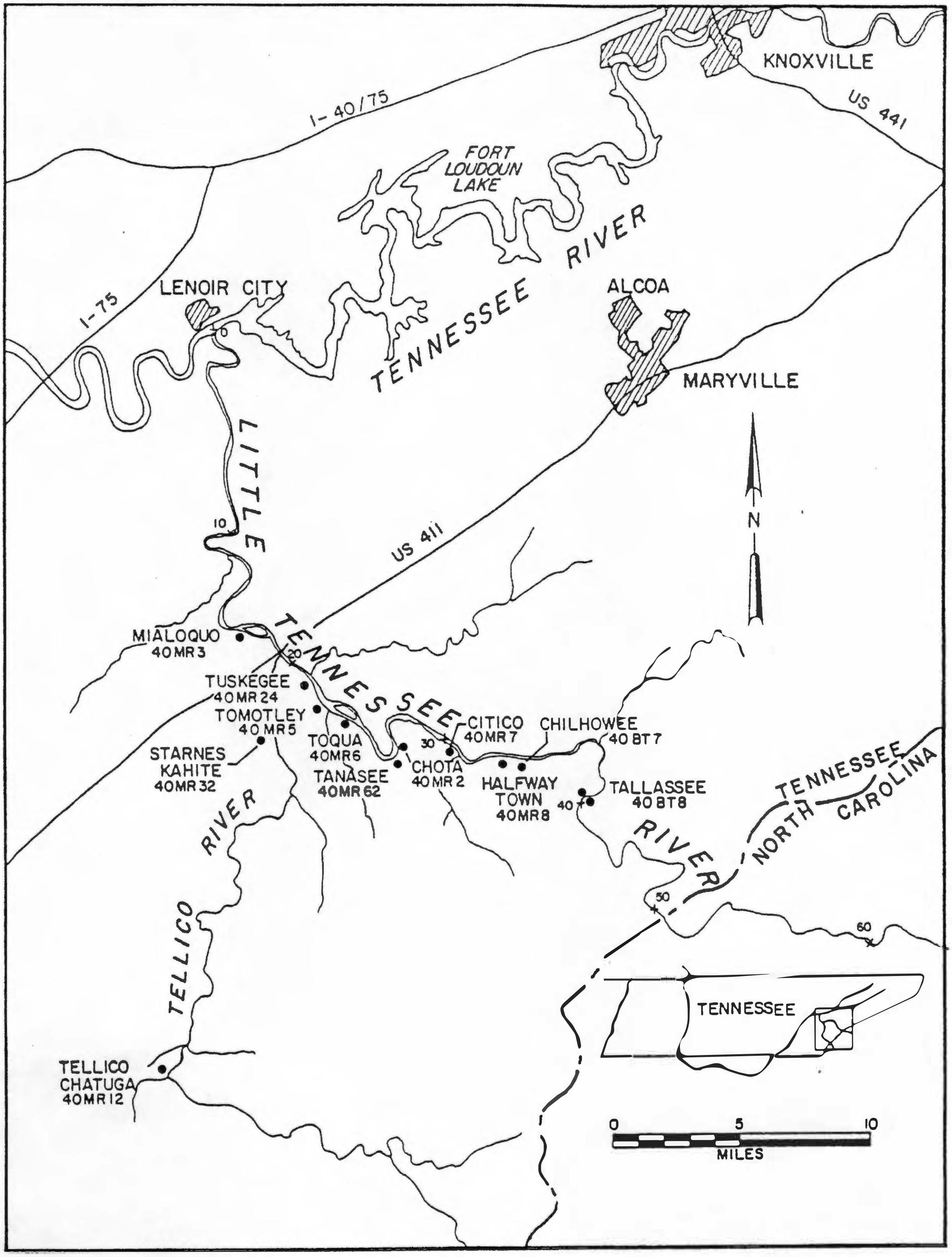

Figure 11. Distribution of historic Cherokee (Mississippian IV) sites along the Little Tennessee River Valley (Schroedl 1986:6).

The Mississippian Sequence

The Emergent phase of East Tennessee Mississippian, Mississippian I, is characterized by small settlements appearing ca. A.D. 900. Some villages included the construction of substructure mounds [such as the one found at Martin Farm (40MR20)] (Schroedl et al. 1985:462). The overall settlement distribution appears to have been dispersed along first terrace (T1) surfaces [i.e. floodplain surfaces abandoned by the Little Tennessee River between 3500 and 4000 years ago (Delcourt 1980)].

Mississippian II sites appear ca. A.D. 1000 and consist of more centralized and complex villages such as those at Bat Creek (40LD24) and Martin Farm. Site selection shifted to second terraces (T2), possibly due to increased flooding of T1 elevations or, alternatively, selective use of the lower terrace for agriculture (Schroedl et al. 1985:466). The villages appear, based on evidence from Bat Creek, to have represented brief, intensive occupations without subsequent Mississippian III development (Schroedl 1975:278-279).

The Mississippian III period (Dallas) is most prevalent at Toqua (40MR6), Citico (40MR7), and Great Tellico beginning around A.D. 1300. This was the period of organizational climax growing out of an elaborate Mississippian II base in East Tennessee. Toqua served as a major center during the period with one of two substructure mounds dating to A.D. 1208 ± 133 years (middle Mississippian II; C14 corrected) (Baden 1980). Archaeomagnetic dating documents the primary occupation occurred between A.D. 1370 and 1470 (Baden 1980).

Late in the period, probably during the fifteenth century A.D., a more dispersed, remnant settlement pattern developed which we call Mouse

Creek (after the type site 40RH41 in the Chickamauga reservoir) (see Lewis and Kneberg 1941:7-11; Garrow 1974). Concentrated in the Ridge and Valley Province of northern Georgia and southeastern Tennessee, this developmental phase shares several material and structural similarities with Dallas and Overhill sites. Limited exposure of a possible square townhouse at Tomotley (40MR5) (Baden 1983:129) in close proximity to late Dallas features (Guthe and Bistline 1978:42-43) demonstrates the existence of this phase in the study area (cf. Lewis and Kneberg 1941:7). However, with this exception, obvious Mouse Creek contexts are not recognizable in the Valley. The lack of a clearcut transition between elaborated Mississippian and historical Cherokee has led many to presume an occupational hiatus occurred during the seventeenth century A.D. (see Schroedl 1986).

By 1720 early military and economic surveys of the region began to produce an Anglo-American record of the Cherokee occupation. Census data generated in 1721 (Fernow 1890:273-275) give us the first quantitative measure of aboriginal occupation in the area. Such data continued to be produced until the final Cherokee removal in 1836.

Generalized site distribution early in the eighteenth century consisted of a limited number of villages (Chota, Tanasee, Toqua, and Great Tellico/Chatuga). By A.D. 1750 military disruptions forced Cherokee refugees from the Lower (South Carolina), Middle (mountains of North Carolina), and Valley (Valley River, North Carolina) Cherokee towns to seek refuge in the Overhill country (Baden 1983:20). This resulted in the village pattern witnessed by Timberlake (1927) in 1762 (Figure 12). This settlement system was destroyed by Revolutionary

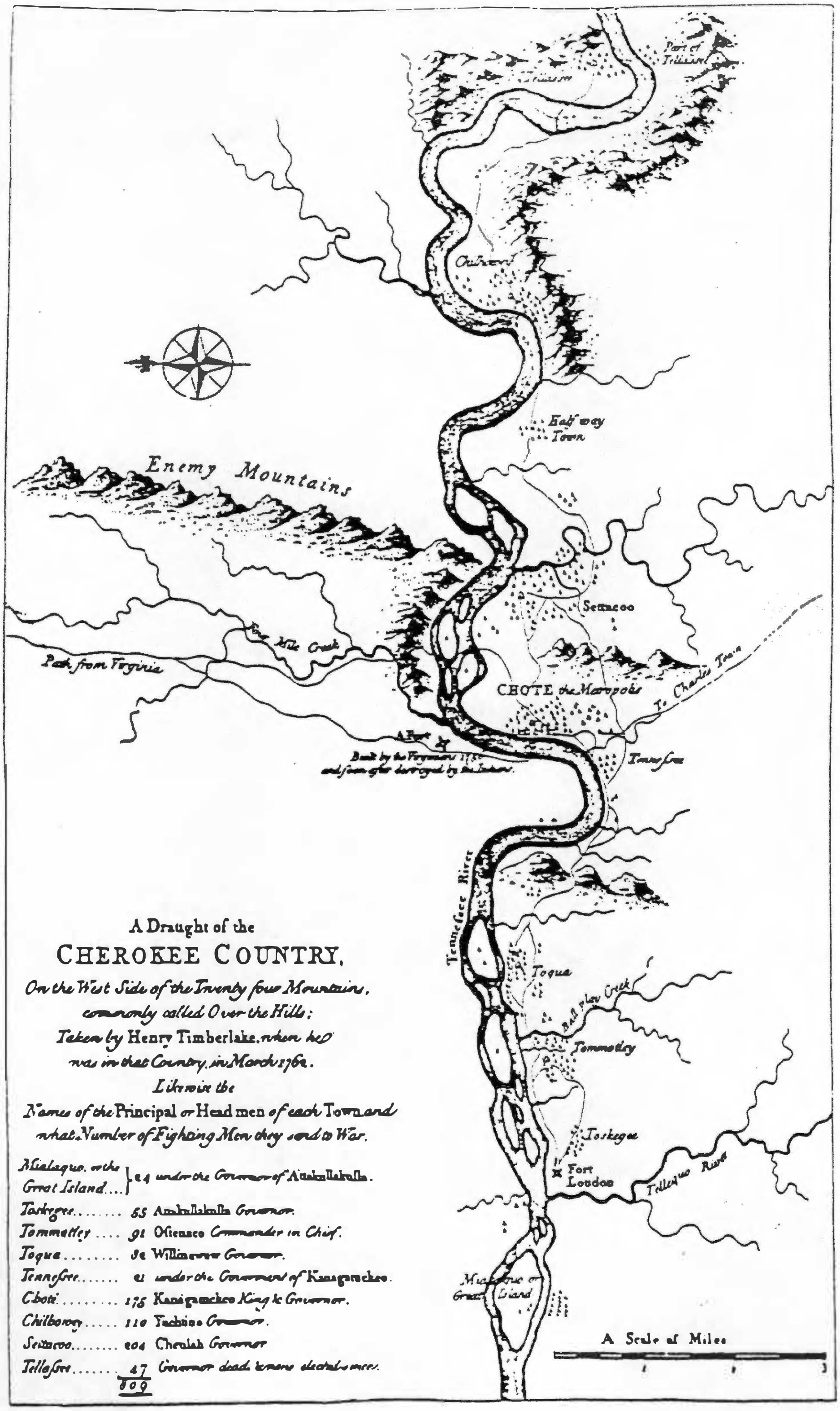

Figure 12. Lieutenant Henry Timberlake's 1762 map of the Overhill Cherokee villages (Timberlake 1927).

forces in 1776 when the pro-British inhabitants were driven south to the Chickamauga area. Subsequent aboriginal occupation of the Valley was limited to a few reservations and four small, more traditional settlements (Citico, Chilhowee, Great Tellico, and Tallassee) until final Cherokee removal in 1836 (Riggs 1987).

Resource Utilization

We have hypothesized several utilization characteristics for the Mississippian Period. Early maize consumption was limited to approximately one third of the total caloric intake. Later, production levels increased the dependance to almost 75%. This expanded consumption is correlated with improved productivity as 12/14 row races were replaced by 8/10 row types. The increase is also a reflection of an expanding population's impact on less stable wild resources. Because traditional resources are subject to cyclical yield fluctuations, horticultural substitutes offered an increase in expected productivity. To use these hypotheses effectively, our model requires verification of their validity under East Tennessee conditions.

The task of quantifying horticultural utilization by Mississippian groups is a difficult one to undertake. Until recently, paleobotanical recovery and analysis were biased in favor of those situations where preservation conditions were ideal. Today, techniques and sampling schemes have been developed that enhance the systematic recovery of plant remains (Watson 1976). Unfortunately, most of the more critical excavations in the study area predate widespread use of these techniques. This limits our validation to a search for contradictory evidence.

In the Little Tennessee River Valley, there is no ethnobotanical evidence to support heavy aboriginal use of 12/14 row varieties (Chapman and Shea 1981). Throughout the period of maize horticulture, the most abundant forms were the 8/10 row specimens. This extends back to the Middle Woodland Period as revealed in Middle Tennessee's Owl Hollow phase sites where 10 row race(s) were recovered (Crites 1978:82-83). The smaller rowed varieties similarly predominate the record of early maize in East Tennessee (Chapman and Shea 1981:72; Schroedl et al. 1985:456). This runs counter to our expectation, based on Cutler's (1956) data, that older forms will tend to display higher row numbers. On the other hand, looking at the end of the Mississippian period (Kline and Crites 1979; Schroedl and Shea 1986:520), the absence of many-rowed types confirms our belief that the more advanced southern dent varieties did not become prevalent at any time in the precolonial period. Production would not appear to be limited by any obvious varietal component. Therefore, maximum potential yield can be assumed to be constant (18.8 quintals/ha) over the period.

As noted in Chapter III, skeletal analyses document that maize was not an important caloric source prior to A.D. 1000. Early (Mississippian I) dependence on maize was on the order of 35% increasing to over 70% of the diet late (Mississippian III) in the sequence (Lynott et al. 1986:61). Archaeological investigations from East Tennessee have failed to detect such an increase between Mississippian I and II (Schroedl et al. 1985:456). This is based on the lack of a significant change in the abundance of maize remains from one period to another at Martin Farm. Over the entire Mississippian era, however, such a trend has been interpreted from the collective botanical evidence (Chapman and Shea 1981:72).

Our application should reproduce this change with a concomitant adjustment in field size and an increased sensitivity to decreasing annual yields. Lacking contrary evidence, we can use (3.10) to estimate the time-dependent, optimal production needs (quintals per person) for the Mississippian Period. Field sizes would be based on expected yields and required need. With a mean non-depleted yield of 9.99 quintals/ha, a requirement of 0.88 quintals/person could be met by planting 0.09 ha/person. Likewise, 0.16 ha/person would supply 1.63 quintals/person. When failure is defined by a yield in quintals/person below the minimum required, the uselife of a field will be directly related to its size per person. Obviously, small fields will tend to fail sooner while not using as much of the total land reservoir. Because we do not know how large the fields were per person, the size parameter must be defined as a bounded value, [0.1,0.4] ha/person. The boundaries are defined by minimum need and maximum area capable of being cultivated per person. Although this may seem imprecise, we will show that field size does not significantly alter the expected time of total failure by more than three generations.

The palynological evidence gathered from cores taken from Black Pond and Tuskegee Pond (Cridlebaugh 1984) reveals several important facts concerning maize production in the Little Tennessee River Valley. Maize pollen was consistently recovered from levels dating back to the

Middle Woodland. Sharp increases in the pollen spectrum occurred ca. 900 B.P., 700 B.P., and 350 B.P. (A.D. 1050, 1250, and 1600, respectively). A major decline was observed at approximately 450 B.P. (A.D. 1500) (Cridlebaugh 1984:68). Charcoal peaks are correlated with maize production and interpreted to be the result of clearing practices (Cridlebaugh 1984:133-134). A decrease in this charcoal influx from 470 to 360 B.P. (A.D. 1480 to 1590) is assumed to be an indication of a settlement decline. Additionally, because Tuskegee Pond is situated on a third river terrace, we know that upper terraces were used for agricultural purposes as early as the Middle Woodland. Fluctuations in the pollen spectrum may provide us with the only evidence of settlement adjustments as independently predicted by the basic model.

An analysis (Baden 1982,1985) of data from the 1982 probabilistic survey provides another interpretation of Mississippian land use. Using probability models of site location, it is possible to locate areas of increased Mississippian activity over that of the previous Woodland Period. The heaviest concentration lies in the Tomotley Bottoms area between the mouths of Tellico River and Citico Creek. It is in this area that sites like Toqua, Tomotley, Chota, Citico, and Martin Farm flourished. A secondary area of habitation lies along Tellico River and extends to the site of Great Tellico/Chatuga. As will be discussed later, these locations are correlated with Statler-Staser-Transylvania soil associations which constitute the richest agricultural soils of the Valley. These small arable sections will be shown incapable of longterm support of Mississippian development.

These observations are not sufficient for us to make specific statements on the importance of maize in the study area or identify the races grown. However, we can say that there was an increase in utilization based on the observed increase in material deposition during the period and note that the higher row numbered varieties do not contribute more than a trace amount to the botanical assemblages. We can also identify periods of decreased utilization of at least part of the Valley and use these dates as benchmarks to compare with our model's predictions. Our isolation of heavily utilized areas provides useful correlations with soil types which are needed to quantify expected yields for the period.

Population Parameters

Estimating population parameters from archaeological evidence is at best difficult. Of the principal excavated sites, only Toqua produced sufficient evidence to warrant serious demographic estimation. From both village and mound contexts, 439 burials were recovered (Parham 1984:392). Following the standard stationary population assumptions, life table approximations projected a life expectancy of 16.1 years (Parham 1984:422). Estimates of village size were made for a presumed range of 2500 to 5000 possible burials (deaths) at the site during the primary 300 years of Mississippian use. Using the methods described by Ubelaker (1974:66) and Acsadi and Nemeskeri (1970), these constant population values fell between 134 and 299 individuals.

An intersite osteobiography of late Mississippian phase sites (Boyd 1984:92) presented constant village size calculations of 890 for Ledford

Island (40BY16) and 193 for Rymer (40BY15). Both sites represent Mouse Creek phase occupations (ca. A.D. 1500) in the Chickamauga Reservoir area. The estimated numbers of burials at each of these sites are 3962 and 811, respectively.

In order to incorporate stable population parameters (3.2) into such an exercise, the formula:

$$P_0 = \frac{rT}{d\{\exp(rt) - 1\}} \tag{4.1}$$

can be used to estimate the starting population needed to produce T burials after t years where the death rate is d and the net growth rate is r. Using the data in Table 1 (p. 39), a stable population with a GRR(23) of 3.0 and a r of 0.003 will have a death rate of 0.051. Under such conditions a P_0 of 101 at Toqua would produce 2500 deaths in 300 years and a final population of 248 people. This is a reasonable estimate, given the argument that the reciprocal of the mean age at death (16.1 years) is either a measure of the birth rate for a stable population (Sattenspiel and Harpending 1983:493) or the death rate for a stationary population. Toqua's death rate would fall in the range of 0.059 (implying a P_0 of 87.09 for $r = 0.003$).

Both approaches assume continuous site occupation for the period. If the village is intermittently abandoned, as the Kinkaid example implied, the relationship between total burials and population size is invalidated. In such a case the interval, t, is discontinuous and site specific. To be valid, the number of burials must be calculated in terms of the entire settlement area. If it can be shown that continuous occupation is highly unlikely, we would need to reconsider many of our assumptions about "contemporary" sites.

We can, therefore, simplify our analysis by presenting the population parameters for the study region as an aggregate rather than a sum of individual values for each specific site. During the early contact period, Cherokee villages tend to have less than 200 residents. This is supported by the 1721 census listed in Table 5 (Fernow 1890). The average village size was 196.9 with a range of 62 to 622. A similar tabulation by Haan (1981:353) produces an average village size of 186.8 for 60 Cherokee towns in 1720. Using the data in Table 5 we can estimate the relationship between the numbers of men (m) and the total village size (V_s) as :

$$V_s = 2.989m - 1.05 \qquad r^2 = 0.8 \qquad (4.2)$$

This allows us to estimate the 1762 population of the nine principal Overhill villages to be 2417 based on Timberlake's census of 809 warriors (see Figure 12, p.91). From a similar setting, Schoolcraft's (1847:32-33) data on Iroquois reservations (Table 6) allow us to estimate the average aboriginal family size to be 5.3 with an average aboriginal growth rate for one year of 0.006.

All of these values are within the expected range for Mississippian populations given the arguments in the preceding chapters. This is true despite the fact that historical data encompass the effects of decimating diseases introduced by western colonists (Dobyns 1983:8-32). It is difficult to assess to what extent historical accounts reflect reduced population sizes. Size estimates of Florida's Timucan population, generated from early Spanish recollections (Dobyns 1983:186-205),

Table 5. The 1721 census of all known Cherokee villages (taken from Fernow 1890).

Village	Men	Women	Children
Kewokee	168	155	137
Eascenica	44	42	48
Oakenni	57	52	75
Timotly	42	68	42
Checlokee	71	71	77
Tockaswoo	50	60	60
Toogellon	70	66	68
Changee	80	60	60
Eastatoe	150	191	281
Echie	55	50	44
Chattoogie	30	40	20
Kittowah	143	98	47
Stickoce	97	90	95
Noonnie	61	56	60
Suskasetchie	150	140	145
Tarrahnie	72	11	7
Echotee	59	97	65
Tuckoe	34	33	27
Turrurah	60	40	22
Wooroughtye	30	20	12
Taseetchie	36	44	45
Quannisee	37	31	36
Tookarechga	60	50	45
Stickoce	42	30	30
Old Estatoe	40	50	34
Mougake	57	31	42
Echoce	44	30	36
Nookassie	53	50	39
Cunnookah	89	59	54
Cattojay	48	51	39
Elojay ye little	58	50	64
Wattogo	64	59	53
Torree	59	60	69
Cowyce	78	78	102
Taskeegee	60	62	64
Erawgee	43	49	41
Tookareegha	77	114	36
Cheowhee	30	42	42
Tomotly	124	130	103
Elojay	56	70	65
Little Terrequo	50	56	48
Suoigella	50	65	60
Little Euphusee	70	125	54
Little Tunnissee	12	30	20

Table 5 (Continued)

Village	Men	Women	Children
Great Euphusee	70	72	60
Terrequo	100	125	116
Tunnissee	160	193	190
Settequo	77	123	73
Charraway	70	71	35
Tarrassee	33	38	24
Sarrawotee	40	55	50
Taskeegee	70	69	75
Elojay	30	39	47
-TOTAL-	3510	3641	3283
-MEAN-	66.2	68.7	61.9
- SD -	35.1	40.1	45.5

Table 6. Schoolcraft's Iroquois reservation census for a single year (Schoolcraft 1847:32-33).

Village	Families	Population	Births	Deaths
Oneida	31	157	13	1
Onondaga	56	368	16	23
Tuscarora	53	312	10	4
Buffalo	92	446	10	21
Cattaraugus	189	808	28	24
Cayugas	20	114	5	6
Alleghany	153	783	19	26
Tonawanda	104	505	13	7
St. Regis	48	260	7	8

have exceeded 130,000. If depopulation trends followed Dobyns' (1983:29) proposed 94.9% reduction rate between A.D. 1515 and 1625 (something unsupported paleodemographically), the Mississippian population of the Valley would have climaxed at 47,151 individuals late in Mississippian III given the "surviving" 2400 inhabitants in 1762. Such estimates are probably extreme and fail to recognize that archaeological and historical records are not capable of extrapolating total settlement size from site specific observations (see Zambardino 1980 for a critique of using such data). Although a village like Estatoe (Table 5) may have 622 inhabitants, others may be substantially smaller and more dispersed across the catchment area. Also, one village of 600 that periodically moves will produce several archaeological sites each apparently capable of supporting 600 people.

Population estimates should be framed in terms of socio-political and technological levels of organization and applied to catchment regions rather than individual sites. Following observations involving implications from basic information theory (Forge 1972:374; Johnson 1978, 1982; Root 1983), socio-political control is limited by the ability of a society's hierarchical structure to maintain accurate and efficient information flow. For the contact period this would be around 200 people per village aggregate and probably no more than a dozen villages per political unit (i.e. the Overhill, Middle, Lower, and Valley towns). The Little Tennessee Valley supported approximately 2400 people in nine villages in 1762. This would mean a population density of 0.006 per ha (1.62 per mi^2) was maintained over the three county area, at least for a short time. Obviously the hunting range for these villages extended great distances beyond this arbitrary area. But, because agricultural catchment tends to lie within a two mile radius from each village (Chisholm 1962:66), density defined in terms of the study area would seem appropriate.

Calculations by Parham and Boyd confirm probable village sizes of about 200 for sites like Toqua, with major centers having up to 1000 inhabitants. With primary (though not necessarily contemporaneous) Mississippian III settlements at Toqua, Bussel Island, Citico, and Great Tellico a minimum Dallas population of 800 people might be expected for the Little Tennessee Valley. Similarly, the Mississippian II villages were probably fewer in number with concentrations at Toqua and Bat Creek. Mississippian I sites predate heavy dependence on agriculture. As hunter/gatherers they probably consisted of small, dispersed settlements.

If we use a conservative r value of 0.003 and a P_0 of 200, the expected population of the Valley in 800 years (A.D. 900 to 1700) would be 2205. This is conveniently close to the estimated 1762 Cherokee population without allowance for disease effects. But could such a low density support the development of stratified socio-political organizations during this period? The literature is unclear on the minimum population size required to encourage and pay for the development of Mississippian traits such as substructure mounds, apparent elite and artisan classes, and an inter-village political network. Considering these factors, we might suppose that population densities during Mississippian I-III were higher than those of the historical period. If this were the case, our estimate of P_0 might have to exceed 1000.

Because we lack specific lower threshold limits, we will analyze the model for ranges of P_0 and r values. In choosing this course we partially reject the need for site specific estimates in favor of bounded ranges of possibilities. The model's responses are then probable expectations of what should occur within the context of our overall demographic assumptions.

Soil Productivity

Until now we have assumed a constant maximum potential yield per unit area. This value has been shown to be approximately 18.8 quintals/ha. In reality this parameter will vary with soil type across a study area. Modern maximum yields and other soil characteristics for Monroe, Blount, and Loudon counties have been documented by soil conservationists (United States Department of Agriculture 1953, 1961, 1981). Using these observations it is possible to select those soils conducive to aboriginal use and predict the yield potential for each. Although soil characteristics have changed since the Mississippian occupational period, modern measurements should be sufficiently proportional to their prehistoric values to allow us to use them to scale our model's parameters to fit the East Tennessee situation.

Not all soils would have been suitable for primitive hoe agriculture. Soil characteristics of slope, depth, drainage, and tendency to erode combine to form a capability grouping useful in determining limitations for modern land development (United States Department of Agriculture 1981:62-63). This index refers to soils as Class I (no limitations) through Class VIII (extreme limitations on crop production). Specific limitations are also coded using designations like IIe to indicate susceptibility to erosion and IIw to indicate a tendency to flood. Under minimal technologies, only Class I and some II, IIe, and IIw soils could be expected to be used by Mississippian cultures. All others would require extensive management practices, by today's standards, in order to produce marketable crops. Capability groupings are readily available for Monroe and Loudon county soils. Blount designations are lacking and require estimation based on cross-correlations with soil types from the adjacent counties. The 40 soils selected on the basis of capability grouping and potential yield are listed in Table 7. These are the soils most likely to be used by Mississippian farmers.

To estimate yield under aboriginal conditions, maximum, modern maize yields were equated with our expected prehistoric yield of 18.8 quintals/ha. These values are 72.19, 48.96, and 62.77 quintals/ha for Monroe, Blount, and Loudon counties, respectively. The relatively low yields for Blount County are a reflection of the 1950's agricultural technology. Today we would expect the measures to be proportionally higher and in line with the figures quoted for the other counties. If we multiply each soil type's modern yield estimate, as given in the soil reports, by the appropriate 18.8/(modern maximum) value we will have estimates of the aboriginal yields of each soil type. These are listed in Table 7 along with the surface area represented by each type. The product of each type's maximum yield and surface area is the maximum potential harvest for that type. The sum of these harvests divided by the total field area (29185.4 ha) for the study area is the weighted average maximum potential yield for the Valley. This is calculated to

Table 7. Soil productivity data for the study area under aboriginal conditions.

County	Soil Type	Capability Index	Max. Yield (quintals)	Hectares
Loudon	Barbourville silt loam	I	16.01	75.7
Loudon	Congaree loam	I	18.83	426.1
Loudon	Congaree loam	I	16.01	102.0
Loudon	Emory silt loam	I	16.95	1736.9
Loudon	Emory silty clay loam	I	14.12	178.5
Loudon	Greendale cherty silt loam	I	16.01	892.4
Loudon	Greendale silt loam	I	13.18	361.8
Loudon	Huntington loam	I	18.83	467.4
Loudon	Huntington loam	I	16.01	105.2
Loudon	Neubert loam	I	16.01	359.4
Blount	Barbourville fine sandy loam	I	15.45	932.4
Blount	Emory silt loam	I	18.83	164.3
Blount	Emory silt loam	I	17.87	4038.0
Blount	Emory silty clay loam	I	16.42	443.9
Blount	Greendale silt loam	I	17.38	962.8
Blount	Hamblen silt loam	IIw	16.42	454.9
Blount	Hamblen silt loam	IIw	16.42	1095.5
Blount	Hamblen silt loam	IIw	16.42	1633.3
Blount	Hermitage silt loam	IIe	15.69	356.9
Blount	Lindside silt loam	IIw	16.90	910.2
Blount	Neubert loam	I	17.38	1094.7
Blount	Sequatchie fine sandy loam	IIe	15.21	187.0
Blount	Sequatchie loam	IIe	17.38	299.9
Blount	Sequatchie silt loam	IIe	17.38	566.6
Blount	Staser fine sandy loam	I	16.90	461.8
Blount	Staser loam	I	18.35	446.8
Blount	Staser silt loam	I	18.35	451.2
Monroe	Allegheny loam	I	18.01	335.9
Monroe	Chagrin silt loam	I	18.01	514.0
Monroe	Emory silt loam	I	18.83	1141.2
Monroe	Etowah silt loam	IIe	16.38	1293.0
Monroe	Greendale silt loam	I	18.01	366.2
Monroe	Hamblen silt loam	IIw	16.38	2470.7
Monroe	Lobdell silt loam	IIw	16.38	358.2
Monroe	Neubert loam	I	15.56	821.5
Monroe	Pope loam	I	16.38	588.8
Monroe	Sequatchie loam	I	17.19	147.7
Monroe	Staser loam	I	18.83	505.9
Monroe	Statler loam	I	18.01	953.1
Monroe	Transylvania loam	I	18.83	483.6

be 17.06 quintals/ha and represents the standardized yield estimate for the 40 soil types. All yield equations (3.7-3.9) can be rescaled by 17.06/18.8 to adjust to these region specific potentials. It is possible that those soils subject to flooding and erosion may not have been usable by prehistoric populations. If this were the case, only Class I soils would have been used. This would result in 19559.2 ha of arable land and a valley-wide average yield of 17.35 quintals/ha. Because the average maximum yields are approximately equal, we can simplify our calculations by assigning their average (17.2 quintals/ha) as the overall Valley yield potential. The total arable land ranges between 19559.2 and 29185.4 ha. As a shorthand notation, we will refer to these sizes as L and H, respectively. By comparison, the more extensive Moundville settlement system along Alabama's Black Warrior River appears to have been supported by only 11,095 ha of arable land (Peebles 1978:407).

Applying the Model

The application of the model involves two steps. The first consists of defining the interacting variables in terms of the physical and behavioral restraints pertinent to an East Tennessee setting. As discussed above, most of these parameters will be expressed as bounded ranges rather than single values. This continuum of initialization conditions will still be useful in providing the output that constitutes the second step of generating model responses to these parameters.

Stability was initially defined as a measure of a system's maintainability in the presence of changing conditions. In particular, we want to determine the conditions which might encourage the system's response to converge on non-maintainable situations given behavioral and physical restraints. These situations are, topologically speaking, critical points in the phase space of a Mississippian agricultural system. The primary response variable at these points is a measure of insufficient arable land to meet demand at some point in time, t. To simplify and place this discussion into the perspective of temporally defined archaeological phase-shifts, this variable is defined to be the time in years since t=0 required for the system conditions to reach some level of failure. Before developing a notation to simplify this discussion, the specific physical and behavioral restraints should be listed.

The model can be formulated in terms of the following restraints and rules:

A. Physical Restraints

1. The boundary values for the population growth rate, r, are [0.003,0.017].
2. The boundary values for field sizes, f_s, are [0.1,0.4] ha/person.
3. The total reservoir, R, of arable land is [19559.2, 29185.4] ha.
4. The weighted maximum yield for the study area is 17.20 quintals/ha.
5. The recovery period for exhausted land is 125 years.
6. Adjusting for quintals/ha and rescaling by 17.20/18.8, expected yield (3.8) and yield standard deviation (3.9)

become ($E_0 = 9.14$ and $s_0 = 3.03$) (substitute 2t for t to account for weedy plants) :

$$E_t = 8.48t^{-.2249} \quad \text{quintals/ha} \qquad t > 0 \qquad (4.3)$$

$$s_t = 2.81t^{-.2249} \quad \text{quintals/ha} \qquad t > 0 \qquad (4.4)$$

7. Crop failure is defined in terms of the minimum caloric need and field size per person. The minimum yield, Y_F, below which there would be failure is a function of (3.10):

$$Y_F = \frac{C_t}{\text{hectares}/P_t} \qquad \text{for } t \in [900,1700] \qquad (4.5)$$

8. Surplus yield, Y_S, is equal to the excess production above Y_F.
9. The application period is 800 years (A.D. 900 to 1700).
10. The total area planted ($P_t f_s$) will be defined when an old field is abandoned and a new one cleared (i.e. not on an annual basis).

B. Behavioral Rules

1. The point at which field exhaustion takes place is defined as the year following three consecutive crop failures (when production is less than Y_F).
2. If insufficient land exists for a population, the value of P_t will be reduced by fissioning to one that can be supported by the amount of remaining land (i.e. divide the total amount of available land by the field size per person).
3. If all the land is exhausted, the entire population (P_t)

will abandon the Valley. If, after the recovery period (125 years), the population should need to return it will do so at the $P_{(t+125)}$ level.

4. There will not be any significant technological changes during the period that would alter any of the above equations.

To implement the dynamics of this model, a Pascal program (Appendix B) was developed. This algorithm, with relevant adjustments, served as the basis for the following observations. Unless otherwise noted, all output was the result of a single simulation using the same sequence of random [n(0,1)] deviates (Kolmogorov-Smirnov Z = 0.844, p = 0.416) to estimate annual yields (using 4.3 and 4.4). We will use the notation, (P_0,r,f_s,R), to represent the initialization parameters of starting population, population growth rate, field size per person (* will denote an adjustable value), and total area of the land reservoir (L = 19559.2 and H = 29185.4 ha). Thus, a simulation using a starting population of 100, a growth rate of 0.003, 0.1 ha planted per person , and 19559.2 ha of land is denoted by:

$$(100,0.003,0.1,L)$$

As P_0, r, f_s, and the net value of R vary, does the system lose its ability to maintain itself in terms of supplying its population's harvest needs (C_t)? This is the basic question to be addressed by examining the response of the system to different sets of input parameters.

As stated, the system's response can be simplistically reduced to the maintenance of some potential function, V (see page 5). If $dV/d\mathbf{x}=0$

then stability is defined. If, for some t, dV/dx is undefined the point, t, is considered a critical point. In a system's sense, this occurrence is termed a catastrophe and a discontinuous transition in the form of an archaeological phase shift will take place. There can be two kinds of "conflicts" that might induce such adjustments given a system trajectory that converges on a critical point. The first occurs when the population's need for land exceeds the finite amount of available land. Such an occurrence will be referred to as a fissioning point: the time, t, when P_t must be reduced sufficiently so as not to exceed the number of people that can be supported. The second type of critical point occurs when no land remains in the land reservoir. In this case total soil depletion takes place and the system collapses (Valley abandonment). We can refer to these situations as system transition points and represent them as functions of the starting parameters. In both cases one or more of the initialization parameters must be adjusted in order to maintain acceptable levels of system production. The point (in years after t=0) of first fissioning can be denoted as:

$$S_f(P_0, r, f_s, R)$$

Similarly, the critical point of first total soil depletion will be:

$$S_d(P_0, r, f_s, R)$$

The values of S_f and S_d will be said to be undefined when, for a given set of parameters, either fissioning or total depletion does not occur. In stability terms, the initialization parameters fail to cause the system to converge on a critical point over the 800 year study period. In the case of an undefined S_f the system can be said to be relatively stable. In the absence of a real valued S_d, however, unstable periods may occur. To analyze the model we will consider three classes of parameter values. From these special cases we will be able to extrapolate the dynamics of a Mississippian agricultural system.

In the first case r will be a positive value and f_s will be fixed. This will be useful in demonstrating the affect of individual parameters on the values of S_f and S_d. In particular, we need to map the interaction of different values of P_0 and r over an 800 year period and determine their influence on defining the duration of S_f and S_d.

The second type sets r equal to 0.0 for P_0 set to the largest value producing an undefined response for S_f and S_d, respectively. In this situation we are able to examine the affect of zero-growth, carrying capacity arguments used by other researchers. It will be shown that these values are representative of all conditions producing undefined responses (i.e. where P_0 is less than this maximum value). Therefore, we can define a small subset of all possible input parameters to summarize a precariously successful system.

The final situation will involve adjusting f_s such that the size of the fields increases in response to current need and past production experience. This is a more realistic approach to defining f_s where the parameter starts out small and increases in size according to the system's needs. By combining this approach with the zero growth P_0 values, we can produce generalized models of system response under optimal, Mississippian conditions. This application best represents the probable trajectory of Mississippian systems. The output under these conditions will be used to correlate this model with the archaeological record.

The values of S_f for fixed f_s of 0.1, 0.2, 0.3, and 0.4 ha/person and 0.003 through 0.017 values of r are presented in Appendices C (R = 19559.2 ha) and D (R = 29185.4 ha). Similar projections for S_d are given in Appendices E and F. From these we can observe the trivial verification that successively larger P_0's and r's produce successively smaller critical points (earlier conflicts) for a given f_s. From a nontrivial perspective, we also sense that f_s values have an impact on the system's response. For example, comparing $S_f(400,0.003,0.1,L)$ with $S_f(400,0.003,0.2,L)$ suggests that smaller f_s values imply later S_f critical points. Yet, this only holds true for the upper portion of the f_s=0.1 matrices [see $S_f(400,0.003,0.2,L)$ versus $S_f(400,0.003,0.3,L)$]. A look at the mean harvest, surplus, and duration of land use per field (response statistics) for common values of P_0 and r suggests that the S_f values mask important measures of system "quality".

	(400,0.003,-,L)			
Response	0.1	0.2	0.3	0.4 (ha/person)
Harvest (quintals/ha)	7.432	6.549	5.720	5.054
Surplus (quintals/ha)	-6.418	-1.068	0.483	1.081
Planting Duration (yr)	3.347	6.504	13.559	23.529

Increasing the fixed field size results in decreased harvest potential while improving surplus and field life expectancy. This interaction requires some elaboration.

Harvest potential is an *a posterior* function of time that is "locked" by our sequence of random deviates just as the real system's weather patterns are now locked historically. Surplus, on the other hand, is a culturally regulated response. It is dependent on the demand curve and the amount of land allocated to each individual. Although climatic potential cannot be influenced behaviorally, cultures can minimize its environmental impact by making technical adjustments. The function, Y_F, gives us the minimum harvest required to sustain the needs of the population. We can observe the interaction of harvest potential and various behavioral choices, in the form of selecting f_s, by plotting this minimum requirement curve against the simulated harvests for f_s values of 0.1 and 0.4 ha/person (Figures 13 and 14).

The relatively high position of the minimum demand curve for 0.1 ha/person results in a significant number of crop failures (harvest points below the curve). After frequent crop failures we would expect the new fields to support higher yield potentials according to (4.1). This is reflected in Figure 13's wider dispersion of harvest values compared with that shown in Figure 14 for 0.4 ha/person. Although forced field abandonment tends to raise the yield potential (as seen in the higher mean harvest for 0.1 ha/person fields), in the face of increased demand, small f_s choices will fail to meet the population's requirements. Figure 14 shows the flattening effect of larger field sizes on the minimum yield curve. We also see a tighter distribution of harvest values as a result of the extended planting duration brought about by, in a sense, over planting. Even in a bad year, if enough land is planted, sufficient harvest needs can be met. This will occur at the expense of increased labor costs.

What adaptive lessons can be learned from these observations? First, planting smaller fields, although desirable from a conservation and labor point of view, is not a productive solution for expanding agricultural societies. A gardening approach could not sustain the trends we see in Mississippian demand. Secondly, the use of larger

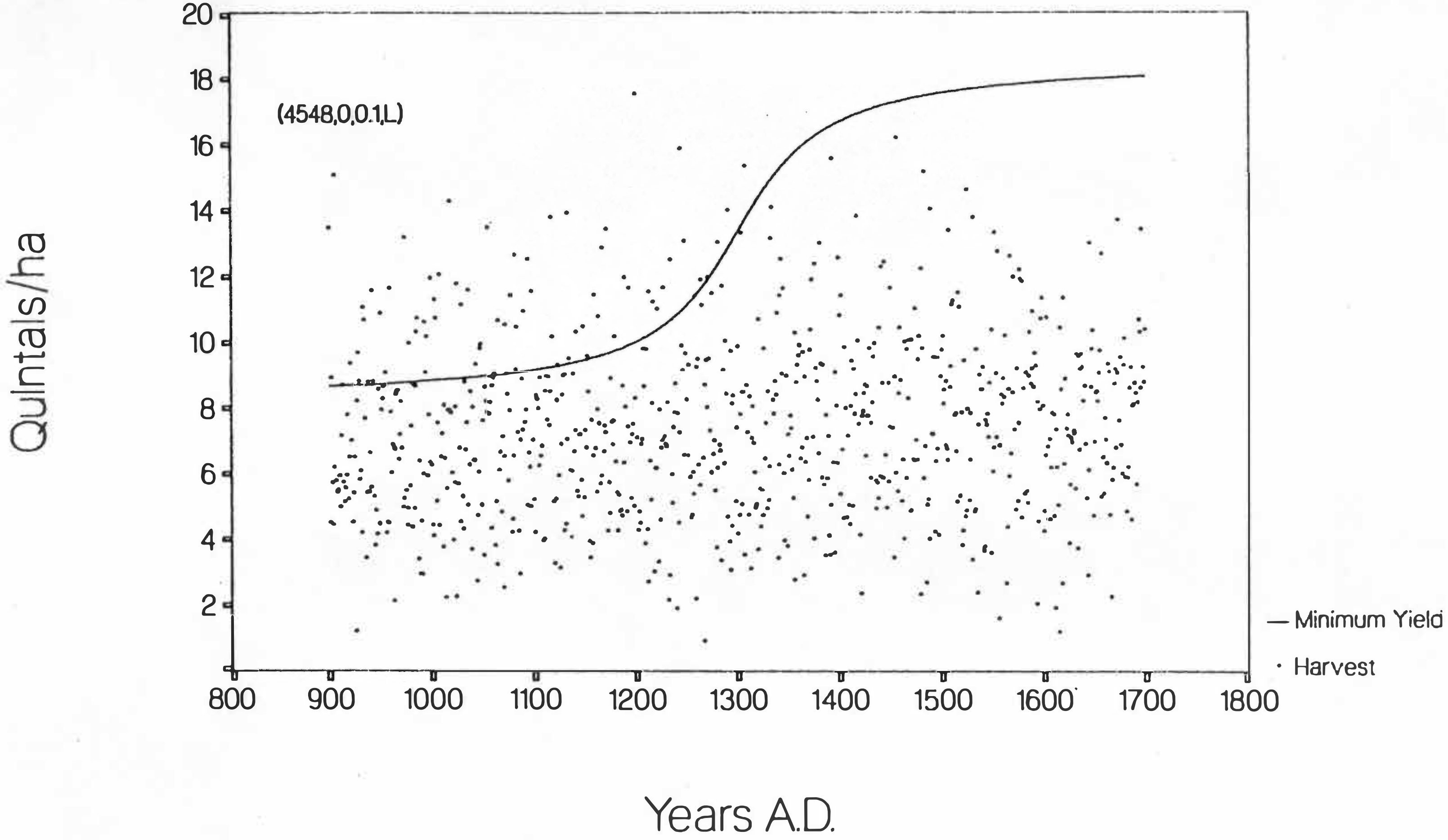

Figure 13. Minimum required harvest versus real harvests for f_s of 0.1 ha/person.

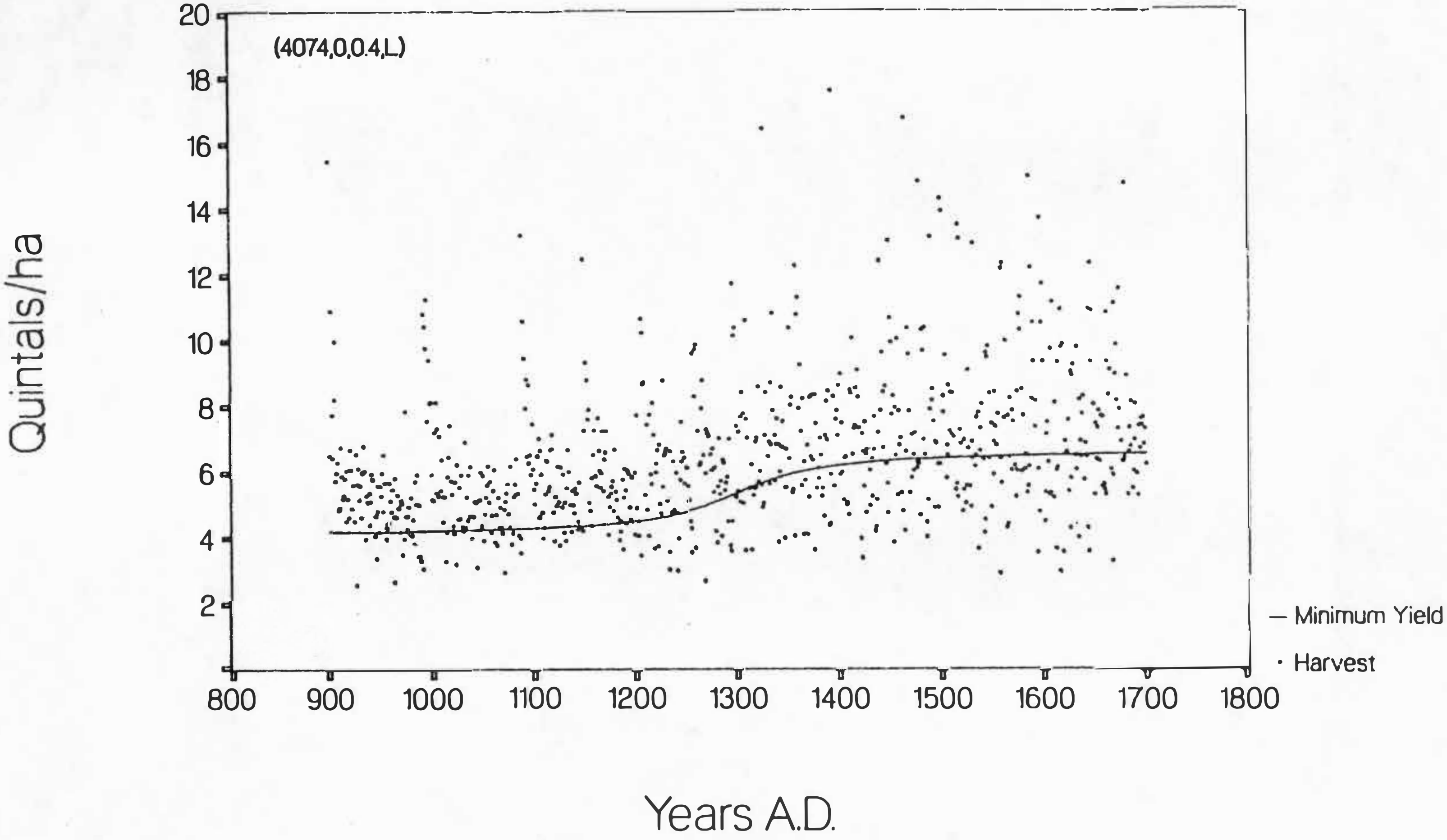

Figure 14. Minimum required harvest versus real harvests for f_s of 0.4 ha/person.

fields to compensate for this growing demand will, perhaps surprisingly, extend the use life of the land reservoir while producing higher surpluses at the expense of increased demands on labor. At some point, society may become unwilling to contribute to such a labor intensive system.

If there is an indication that Mississippian agricultural systems are unstable, it lies in the S_d values in Appendices E and F. Isolated, undefined values of S_d and nonlinear trends separating adjacent conditions for fixed f_s indicate a highly variable response pattern. In many cases an undefined point like $S_d(1000,0.008,0.4,L)$ reflects an ill-conditioned set of parameters causing repeated population fluctuations (see Figure 15). Slight shifts in P_t could change a system's trajectory from a maintainable trend to a more disastrous one rather quickly. Also, the repeated values of S_d for differing initialization parameters suggests the existence of attractive critical points. That is, common system conditions that inevitably develop from different trajectory paths. These are qualitative indications of instability.

Throughout this part of the examination, population growth has not demonstrated an impact. Indeed, the contribution of population pressure on determining the longevity of the system is only manifested when fields are abandoned and new land is needed at the f_s rate. Yet, in situations where fissioning occurs, the fluctuations in P_t are important indicators of system stress. By mapping P_t over time we can quantify societal conflicts for growing ($r > 0.0$) populations. A system trajectory like that shown in Figure 15, where multiple fissioning is required to maintain the system, forces the parent society to develop

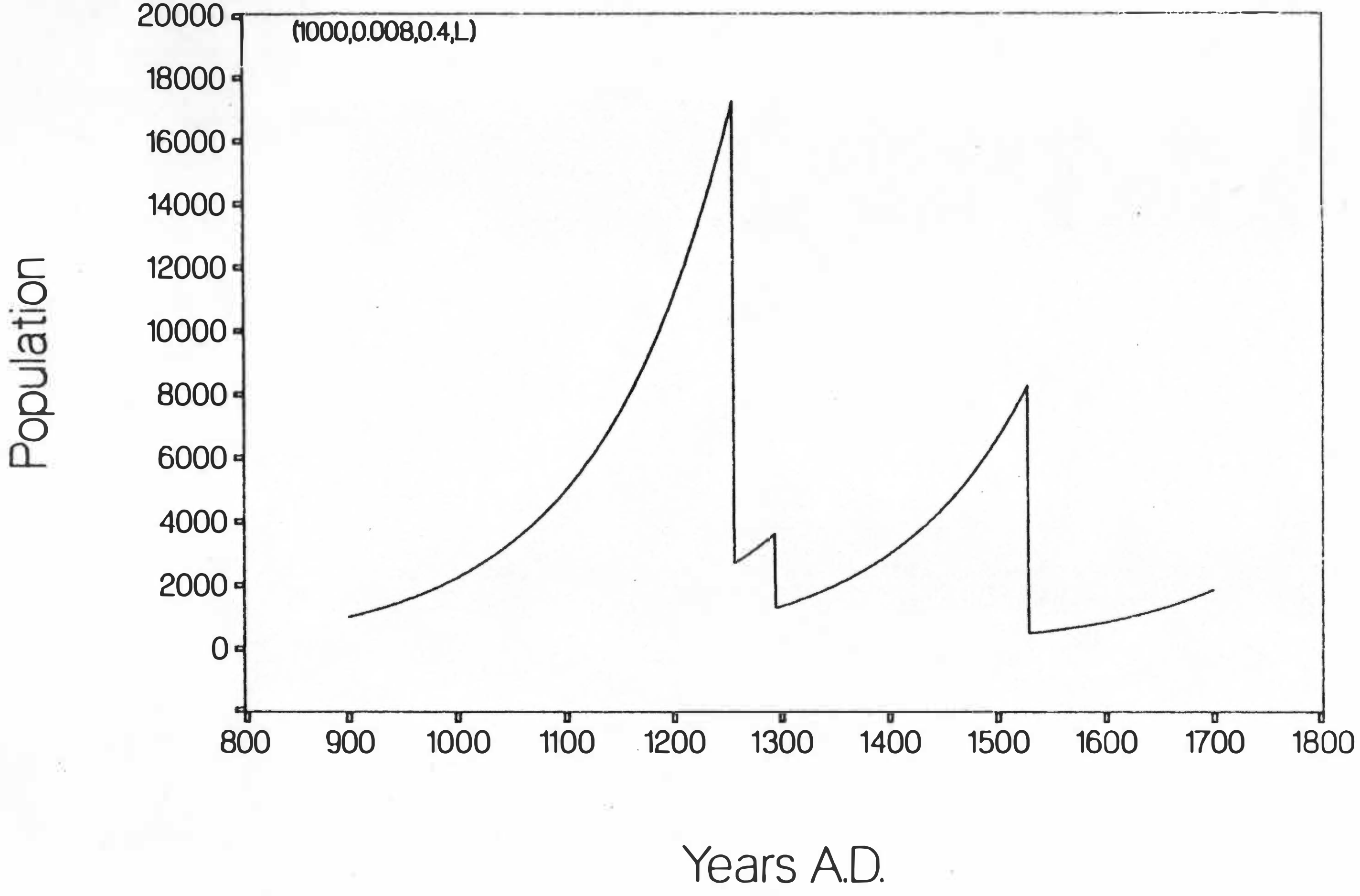

Figure 15. P_t for (1000,0.008,0.4,L).

stabilization protocols and colonization capabilities. The implication of these organizational structures on Mississippian settlement systems will be discussed in the next chapter, but it should be clear that system maintenance will involve more than just agrarian decisions. Stress management in the form of carrying capacity control will also be needed.

As discussed earlier, some have argued that r is sufficiently small so that Mississippian populations can be considered stationary. Although not supported here, adoption of this theory does offer a way to quantify sets of undefined responses. All so called zero-growth P_0's, where r is set to 0.0, which fail to converge on a critical point under either S_f or S_d conditions will display exactly the same system responses (average harvest, surplus, and planting duration per field) for common associated values of f_s. Through iteration we can determine the zero-growth limits for each value of f_s. Figure 16 is a graph of these values for total land reservoirs of 19559.2 and 29185.4 ha. Table 8 lists the response statistics for a few of these P_0 values and Table 9 provides these values for the total depletion situation.

Holding f_s constant, all zero-growth P_0 values below the maximums listed in Table 9 will yield constant response statistics over the 800 years of simulated system development. This result may not be evident from the model definition. Restated, all cultural systems that, regardless of their initialization parameters, respond to ecological pressure by reducing population levels will perform equally well independent of P_t for all t until a S_d critical point is reached. It therefore follows that the curves in Figure 16 loosely approximate the

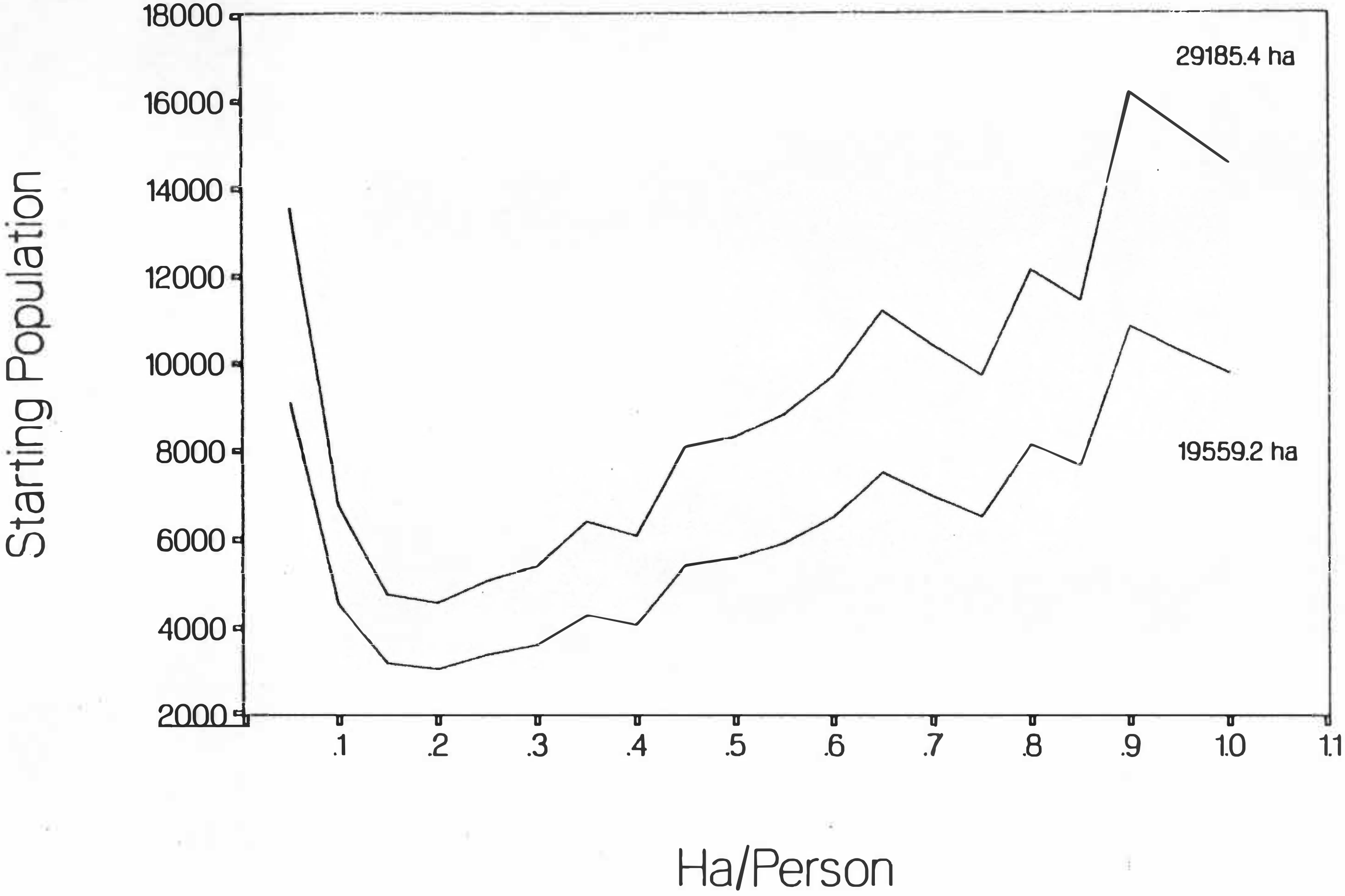

Figure 16. Maximum zero-growth P_0 values for various f_s specifications and total land reservoir limits of 19559.2 and 29185.4 ha.

Table 8. S_f response statistics for zero-growth P_0 values.

f_s	R	P_0	Harvest (mean/sd) quintals/ha	Surplus (mean/sd) quintals/ha	Duration (mean/sd) years
0.1	19559.2	4548	7.432/1.382	-6.418/3.804	3.347/0.722
0.2	19559.2	3056	6.549/1.171	-1.068/1.488	6.504/4.390
0.3	19559.2	3622	5.720/0.862	0.483/0.631	13.559/11.357
0.4	19559.2	4074	5.054/0.778	1.081/0.422	23.529/22.466
0.1	29185.4	6787	7.432/1.382	-6.418/3.804	3.347/0.722
0.2	29185.4	4560	6.549/1.171	-1.068/1.488	6.504/4.390
0.3	29185.4	5404	5.720/0.862	0.483/0.631	13.559/11.357
0.4	29185.4	6080	5.054/0.778	1.081/0.422	23.529/22.466

Table 9. S_d response statistics for zero-growth P_0 values.

f_s	R	P_0	Harvest (mean/sd) quintals/ha	Surplus (mean/sd) quintals/ha	Duration (mean/sd) years
0.1	19559.2	6112	7.432/1.382	-6.418/3.804	3.347/0.722
0.2	19559.2	4251	6.549/1.171	-1.068/1.488	6.504/4.390
0.3	19559.2	5015	5.720/0.862	0.483/0.631	13.559/11.357
0.4	19559.2	6112	5.054/0.778	1.081/0.422	23.529/22.466
0.1	29185.4	9120	7.432/1.382	-6.418/3.804	3.347/0.722
0.2	29185.4	6344	6.549/1.171	-1.068/1.488	6.504/4.390
0.3	29185.4	7483	5.720/0.862	0.483/0.631	13.559/11.357
0.4	29185.4	9120	5.054/0.778	1.081/0.422	23.529/22.466

carrying capacities of Mississippian populations in the study region for specific, constant f_s choices. However, we would not expect societies to use fixed f_s levels over an 800 year period while demand is allowed to increase exponentially. This brings us to the third and last method of applying our model.

It would seem reasonable to expect f_s to grow in size as demand, C_t, increases. To simulate this, we can superimpose the rule that after each field failure, f_s is adjusted in a way that extends the next field's planting duration based on the last field's mean harvest and P_t's current C_t requirements. As C_t rises so will the value of f_s. We will further stipulate that f_s will never decrease despite occasional short term peaks in harvest potential that might encourage such a reduction. Over time, f_s will now be a nondecreasing function of harvest potential and C_t. Appendix G presents the resulting S_f values for both levels of R. Appendix H provides the S_d values. The maximum zero-growth P_0 values for nonconverging responses are 4010 (S_f, R = 19559.2 ha) and 8224 (S_d, R = 19559.2 ha). For R = 29185.4 ha the maximum zero-growth P_0's will be 5984 (S_f) and 7850 (S_d). The mean response statistics per field are:

	mean	sd	
Harvest	5.808	0.679	quintals/ha
Surplus	0.431	0.767	quintals/ha
Planting Duration	9.877	3.750	years

with an overall mean f_s of 0.255 ha/person.

Using (4010,0.0,*,L) (where * denotes an adjustable f_s value) we can plot shifts in f_s (Figure 17) and the minimum required yield against harvest (Figure 18) over the study period. The dynamics shown here, based on all the preceding data, are our best estimation of a successful

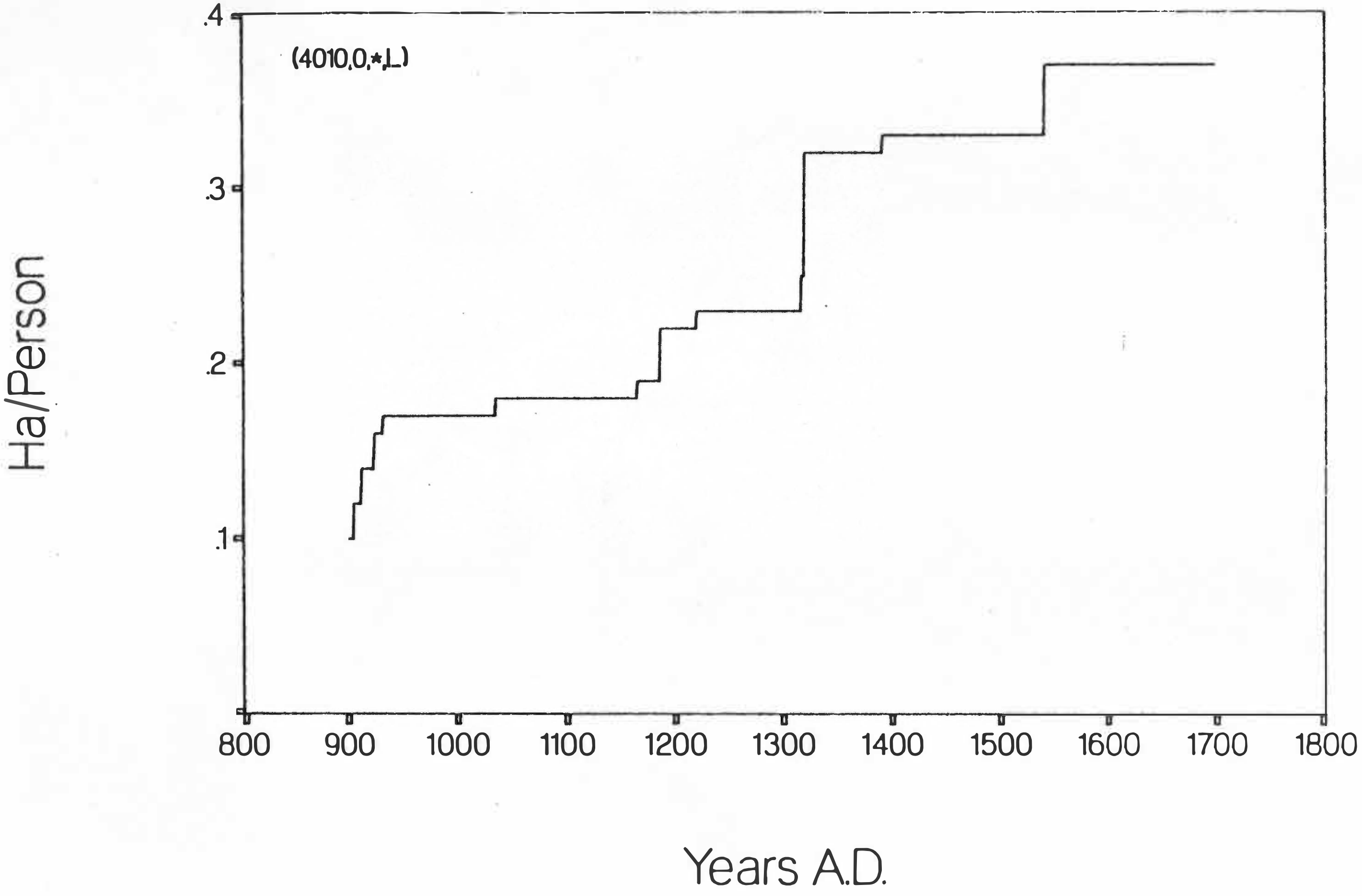

Figure 17. Adjusted f_s values for (4010,0.0,*,L).

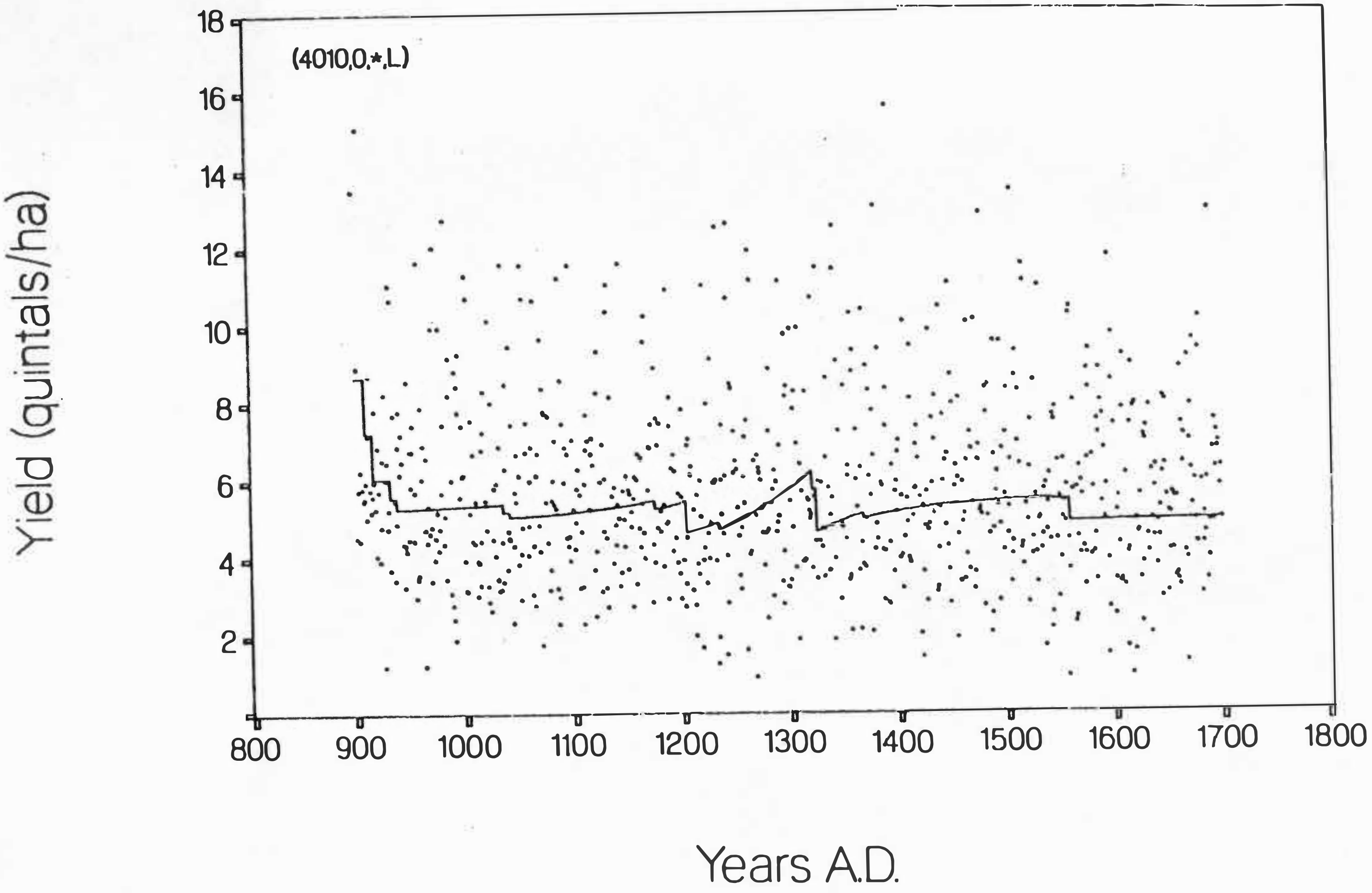

Figure 18. Minimum required harvest versus real harvests for (4010,0.0,*,L).

East Tennessee Mississippian agricultural system. We see a sharp increase in f_s over the first century (Mississippian I) followed by small, gradual increases until A.D. 1200 (Mississippian II) at which time more frequent adjustments occur. By A.D. 1300 the sharpest increase in C_t sparks a rapid rise in f_s and, with it, a concomitant increase in surplus potential. The critical transition points appear to coincide with major Mississippian phase changes. If the real system were to fail as a result of cultural inflexibility, it would most likely do so ca. A.D. 950, 1200, 1325, and 1550. If $r>>0$, we would expect this process to be exacerbated. The results in Appendix H suggest that under such circumstances total system collapse might occur ca. A.D. 1187, 1327, 1394, 1585, and 1629. However, earlier fissioning would probably put extreme pressure on the society prior to complete collapse.

If we approximate the potential function as a mapping of the land reservoir over time (Figure 19) for (4010,0,*,L) we can more fully characterize the dynamics of this system. As an approximation of V, this curve indicates that, at best, the Mississippian Period will consist of two centuries of unstable conditions (A.D. 900-1000 and 1300-1400) separated by a long, stable phase. This pattern is a response to behavioral decisions being superimposed on a ecological system. Mississippian I can be characterized as a period of technological development when hunters became part-time farmers under a low demand situation. During Mississippian II f_s reaches a proper balance with demand and a stable situation occurs. By A.D. 1300 demand starts to increase and, despite f_s adjustments, the system is driven towards a possible collapse ca. A.D. 1400. By slightly increasing P_0, $t = 1000$

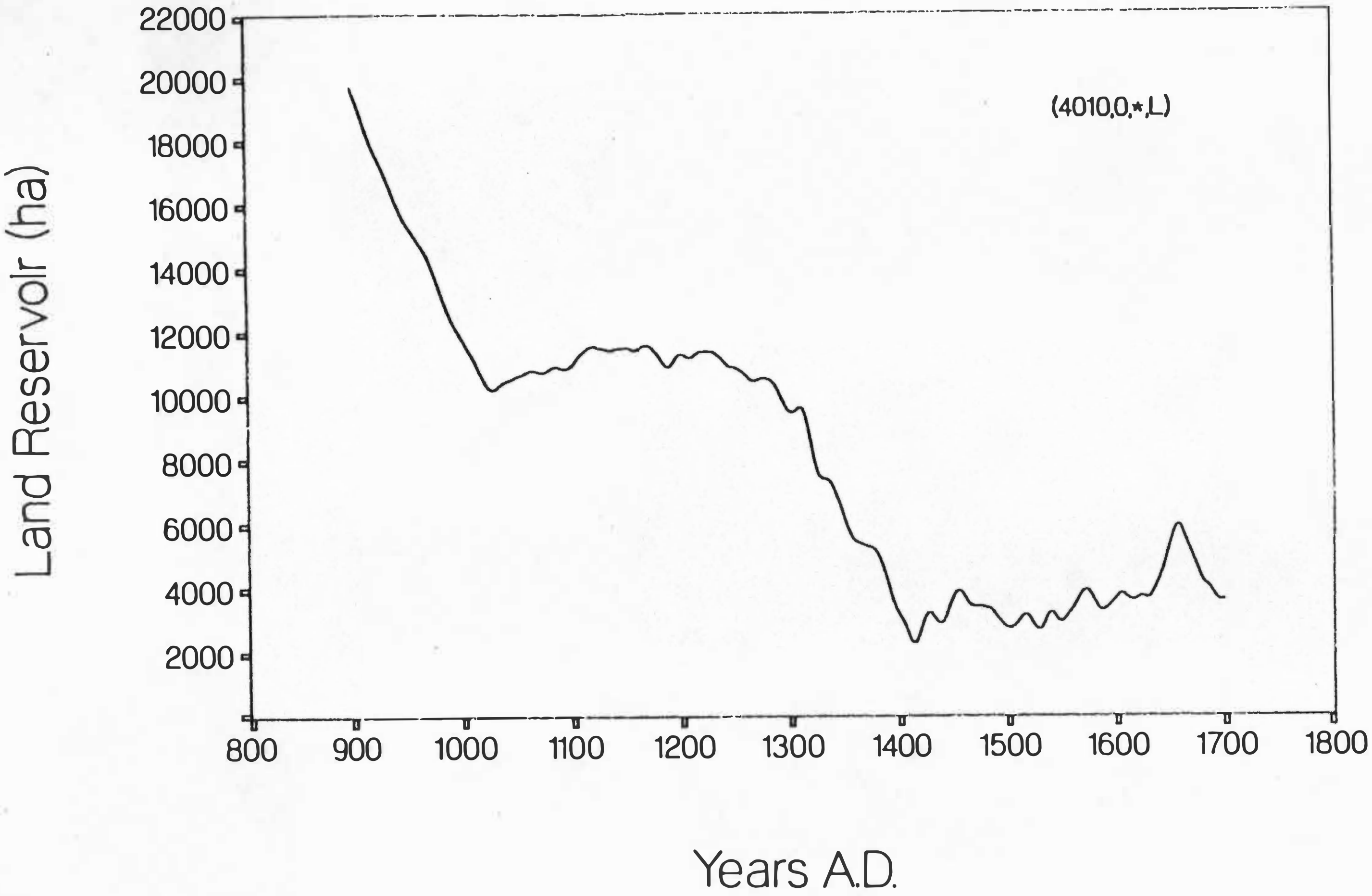

Figure 19. Land reservoir levels for (4010,0.0,*,L).

and 1400 will become critical points, which coincide with the more general results in Appendix H.

From the standpoint of stability, Appendices E, F, and H strongly imply the existence of a finite set of such critical points under almost all probable initialization conditions. Figure 19 graphically represents the Mississippian Period as a continuum of stable and unstable phases which correlate with both palynological and chronometric data. More exacting specification of P_0 and r, based on future analyses, would improve model accountability. Until such time, we are left with this attempt to demonstrate the range of growth limitations and the predisposition of such systems to require cultural adjustments at predictable points. A summary of the implications of this data on archaeological interpretations follows in Chapter V.

CHAPTER V

DISCUSSION

This study presents an alternative perception of cultural change. Culture change is seen as the inevitable result of a system, far from equilibrium, adapting to fluctuating conditions. Such a system displays a dissipative structure (Friedman 1982; Nicolis and Prigogine 1977) in that, while maintaining local stability at some material/energy cost, it eventually reaches a threshold where it evolves into an unstable order in response to fluctuations. It is under these conditions that new phases are produced (morphogenesis). One goal of explanatory archaeology should be the identification of such structures. Sufficient non-archaeological data indicate that prehistoric agricultural systems were subject to such fluctuations. In this study, both historical and empirical observations were used to specify an approximate model of a dissipative, Mississippian system which could be compared to the documented late prehistoric development scheme of East Tennessee.

From a regional standpoint, Mississippian morphogenesis has been associated with the question of Overhill Cherokee origins (Schroedl 1986). The level of pre-Mississippian IV social organization has been correlated with elaborate material remains and implicitly characterized as being more complex than the later Cherokee order. This tendency to correlate material elaboration with social complexity necessarily demands an explanation for the obvious material discontinuity between Mississippian III and IV, not only in East Tennessee but throughout the Southeast. Yet, ceramics, mounds, structures, and so on are not equivalent to ethnic groups, social organizations, or linguistic categories. If there has been a single weakness in any explanation, it is this leap from material order to social order ignoring the dynamic nature of culture as an evolving system. In particular, such an approach ignores the fact that society tends to reproduce itself through structured processes influenced by external parameters. Lacking a solid theoretical basis for such a transformation, various logical rationalizations have been presented as "explanations".

Early Mississippian research emphasized bridging the macroscopic discontinuity between the more complex mound building populations and their supposed descendants, the various historic Indian groups. The only available inductive tool was the axiomatic assumption that proximity in archaeological space was equatable with cultural similarity, regardless of material discontinuities (Harrington 1922, Thomas 1894). Two cultural manifestations separated in time, but not in space, must be ethnically equivalent.

Synchronic trait associations (Lewis and Kneberg 1946, Webb 1938, among others) and ethnohistoric interpretations (after Swanton 1928, 1946) were later used to promote a population replacement model (i.e. migrations) as the mechanism explaining material differences dividing the subphases of the Mississippian period. This particularistic model rejected the concept that change was internally induced by adjustments to fluctuating conditions. Instead, they chose a one-to-one equivalence between material assemblages and ethnic units. Whatever could not be explained by ethnic conflicts was resolved by calling on external disruptions like European contact and the spread of disease.

We now recognize the impact of agriculture on settlement systems. Villages should be seen as semi-sedentary in response to the need to be relatively close to their fields. When a land reservoir became exhausted, other river valleys would be needed for colonization. If such unclaimed locales existed, Mississippian "traits" would spread at the expense of extending the geographic limits of influence (perhaps beyond some limit defined by information theory). If not, conflicts between valley inhabitants would develop unless some social mechanism existed that could bind villages together or facilitate the shifting settlement system. The dispersed hamlet system of the historical period would have maximized aerial coverage while minimizing population disruption (by raising f_s).

These mechanisms, or social operators, would provide an order to the interactions between villages. If the underlying subsistence system failed, new operators would be developed to perpetuate the society. For Mississippian cultures these transition periods correlate with the occurrence of instabilities in our potential function. Such sudden transformations, predicted by the rate of change in potential functions, closely follow Thom's (1975) Theory of Catastrophes which has been applied to other cultural phenomena (Friedman 1982; Poston 1979; Renfrew and Poston 1979). Here, society lies along a trajectory determined by how it challenges its social and physical environments. It will tend to move further and further from equilibrium (assuming there are no external constraints). Under such conditions, the potential function serves as a measure of the stress placed on the production subsystems.

When these mechanisms undergo rapid change, the society crosses a threshold of instability and rapid transformations can occur.

Turning back to the question of Cherokee (and Creek, Chickasaw, Choctaw, etc.) origins, the social cost of maintaining nucleated, egalitarian villages would be small in comparison to that required by Mississippian II and III systems built around exchange networks. Yet such exchange systems (and their associated material assemblages) were needed to maintain the extensive agricultural system presented here. When that system could no longer be supported, the social order binding it together could devolve into a less complex structure (Mouse Creek?). In areas where extensive agriculture was less feasible (e.g. the Appalachian Summit) and therefore more quickly constrained, we would expect the pinnacle social structure to be less complex (Dickens 1986). Under these circumstances, society's ability to maintain itself beyond some equilibrium point would be more limited. Such a system would produce a totally different potential curve and accompanying social order.

Summarizing, the East Tennessee Mississippian sequence is seen as an ebb and flow of unstable to stable conditions wherein the current phase state is defined by choices made by the previous one. Although the Spanish (and later English and French) presence late in the period served as an external "mutation", opening new trajectories for Mississippian evolution, the primary evolutionary force affecting Southeastern aboriginal populations originates in the adjustments required to maintain some potential function under conditions far from equilibrium. Given a specific set of behavioral rules and a bounded environment, an expanding society's potential function can be calculated and used to predict periods of instability. This study challenges our ability to recognize contemporary sites, demands a more accurate accounting of the space-time continuum linking archaeological sites with their original cultures, and begins to address Netting's (1974) call for a more systematic examination of agricultural processes.

Although it may be tempting to use the results of this application to "explain" Cherokee morphogenesis, the reader must recognize that maize agriculture served as only one part of the total socio-techno complex we call Mississippian. Other dissipative factors, such as the depletion of fire wood resources and the dependence on inadequate information systems, worked in conjunction with the agricultural limitations to define an overall potential function. Broader examinations are needed that combine all of these subsystems to fully deal with Mississippian morphogenesis. This study serves as a first step toward such a synthesis.

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APPENDIXES

APPENDIX A

UNITS OF MEASURE

1 bu = 2150.42 cu in = 32 qt

1 bu = 56 lb shelled corn = 68 to 72 lb ear corn (Myrick 1903:368)

1 qt = 1988.2 kernals of maize (approximately) (U.S. Commissioner of Patents 1848:130)

1 quintal (US) = 100 kg = 220.46 lb = 3.937 bu shelled corn

1 acre = 43,560 sq ft

1 ha = 2.471 acres

1 quintal/ha = 1.593 bu/acre

APPENDIX B

PROGRAM LISTING

```
program STUDY (input,output);   {DEC VAX/Pascal v.3.4}
{
===========================================================================
 Program to simulate Mississippian agricultural impact on soil
 productivity.  Input consists of a starting population size, a
 population growth rate, and field size per person.

       STUDY_AREA      = total area of arable soil [19559.2,29185.4]
       P               = population at time t
       P_LAST          = population in year t-1
       R               = rate of population increase [0.003,0.017]
       NEEDS           = amount of maize required per person/year
       FIELD_ID        = identifier for each field
       FIELD_SIZE      = field size (ha/person)
       GETBY           = NEEDS/FIELD_SIZE
       N_FAILS         = maximum number of failures allowed per field
       REPLENISH       = number of years to restore depleted land
       FAILURES        = number of years crop fails in current field
       LAND[T]         = amount of land available to be planted in year t
       FIELDS[T]       = amount of land being planted in year t
       DEPLETED[T]     = amount of depleted land at time t
       RETURN_FIELD[T] = amount of land to be returned in year t
       E               = expected yield as a function of time
       SD              = expected s.d. of E[T] as a function of time
       YIELD           = maize yield as a function of E[T] and SD[T]
       CONSUME         = maize consumption as a function of time
       SURPLUS         = YIELD[T] - GETBY
===========================================================================
}


const  REPLENISH = 125;      {years to replenish soil}
       CYCLE = 800;          {duration of simulation}
       N_FAILS = 3;          {max number of crop failures per field}
       STUDY_AREA_1 = 29185.4; {largest ha of arable land in study area}
       STUDY_AREA_2 = 19559.2; {smallest ha of arable land in study area}

var  P_HOLD,R,HARVEST,NEEDS,FIELD_SIZE,GETBY,SURPLUS,STUDY_AREA: real;
     LAND,FIELDS,DEPLETED,RETURN_FIELD: array[0..CYCLE+REPLENISH] of real;
     P_LAST,FAILURES,T,DSEED,YEARS,FIELD_ID: integer;
     OUTDAT: text;

{______________________________________________________________________}
{------- Generate a uniform random number                              }
{ ... Uses FORTRAN RAN(DSEED) to generate a uniform random number ... }
function UNIFORM(SEED:integer):real;fortran;   { EXTERNAL }
```

```
{________________________________________________________________________}
function E: real;    {equation 3.8 adjusted for Tellico}
 begin
  if YEARS = 0 then E := 9.14 else
   E := 8.48*((2*YEARS)**(-0.2249));  {quintals/ha}
 end;

{________________________________________________________________________}
function SD: real;   {equation 3.9 adjusted for Tellico}
 begin
  if YEARS = 0 then SD := 3.03 else
   SD := 2.81*((2*YEARS)**(-0.2249));  {quintals/ha}
 end;

{________________________________________________________________________}
function YIELD: real;   {using 3.8 & 3.9 to produce yield estimates}
 var U1,U2,Z: real;
 begin
  U1 := UNIFORM(DSEED);
  U2 := UNIFORM(DSEED);
  Z  := sqrt(-2.0*ln(U1))*cos(6.283*U2);      { random normal deviate }
  YIELD := Z*SD + E;                          {quintals/ha}
 end;

{________________________________________________________________________}
function P: real;      {equation 3.2}
 begin
  P_HOLD := P_HOLD*exp(R);
  P := P_HOLD;
 end;

{________________________________________________________________________}
function CONSUME(X:real): real;    {equation 3.10 where t = [0,800]}
 begin
  CONSUME := 0.3326*arctan(-6.2832 + 0.0157*X) + 1.3385;
 end;

{________________________________________________________________________}
procedure MIN_YIELD;       {minimum yield required - quintals/ha}
 begin
  if P_LAST > 0 then GETBY := CONSUME(T-1)/(FIELDS[T]/P_LAST)
    else GETBY := CONSUME(T-1)/FIELD_SIZE;
end;

{________________________________________________________________________}
procedure PUT_LAND_BACK;   {return depleted land}
 begin
  DEPLETED[T] := DEPLETED[T-1] - RETURN_FIELD[T];
  if DEPLETED[T] < 0.0 then DEPLETED[T] := 0.0;
 end;
```

```
{______________________________________________________________________}
procedure FALLOW;          {remove depleted land from total pool}
 begin
  DEPLETED[T] := DEPLETED[T] + FIELDS[T-1];
  if (T+REPLENISH) <= CYCLE then RETURN_FIELD[T+REPLENISH] := FIELDS[T-1];
  FIELDS[T] := P_LAST*FIELD_SIZE;
  LAND[T] := LAND[0] - DEPLETED[T];
  FAILURES := 0;
  YEARS := 0;
  FIELD_ID := FIELD_ID + 1;
 end;

{______________________________________________________________________}
procedure FISSION;    {reduce supported population to acceptable level}
 begin
  writeln(' Fissioning in the year: ',(900+T-1):4);
  writeln(' T = ',T:3,' pop.= ',P_LAST:6,' Land: ',LAND[T]:5:2,' Fs: ',
          FIELDS[T]:5:2,' Depl: ',DEPLETED[T]:5:2,' F id: ',FIELD_ID:3);
  if LAND[T] > 0.0 then                                 { fission pop.}
   begin
    P_LAST := round(LAND[T]/FIELD_SIZE);
    P_HOLD := P_LAST;
   end
   else                                            { or abandon valley  }
    begin
     writeln('Total depletion in the year: ',(900+T-1):4, ' after ',
              T:3,' years.');
     P_HOLD := P_LAST;
     P_LAST := 0;
    end;
  FIELDS[T] := LAND[T];
  YEARS := 0;
 end;

{______________________________________________________________________}
procedure BRING_BACK_PEOPLE;  {return population after REPLENISH years}
 var IV: integer;
 begin
   { v-- write out data for abandon years in OUTDAT file }
  for IV := 0 to (REPLENISH-1) do
   if (T+IV) <= CYCLE then writeln(outdat,(T+IV):4,' 0 0 0 0 0 0 0');
  YEARS := 0;
  T := T + REPLENISH - 1;
  P_LAST := round(P_HOLD*exp(R*(REPLENISH-1)));
  P_HOLD := P_HOLD*exp(R*(REPLENISH-1));
  FIELDS[T] := P_LAST*FIELD_SIZE;
  HARVEST := YIELD;
  MIN_YIELD;
  if HARVEST < GETBY then FAILURES := FAILURES + 1;
 end;
```

```
{______________________________________________________________________}
procedure DUMP_DATA;     {print out simulation data}
 begin
  { Output : T, Field Id, Field Size, Harvest, Surplus yield, Area planted,
             Surplus land, Pop.}
  writeln(outdat,T:4,' ',FIELD_ID:3,' ',FIELD_SIZE:2:2,' ',HARVEST:2:2,
                     ' ',SURPLUS:3:2,' ',FIELDS[T]:5:2,' ',
                     LAND[T]:5:2,' ',P_LAST:5);
 end;

{______________________________________________________________________}
procedure INIT;        {initialize all parameters and open output file}
 var I: integer;
     ANSWER: varying[1] of char;
 begin
                         { Open output file containing simulation data}
  open(OUTDAT,file_name:='STUDY.DAT',history:=new);
  rewrite(outdat);
                                   { Define variable input parameters }
  write('Input starting population size -> '); readln(P_LAST);
  write('Input population growth rate -> '); readln(R);
  write('Input field size -> '); readln(FIELD_SIZE);
  write('Do you wish to use the High or Low land area estimates ',
        '( H/[L] ) -> ');
   readln(ANSWER);
                                          { Define initial parameters }
  if (ANSWER = '') or (ANSWER = 'L') or (ANSWER = 'l') then
   STUDY_AREA := STUDY_AREA_2
  else STUDY_AREA := STUDY_AREA_1;
  writeln('Using ',STUDY_AREA:5:1,' ha as total study area size.');
  P_HOLD := P_LAST;
  T := 0;
  YEARS := 0;
  FIELD_ID := 1;
  FIELDS[0] := P_LAST*FIELD_SIZE;
  LAND[0] := STUDY_AREA; {ha}
  DEPLETED[0] := 0.0;
  FAILURES := 0;
  for I := 0 to CYCLE do RETURN_FIELD[I] := 0.0;
  DSEED := 12345;

  writeln('Working...');
 end;
```

```
{**************************************************************************}
{                           M A I N   P R O G R A M                        }
{**************************************************************************}
begin
 INIT;   { initialize input variables }

 { run simulation for CYCLE years }
 repeat
  T := T + 1;                               { keep track of simulation time}
  P_LAST := round(P);                          { calculate population size }
  if RETURN_FIELD[T] > 0.0 then PUT_LAND_BACK        { return depleted land}
   else DEPLETED[T] := DEPLETED[T-1];
  LAND[T] := LAND[0] - DEPLETED[T];                       { available land }
  if FAILURES = N_FAILS then FALLOW                     { put land in rest }
   else FIELDS[T] := FIELDS[T-1];
  if LAND[T] < FIELDS[T] then FISSION;            { no more land available }
  HARVEST := YIELD;
  MIN_YIELD;                                             { set GETBY value }
  if (HARVEST < GETBY) then                        { look for crop failure }
   if FAILURES = 0 then FAILURES := 1
    else if SURPLUS < 0.0 then FAILURES := FAILURES + 1
     else FAILURES := 1;
  SURPLUS := HARVEST - GETBY;
  if P_LAST > 0 then DUMP_DATA;                 { write data for this year }
  YEARS := YEARS + 1;                                    { field use years }
  if (P_LAST = 0) then                                    { return people }
   BRING_BACK_PEOPLE;
 until T >= CYCLE;

 close(outdat);
 writeln('...done.');
end.
```

APPENDIX C

S_f FOR CONSTANT f_s AND $R = 19559.2$ HA

Predicted time of first fissioning for constant field size (ha/person) and a total land area of 19559.2 ha.

Point of first fissioning for field size of 0.1 ha/person

								P_0						
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	872	797	737	686	641	602	566	455	384	279	203
0.004	+	842	740	671	614	569	533	500	473	455	381	311	218	160
0.005	824	686	605	548	506	473	449	428	408	393	318	268	191	141
0.006	698	581	515	473	443	416	393	378	362	349	279	231	166	130
0.007	605	509	455	422	393	372	356	339	318	305	249	209	156	123
0.008	536	455	408	381	359	339	314	301	287	276	223	191	144	119
0.009	485	416	378	353	326	305	290	276	260	249	209	173	134	116
0.010	446	384	349	318	301	284	264	253	242	231	195	163	126	113
0.011	413	359	322	298	276	260	246	234	223	215	177	156	123	109
0.012	384	335	301	276	257	242	231	218	209	203	166	144	119	104
0.013	362	311	284	260	242	226	215	206	199	191	160	137	116	100
0.014	342	294	264	246	226	215	206	199	191	177	153	134	113	94
0.015	322	276	249	229	215	206	195	188	177	170	144	126	109	91
0.016	305	264	238	218	206	195	188	177	170	163	141	123	104	91
0.017	290	249	226	209	199	188	177	170	163	156	134	119	100	86

Point of first fissioning for field size of 0.2 ha/person

								P_0						
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	825	746	676	617	585	561	523	511	444	419	370	285
0.004	+	746	650	588	557	514	494	478	458	444	409	370	306	258
0.005	746	614	557	511	487	458	444	426	419	409	370	328	276	223
0.006	639	539	494	458	439	422	409	396	382	375	328	285	233	189
0.007	565	490	450	422	409	390	375	359	344	344	298	268	199	166
0.008	511	444	415	391	374	355	335	328	322	305	268	233	189	155
0.009	469	415	386	365	344	328	313	305	298	285	245	223	182	143
0.010	439	391	359	335	322	313	305	285	276	268	233	199	162	124
0.011	415	365	335	321	301	284	276	268	256	245	211	182	143	124
0.012	391	344	321	301	284	276	256	245	233	233	199	166	137	115
0.013	365	322	301	284	268	256	245	233	223	211	182	155	137	115
0.014	355	305	284	267	256	245	233	223	211	199	182	155	124	115
0.015	328	288	276	256	245	223	223	211	199	189	166	143	124	104
0.016	313	284	256	245	223	211	211	199	189	182	155	137	115	104
0.017	298	268	242	233	223	211	199	189	182	182	143	137	115	93

Point of first fissioning for field size of 0.3 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	813	728	684	652	630	588	539	489	449	415	357
0.004	+	790	709	652	608	572	517	511	494	489	427	396	344	287
0.005	784	667	596	539	511	494	482	458	449	433	396	357	306	276
0.006	675	579	511	489	450	444	427	427	422	396	357	328	287	212
0.007	588	505	469	444	427	422	414	396	380	357	328	287	245	189
0.008	530	458	427	422	396	377	357	357	344	328	287	258	212	166
0.009	489	427	414	391	357	357	344	328	306	306	276	258	189	166
0.010	450	414	391	357	344	328	305	305	287	287	249	233	189	166
0.011	427	391	357	344	328	305	287	287	276	276	233	212	166	143
0.012	414	357	344	305	305	287	276	276	249	249	212	189	166	143
0.013	382	335	322	287	287	276	276	249	249	233	211	189	166	137
0.014	370	322	305	287	276	249	249	249	223	223	189	189	137	137
0.015	344	305	285	268	249	249	223	223	223	204	189	166	137	115
0.016	322	287	258	258	245	223	223	204	204	204	189	162	137	115
0.017	305	276	258	245	223	223	204	204	204	189	162	137	115	115

Point of first fissioning for field size of 0.4 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	873	780	728	685	644	600	589	507	458	422	396
0.004	+	844	745	685	631	589	565	539	530	507	450	422	396	357
0.005	822	685	600	565	539	507	489	489	482	458	422	396	357	286
0.006	697	589	539	507	482	458	450	422	422	415	382	357	328	286
0.007	617	539	489	458	422	415	396	396	382	382	335	306	276	233
0.008	565	489	449	415	396	396	382	357	357	357	306	306	276	233
0.009	494	444	422	396	396	380	380	344	344	322	285	249	212	172
0.010	469	422	396	377	377	344	344	322	322	322	285	249	203	166
0.011	443	396	370	344	344	322	322	322	284	284	249	204	172	137
0.012	415	382	357	335	305	305	276	276	276	276	245	204	172	137
0.013	396	356	328	305	305	276	276	276	242	242	204	204	172	137
0.014	380	328	305	276	276	249	249	249	212	212	189	166	166	130
0.015	356	305	276	276	249	249	249	212	212	212	189	166	124	124
0.016	328	305	276	249	249	249	212	212	212	212	189	162	124	124
0.017	328	276	276	245	245	212	212	212	189	189	162	162	124	124

+ denotes a value greater than 900 years

APPENDIX D

S_f FOR CONSTANT f_s AND R = 29185.4 HA

Predicted time of first fissioning for constant field size (ha/person) and a total land area of 29185.4 ha.

Point of first fissioning for field size of 0.1 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	872	821	776	737	701	566	476	384	308
0.004	+	+	842	770	713	668	629	596	566	539	455	396	311	246
0.005	+	767	686	626	584	545	518	494	473	455	390	345	268	212
0.006	764	647	581	536	497	470	449	431	416	399	345	301	231	188
0.007	662	563	509	470	443	422	399	384	372	362	305	264	209	166
0.008	587	503	455	425	399	381	365	353	339	322	276	239	191	156
0.009	527	455	416	387	369	349	335	314	305	294	249	215	173	144
0.010	482	419	384	359	339	318	305	294	279	272	231	203	163	137
0.011	446	390	359	335	311	298	284	272	260	249	215	191	156	130
0.012	416	365	335	308	290	276	264	253	242	234	203	177	144	126
0.013	390	342	311	290	272	260	246	233	226	218	191	166	137	123
0.014	369	318	294	272	257	242	233	223	215	209	177	160	134	116
0.015	349	305	276	257	242	229	218	212	206	199	170	153	126	113
0.016	332	287	260	246	229	218	209	203	195	191	163	144	123	113
0.017	311	272	249	229	218	209	203	195	188	177	156	141	119	109

Point of first fissioning for field size of 0.2 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	863	799	746	688	650	614	588	511	458	419	382
0.004	+	837	746	672	622	588	561	532	514	504	444	419	370	321
0.005	825	688	614	573	532	511	490	476	458	444	409	378	328	285
0.006	697	597	539	504	482	458	444	431	422	415	375	335	285	249
0.007	608	527	490	458	439	422	415	396	382	382	344	305	268	223
0.008	557	487	444	419	402	391	380	365	355	344	305	276	233	199
0.009	504	444	415	391	380	365	355	335	328	322	285	258	223	189
0.010	469	419	391	365	355	335	328	313	313	305	268	245	199	172
0.011	439	391	365	355	335	321	301	288	284	276	245	223	182	155
0.012	415	374	344	328	306	301	284	276	276	268	233	199	166	143
0.013	391	355	322	306	288	284	276	268	256	245	211	189	155	143
0.014	374	328	305	288	276	267	256	245	245	233	199	182	155	137
0.015	355	313	288	276	267	256	245	233	223	223	189	182	143	124
0.016	335	298	284	267	256	245	233	223	211	211	182	166	137	124
0.017	322	284	268	249	242	233	223	211	199	199	182	155	137	115

Point of first fissioning for field size of 0.3 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	862	813	746	724	684	667	539	505	449	422
0.004	+	889	790	728	684	652	622	588	572	530	489	449	396	357
0.005	869	728	660	622	579	539	517	505	494	489	433	422	357	328
0.006	728	636	579	517	494	489	458	450	444	433	396	357	328	287
0.007	644	549	505	482	450	444	433	427	422	414	357	344	287	276
0.008	572	494	458	433	427	414	396	391	377	357	328	287	258	245
0.009	517	458	427	422	396	391	377	357	357	344	306	276	258	212
0.010	489	433	414	391	377	357	344	344	328	328	287	249	233	189
0.011	450	414	391	357	357	344	328	305	305	287	276	249	212	189
0.012	427	391	357	344	328	305	305	287	287	276	249	233	189	166
0.013	414	370	335	322	305	287	287	276	276	276	233	211	189	166
0.014	396	355	322	305	287	287	276	276	249	249	223	204	189	166
0.015	370	335	305	285	285	268	268	249	249	249	204	189	166	137
0.016	344	305	287	276	258	258	245	245	223	223	204	189	162	137
0.017	335	287	276	258	245	245	223	223	223	204	189	189	137	137

Point of first fissioning for field size of 0.4 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	873	822	769	728	697	589	539	458	422
0.004	+	+	834	769	708	685	631	600	589	565	507	482	422	396
0.005	+	769	685	631	600	565	539	530	507	507	458	422	396	357
0.006	762	660	589	565	530	507	489	458	450	450	415	396	357	328
0.007	675	579	539	489	458	449	422	422	415	396	382	357	306	276
0.008	600	530	489	458	422	415	415	396	396	382	357	335	306	276
0.009	539	487	444	422	415	396	396	380	380	380	322	285	249	212
0.010	494	443	422	415	396	377	377	344	344	344	322	285	249	203
0.011	469	422	396	370	370	344	344	344	322	322	284	249	204	204
0.012	433	396	382	357	335	335	305	305	305	305	276	245	204	172
0.013	415	382	356	328	328	305	305	305	276	276	242	242	204	172
0.014	396	356	328	305	305	276	276	276	249	249	212	189	166	166
0.015	380	328	305	305	276	276	276	249	249	249	212	189	166	166
0.016	355	328	305	276	276	249	249	249	249	212	212	189	162	162
0.017	344	305	276	276	245	245	245	212	212	212	189	189	162	124

+ denotes a value greater than 900 years

APPENDIX E

S_d FOR CONSTANT f_s AND R = 19559.2 HA

Predicted time of total depletion for constant field size (ha/person) and a total land area of 19559.2 ha.

Point of total depletion for field size of 0.1 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	+	+	+	+	+	+	+	289	+
0.004	+	+	+	+	+	+	535	+	+	+	391	+	+	162
0.005	+	+	+	+	+	+	454	445	421	+	+	+	202	+
0.006	+	+	+	+	+	+	+	391	+	+	+	+	+	+
0.007	+	+	+	+	+	+	361	+	+	310	+	214	162	125
0.008	+	+	421	391	361	+	+	+	+	+	+	202	+	122
0.009	+	421	391	+	+	310	+	+	+	+	214	+	+	118
0.010	+	391	+	+	+	+	+	+	+	+	202	+	133	115
0.011	421	361	+	300	+	+	+	+	+	+	421	162	125	112
0.012	391	+	+	+	+	+	+	472	214	535	+	+	122	108
0.013	+	454	+	+	+	+	+	+	202	+	162	+	118	103
0.014	+	300	+	+	232	+	+	202	+	391	162	421	115	99
0.015	+	+	+	232	+	+	202	+	+	+	+	133	112	93
0.016	310	535	+	535	+	202	+	+	361	421	454	125	108	93
0.017	+	+	232	214	202	+	361	361	407	162	391	122	103	90

Point of total depletion for field size of 0.2 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	684	+	599	572	531	513	+	421	+	443
0.004	+	+	+	+	560	+	513	493	+	+	+	599	+	275
0.005	759	+	560	513	489	+	+	438	421	418	+	334	284	284
0.006	646	560	865	+	443	+	418	408	+	381	334	305	715	198
0.007	572	493	457	443	418	+	381	377	377	381	305	275	696	+
0.008	513	457	421	+	381	364	715	334	334	+	275	+	+	497
0.009	475	418	390	560	+	334	+	596	304	304	+	+	560	+
0.010	443	+	364	649	334	475	312	304	284	284	587	+	312	146
0.011	418	379	+	334	560	304	304	275	275	304	304	304	304	142
0.012	421	+	334	305	287	287	275	+	715	+	+	457	142	123
0.013	379	334	305	287	275	275	824	684	+	661	531	443	142	123
0.014	364	531	287	275	275	661	+	649	649	+	+	457	142	123
0.015	334	304	287	513	759	493	497	497	475	817	334	304	142	114
0.016	+	287	513	497	497	475	475	457	457	497	531	287	123	114
0.017	304	275	257	493	715	443	443	443	390	390	334	304	123	103

Point of total depletion for field size of 0.3 ha/person

							P_0						
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	+	+	651	+	+	493	727	421	395
0.004	+	+	+	+	+	727	538	516	510	493	448	421	395	356
0.005	+	+	+	727	516	516	488	493	493	448	426	395	+	286
0.006	683	+	516	493	493	449	443	+	426	421	395	356	683	286
0.007	+	510	488	449	443	426	421	426	395	395	356	+	286	395
0.008	+	488	443	426	421	+	+	+	356	356	+	286	257	+
0.009	493	443	421	395	+	+	356	356	708	+	286	493	+	+
0.010	493	421	395	390	356	356	+	+	651	443	286	286	493	449
0.011	443	395	390	356	356	659	+	443	286	286	286	286	449	395
0.012	421	390	356	+	+	604	286	286	286	286	286	493	443	493
0.013	395	+	334	+	+	286	286	286	286	286	286	457	443	334
0.014	395	369	+	457	286	286	286	286	286	286	286	286	369	369
0.015	369	+	457	284	284	284	+	+	+	532	488	369	343	136
0.016	343	304	510	442	257	257	257	257	257	257	442	745	343	136
0.017	516	304	493	257	257	257	257	257	257	257	257	510	136	136

Point of total depletion for field size of 0.4 ha/person

							P_0						
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	+	+	+	+	599	538	+	449	421
0.004	+	+	+	+	+	599	+	+	538	+	506	449	421	+
0.005	+	+	630	+	+	538	506	506	488	488	449	421	+	356
0.006	+	599	779	538	488	+	+	449	449	421	395	395	356	356
0.007	630	779	+	+	457	421	421	+	395	395	356	356	305	305
0.008	+	+	457	421	421	+	395	395	395	+	356	+	305	305
0.009	+	457	421	421	395	395	395	356	395	+	564	493	443	395
0.010	486	442	421	395	395	395	395	+	+	+	493	284	284	395
0.011	493	421	442	369	369	369	369	369	607	+	+	493	369	369
0.012	421	395	395	356	356	356	+	778	778	607	449	421	356	356
0.013	421	395	356	356	356	+	607	607	457	457	421	395	356	356
0.014	395	395	395	+	493	449	449	421	421	+	395	188	188	188
0.015	395	395	488	468	275	275	275	275	275	275	395	188	188	188
0.016	395	395	468	275	275	275	275	275	275	421	211	211	449	421
0.017	357	481	449	449	421	421	395	395	211	211	211	211	421	421

+ denotes a value greater than 900 years

APPENDIX F

S_d FOR CONSTANT f_s AND $R = 29185.4$ HA

Predicted time of total depletion for constant field size (ha/person) and a total land area of 29185.4 ha.

Point of total depletion for field size of 0.1 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	+	+	+	+	+	+	+	+	310
0.004	+	+	+	+	+	+	+	+	+	+	+	407	+	+
0.005	+	+	+	+	+	+	+	499	+	+	+	+	+	214
0.006	+	+	+	+	+	+	454	445	421	407	+	+	+	+
0.007	+	+	+	+	+	+	407	391	+	+	310	+	214	+
0.008	+	+	+	+	407	391	+	+	+	472	+	+	202	162
0.009	535	+	421	+	+	+	+	454	310	300	+	535	+	+
0.010	+	+	391	361	+	+	310	+	+	+	+	+	+	+
0.011	+	+	361	+	472	300	+	+	+	+	+	+	162	133
0.012	421	+	+	310	+	+	+	+	+	+	535	+	+	+
0.013	+	+	454	+	+	+	+	+	+	+	+	361	+	125
0.014	+	+	300	+	+	+	+	+	+	214	391	162	421	118
0.015	361	310	+	535	+	232	+	214	+	202	+	162	133	115
0.016	+	+	535	+	232	535	214	+	202	+	421	+	125	115
0.017	454	535	+	232	+	214	454	202	+	361	162	445	122	112

Point of total depletion for field size of 0.2 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	865	+	+	+	+	+	+	513	+	421	+
0.004	+	+	+	+	+	+	+	+	+	510	+	421	560	334
0.005	+	+	+	+	+	513	493	493	+	+	418	381	334	+
0.006	+	599	+	510	489	+	+	438	790	418	381	824	305	+
0.007	+	531	493	+	443	443	418	408	+	421	381	457	275	715
0.008	560	493	457	790	418	+	+	381	364	745	+	304	+	+
0.009	+	+	418	844	560	+	364	+	334	334	304	275	+	587
0.010	475	421	+	379	364	649	334	+	649	312	284	599	+	824
0.011	443	+	379	+	334	334	560	304	304	304	304	304	304	304
0.012	418	379	+	334	334	305	287	287	531	275	+	684	457	287
0.013	421	364	334	+	305	287	287	275	275	696	661	649	443	649
0.014	379	334	531	304	287	275	275	+	661	+	+	513	443	142
0.015	364	696	304	287	287	513	865	+	493	493	817	497	304	142
0.016	560	304	287	287	844	497	493	497	475	475	497	513	287	287
0.017	334	287	275	257	257	493	457	745	457	649	390	+	304	123

Point of total depletion for field size of 0.3 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	+	+	727	+	683	651	510	+	426
0.004	+	+	+	+	+	+	+	+	+	538	493	+	421	395
0.005	+	+	+	+	+	+	+	510	+	493	448	426	+	356
0.006	+	651	+	+	510	493	493	493	449	443	421	395	356	+
0.007	651	+	510	488	493	449	443	449	426	421	395	356	+	286
0.008	+	510	488	449	443	426	421	421	+	+	356	708	286	257
0.009	+	493	443	426	426	395	395	+	+	356	+	286	493	257
0.010	493	443	421	395	390	390	356	356	356	884	443	286	286	488
0.011	493	421	395	390	+	356	356	659	659	659	286	286	286	493
0.012	443	395	390	356	356	+	+	604	+	286	286	286	493	449
0.013	421	395	+	334	334	+	+	286	286	286	286	286	457	443
0.014	425	369	369	+	488	457	286	286	286	286	286	286	286	+
0.015	+	343	+	488	457	284	284	284	284	284	532	488	369	343
0.016	+	532	304	304	516	488	257	257	257	257	257	442	+	343
0.017	343	304	304	+	257	257	257	257	257	257	257	257	510	304

Point of total depletion for field size of 0.4 ha/person

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	+	+	779	+	+	599	+	+	449
0.004	+	+	+	779	+	+	+	+	599	+	+	488	449	421
0.005	+	779	+	+	+	+	+	538	538	+	488	449	421	449
0.006	779	+	599	+	538	538	+	488	+	+	421	+	395	356
0.007	684	599	+	+	488	457	457	779	421	421	395	599	356	305
0.008	+	538	+	+	457	421	421	421	+	395	+	356	+	305
0.009	779	493	457	+	421	421	395	395	395	395	+	+	493	421
0.010	+	493	442	421	421	395	395	395	395	395	+	493	284	284
0.011	486	442	421	442	442	369	369	369	369	369	+	538	493	442
0.012	449	421	395	395	356	356	356	356	356	356	607	449	421	538
0.013	421	395	395	356	356	356	356	356	+	607	457	457	395	356
0.014	421	395	395	395	395	778	493	778	449	449	778	395	188	188
0.015	395	395	395	395	468	468	449	275	275	275	275	395	188	188
0.016	395	395	395	468	468	275	275	275	275	275	449	211	211	211
0.017	357	538	481	778	449	449	421	421	421	395	211	211	211	421

+ denotes a value greater than 900 years

APPENDIX G

S_f FOR VARIABLE f_s

Predicted time of first fissioning for self-adjusted field size (ha/person) and a total land area of 19559.2 ha.

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	873	790	724	685	622	588	572	458	422	365	288
0.004	+	809	709	636	608	572	512	494	482	458	419	370	288	245
0.005	801	660	596	539	494	469	433	426	419	402	355	305	242	182
0.006	674	579	507	469	426	419	402	391	377	365	313	276	204	172
0.007	588	494	449	422	402	382	365	355	335	328	284	249	189	155
0.008	523	449	419	391	365	355	335	322	313	305	258	223	172	137
0.009	482	419	382	359	344	322	313	297	287	284	233	204	166	130
0.010	433	391	359	335	313	305	287	284	267	258	211	189	155	123
0.011	419	365	335	313	297	284	276	258	249	242	204	182	137	123
0.012	391	344	313	297	284	267	249	239	233	223	189	172	137	113
0.013	370	328	298	284	267	249	239	233	211	204	182	166	130	113
0.014	355	306	284	267	249	233	223	211	204	199	172	155	123	104
0.015	335	288	267	249	233	223	211	204	199	189	166	143	123	104
0.016	321	284	256	233	223	204	199	189	182	182	155	130	111	93
0.017	298	267	239	223	211	199	189	182	172	172	143	130	111	93

Predicted time of first fissioning for self-adjusted field size (ha/person) and a total land area of 29185.4 ha.

	P_0													
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	873	811	779	724	685	572	482	422	382
0.004	+	+	809	715	685	636	617	588	572	524	450	422	370	313
0.005	880	724	652	617	579	539	507	489	469	449	402	365	305	258
0.006	729	630	579	512	489	469	433	426	419	414	365	322	276	233
0.007	644	549	494	469	433	422	414	396	382	365	328	297	242	204
0.008	579	494	449	422	402	391	377	365	355	344	305	276	223	189
0.009	511	449	419	396	377	359	344	335	322	313	284	249	204	172
0.010	482	422	391	365	355	335	322	313	305	287	258	233	189	166
0.011	433	396	365	344	328	313	305	287	284	276	242	211	182	155
0.012	419	376	344	322	305	297	284	276	267	258	223	199	172	143
0.013	402	355	328	306	288	284	267	256	249	239	204	189	155	137
0.014	380	335	306	288	276	267	249	239	233	223	199	182	155	130
0.015	355	321	288	276	256	249	239	233	223	211	189	172	143	130
0.016	335	298	276	267	249	233	223	211	204	199	182	155	130	115
0.017	328	288	267	249	231	223	211	204	199	189	172	155	130	111

+ denotes a value greater than 900 years

APPENDIX H

S_d FOR VARIABLE f_s

Predicted time of total depletion for self-adjusted field size (ha/person) and a total land area of 19559.2 ha.

							P_0							
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	+	+	631	+	+	+	427	+	+
0.004	+	+	+	+	+	+	729	+	494	709	422	380	+	+
0.005	809	+	+	+	+	685	+	+	427	+	427	+	+	729
0.006	684	+	512	+	+	427	729	427	382	+	+	287	+	382
0.007	+	512	644	427	+	427	729	427	+	+	287	287	866	+
0.008	709	644	427	427	382	427	+	+	+	684	287	572	422	+
0.009	+	427	427	427	+	+	+	305	+	287	652	+	172	+
0.010	+	427	427	729	+	+	572	287	287	287	684	+	+	305
0.011	427	382	+	729	305	287	287	287	287	287	652	+	+	+
0.012	+	+	382	305	287	287	287	287	287	+	422	+	305	123
0.013	+	517	306	288	288	287	287	287	+	+	444	172	427	123
0.014	+	+	288	288	287	287	729	729	+	+	391	+	+	113
0.015	517	427	288	288	288	+	684	+	+	427	172	489	288	113
0.016	494	288	288	422	+	+	729	517	494	494	517	306	115	102
0.017	306	288	288	422	729	684	+	494	494	494	306	306	115	102

Predicted time of total depletion for self-adjusted field size (ha/person) and a total land area of 29185.4 ha.

							P_0							
r	100	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000
0.003	+	+	+	+	+	+	+	+	+	+	+	489	427	391
0.004	+	+	+	729	+	+	630	+	+	+	660	+	380	+
0.005	+	729	660	630	+	+	512	709	685	660	+	+	+	287
0.006	+	+	+	+	709	+	+	630	427	419	+	+	287	+
0.007	+	572	512	+	630	427	419	+	427	382	+	305	+	+
0.008	+	684	644	427	419	427	382	+	427	+	709	287	572	+
0.009	+	652	427	+	382	427	+	+	+	+	287	287	+	+
0.010	+	427	427	382	427	+	729	+	+	305	287	+	+	172
0.011	+	+	382	709	+	729	652	305	287	287	287	+	+	709
0.012	427	382	+	+	382	305	287	287	287	287	+	652	+	305
0.013	422	813	517	494	427	288	288	288	287	287	+	444	172	288
0.014	+	517	+	427	288	288	287	287	287	+	684	427	517	427
0.015	+	494	427	288	288	288	288	288	+	684	427	391	427	+
0.016	517	306	288	288	288	422	+	+	+	729	494	172	306	123
0.017	494	444	288	288	422	652	+	729	684	517	494	172	+	115

+ denotes a value greater than 900 years

VITA

William W. Baden was born in Cleveland, Ohio on December 26, 1952. He was raised in rural northwestern Ohio and graduated from Fairview High School, Sherwood in 1970. He received an Associate in Arts degree from Miami University, Oxford, Ohio in 1973. In 1976 he earned a Bachelor of Arts degree in Anthropology from the University of Toledo, Toledo, Ohio. His Master of Arts degree in Anthropology was earned in 1982 from the University of Tennessee, Knoxville. He was awarded a Doctor of Philosophy degree in Anthropology from the University of Tennessee in 1987.

Dr. Baden's research interests center on the development of mathematical models that describe and explain the prehistoric past and archaeological observations. His research has concentrated on the protohistoric-early historic manifestations in southeastern North America.

He is married to the former Marla M. Beal of Lynchburg, Virginia.