Eroded Landscapes: Agricultural and Environmental Change in the United States Piedmont, 1790 – 1860

By

Michael Clemens Lonneman

(Under the Direction of Don Nelson)

Abstract

Local agricultural land use and environmental change outcomes are tied to variation in farmer decision-making and inequality in access to land and labor. This thesis introduces an agent-based model to investigate how the degree of labor intensification interacts with farm-level land and labor characteristics to influence the likelihood, timing, and nature of changes in fallow management, forest cover and soil fertility change, and agricultural productivity. The model demonstrates that labor extensive farmers would have quickly experienced declining soil quality and agricultural production. Labor intensive farmers maintained soil quality and agricultural production by engaging in a forest-fallow cycle that allowed for the regeneration of soil fertility.

INDEX WORDS: Land Use Change, Labor Intensification, Agent-based Modeling

Eroded Landscapes: Agricultural and Environmental Change in the United States Piedmont,

1790 – 1860

By

Michael Clemens Lonneman

B.A., University of Louisville College of Arts and Sciences, 2011

A Thesis submitted to the Graduate Faculty of the University of Georgia in Partial Fulfillment of

the Requirements for the Degree

MASTER OF ARTS

Athens, Georgia

2018

ERODED LANDSCAPES: AGRICULTURAL AND ENVIRONMENTAL CHANGE IN THE UNITED STATES PIEDMONT, 1790 – 1860

by

MICHAEL CLEMENS LONNEMAN

Major Professor:	Don Nelson
Committee:	Bram Tucker
	Sergio Quesada
	Michael Coughlan

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
December 2018

ACKNOWLEDGEMENTS

I'd like to thank my advisor, Don Nelson, for encouraging this project and providing support and advice throughout its development. I'd also like to thank my entire committee, Don, Bram Tucker, Michael Coughlan, and Sergio Quesada, for valuable insight and friendship during my time at the University of Georgia. I am deeply thankful to Linsey Haram for patiently listening to all my rants about R code not working correctly. Hopefully that was nicely balanced by all coding triumphs! Finally, I am very thankful to my parents John and Kathy Lonneman for being infinitely supportive and understanding during my occasionally tumultuous path through decades of schooling.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1) INTRODUCTION

. Within non-industrial agricultural systems, farmers must carefully manage natural resources to maintain agricultural productivity over time, often by adjusting fallow regimes, the use of land and labor inputs, and the techniques and technologies used to maintain or boost soil fertility (Netting 1993). Yet farmers may be induced or forced into land use practices that result in environmental changes such as widespread deforestation and soil erosion that jeopardize the long-term productivity of farms (Blaikie and Brookfield 1987). Integration into global markets, the widespread availability of land along a frontier, and inequality in access to labor and an adequate size or quality of land resources influence how farmers make decisions to intensify their use of land and labor as they respond to changing socioeconomic and environmental conditions (Blaikie and Brookfield 1987; Bennett 1982). This thesis introduces an agent-based model to investigate how the degree of labor intensification interacts with farm-level land and labor characteristics to influence the likelihood, timing, and nature of changes in fallow management, forest cover and soil fertility change, and agricultural productivity.

In the Piedmont region of the southeast United States, agriculture from Euro-American settlement to the mid-twentieth century is associated with widespread soil degradation, estimated to be on average a loss of 9.5 inches of soil (Trimble 1974). Farmers have been portrayed as soil miners that through ignorance or greed engaged in a continuous cycle of soil erosion and gullying by rapidly exploiting soil resources before moving on to more fertile lands (Montgomery 2007). As early as the mid-nineteenth century, Piedmont farmers were described as careless toward the land and uninterested in rotation, manuring, and ditching necessary to prevent soil fertility loss (Affleck 1851). Yet engaging in such practices demanded considerable labor investment and often were not effective given the infertile, acidic, and easily erodible soils of the Piedmont region (Nelson 2007; Ruffin and Kirby 2000).

Engaging in soil conservation activities, such as manuring, ditching, and crop rotation, broadly represent agricultural intensification that demands increased labor input (Netting 1993). Classically, farmers reliant on long fallow periods are hypothesized to engage in agricultural intensification due to population pressure that limits the availability of land (Boserup 1965). In frontier societies, land may be available elsewhere, lowering farmers' incentive to conserve soil resources (Netting 1968; 1993). Farmers, who vary in terms of their goals, motivations, and access to land and labor, will vary in how they apply labor and make land use decisions (Bennett 1982). In shifting agricultural systems, farmers respond to declining soil fertility loss by clearing new land and allowing for the recovery of soil fertility by fallowing. Yet agricultural strategies may result in a positive feedback loop of soil fertility loss as farmers seek to meet short-term subsistence or income needs without allowing for the adequate recovery of soil resources (Blaikie 1985). The objective of this research project is to investigate how fallow length, agricultural productivity, and environmental changes over time are related to the size and quality of landholdings and the amount of labor available to the household under labor intensive and labor extensive production. An agent-based model (ABM) is presented that is parameterized on yeomen households within a plantation-based agricultural system of the United States southeastern piedmont region from 1790-1860.

The motivations and goals of farmers are complex and variable, shaped by the differential opportunities and constraints facing farmers across race- and class-divisions (Donnelly and Evans 2008). The availability of land along a frontier, institutions such as slavery, advancing railroads, and the international demand for cotton all shaped the opportunities and constraints facing farmers. Agent-based modeling presents an opportunity to investigate how hypotheses relating macro-structure to individual agency, motivation, and opportunity shape how land use and land cover change unfolds locally (Overmars et al. 2007). It is a modelling technique where an artificial environment is populated with autonomous, adaptive decision-making entities that interact with both other agents and their environment to produce emergent system-level outcomes and patterns (Grimm et al. 2010). They are useful in cases where the modeler seeks to utilize or test decision-making based on behavioral theories and where outcome distributions are the object of study and heterogeneity matters (Overmars et al. 2007; Grimm et al. 2010). ABMs capture the heterogeneity of both human actors and the environment, the bounded rationality of decision-making, and out of equilibrium dynamics associated with socio-ecological dynamics (Filatova et al. 2013; Parker et al. 2003).

When modelling environmental change, land use change ABMs often do not take into account land use legacies. Actions taken by agents at one time point have environmental consequences, such as the relationship between land use and land cover change, but decisions at one point in time rarely feedback to influence future land use decisions (e.g. Brondizio 2002; Overmars et al. 2007; Deadman et al. 2004; Manson and Evans 2007). Yet agricultural is historically contingent as human land use decisions at one time point creates a new context within which humans must make decisions (Morrison 1996). This project presents an ABM that explicitly models how feedback loops between agricultural land use and environmental outcomes influence future land use practices. The regeneration and degradation of soil resources, shaped by prior land use decisions, in turn influence the length of continuous cultivation, fallow periods, and agricultural productivity.

This project is part of the Calhoun Critical Zone Observatory project, located within the Sumter National Forest, which explores the legacies of historic land use in present-day hydrology, geomorphology, and biology. Broadly, Critical Zone Observatories seek to expand the notion of the ecosystem from the uppermost plant canopy to the deepest penetration of groundwater, and the Calhoun CZO adds a social and historic dimension to understand how present-day soil processes are the product of human land use legacies. This research project contributes to CZO objectives that seek to broaden natural sciences' knowledge of soil processes by examining the interaction of human decision-making, land use legacies, and processes of environmental change across space and time. By explicitly modeling spatio-temporal variation in opportunities and constraints facing farmers, this project responds to anthropologists' critiques that systems-based approaches avoid studying the role of power in creating inequality in access to material resources (Hornborg 2013) and for relying on abstract structural processes rather than asking normative questions concerning agents and social relations operating at different scales (Cote and Nightingale 2011).

This time period in Union County, 1790-1860, represents the formation and reorganization of a plantation agricultural system. Plantation agricultural systems are dual economies, characterized by the control of land and labor by a small elite, a large, landless labor supply and family-labor based smallholders (Pryor 1982). Historical demographic and agricultural census data are combined to parameterize agricultural practices and productivity amid local variation in rights and access to land and labor amid the context of institutions related to slavery and tenancy, and processes of technological change, frontier settlement, and population change. The ABM is designed to answer the following questions: How does the degree of labor intensification interact with households' land and labor characteristics and demography to influence (1) the rate, magnitude, and pattern of forest cover and soil change, (2) the length of continuous cultivation and fallow periods for individual plots of land, and (3) long-term changes in land and labor productivity?

This thesis uses unit measurements specific to the historical documentation of the U.S. southeastern Piedmont region, including acres, bushels of corn (maize), and pounds of cotton. Metric conversions are as follows: 1 square kilometer equals 247.105 acres, 1 pound of cotton represents .454 kilograms, and 1 bushel of corn represents a volume of 60.893 cubic meters or a weight from 20.412 to 27.216 kilograms.

The second chapter provides a literature review on agricultural intensification, shifting agricultural systems, and environmental change. In particular, it delineates the connections between these topics in order to understand how changing agricultural strategies influence broader changes in human organization and environmental change. The third chapter provides background on the United States southeastern piedmont region from Euro-American settlement to the Civil War. It describes the environmental conditions and institutions that shaped agricultural land use in the region, and how the relationships between the environment and human land use changed over time. The fourth chapter presents the agent-based model and describes the model components, processes, and outcomes. The final chapter presents an analysis and discussion of model outcomes.

2) THEORETICAL BACKGROUND

This project responds to and builds on multiple bodies of literature, particularly agricultural anthropology, socio-ecological systems, and political economy. Agricultural anthropology has studied how and under what conditions agricultural systems change, positioning individuals and households within broader political, economic, and environmental spheres (Netting 1993; Stone 2001; Morrison 1996). It's explores how farmers make decisions amid risky and uncertain environments and how those decisions influence other aspects of social, economic, and political life and environmental change (Barlett 1984). Political economy investigates how class-, race-, and gender-based stratification differentially shape the opportunities and constraints facing different actors, leading to negative well-being and livelihood outcomes and environmental change amid uncertain socio-economic and environmental conditions (Blaikie and Brookfield 1987; Robbins 2004). Finally, socio-ecological systems integrates aspects of ecosystem theory with advances in population ecology and political ecology to understand the complex, uncertain, nonlinear and hierarchical relationships between natural and social systems (Biersack 1999; Cumming 2014). Environmental systems are here understood to be affected by the purposive behavior of humans, which is differentially distributed, reflecting conflict over goals and system behavior (Duit et al. 2010; Leslie and McCabe 2013; Beier et al. 2009).

This chapter first examines processes of agricultural change within the perspective of agricultural intensification. It reviews the conditions and contexts within which agriculturalists vary their production strategies in response to socio-economic and environmental processes operating from the household- to global level. It then explores shifting- and plantation-based agricultural systems in more depth and reviews the links between deforestation, soil fertility change, and environmental degradation.

Agricultural Intensification

Agricultural intensification and extensification are used by social scientists to categorize systems of production based on how labor, land, and technology is brought together in particular ways and to understand agricultural change over time. Agricultural intensification represents the process of increasing total agricultural production per unit area and time by a broad suite of agricultural strategies (Morrison 1996). Extensive land use is on the opposite end of the spectrum of intensive agriculture; agriculturalists will increase the number or size of their landholdings without increasing labor or other types of inputs (Coughlan and Gragson 2016). Central themes of research include understanding how the degree of agricultural intensification or extensification can vary as farmers differentially respond to changes in demography, the environment, and socio-economic institutions, and how agricultural intensification or extensification can represent, simultaneously, adaptations to meet household needs as well as a process that introduces negative outcomes for livelihoods and the environment.

Boserup (1966) linked the degree of agricultural intensification to population pressure. As population pressure on an area grew, fallow length would shorten. Agricultural intensification, driven by population pressure, would further influence the rise of complex divisions in labor, specialization in production, and the movement away from solely subsistence production (Boserup 1966). However, Boserup also argued that that market demand, taxes, or tribute could also influence changes away from subsistence agriculture, independent from population pressure. Therefore, intensification is an endogenous response to exogenous sources of change. Boserup was critiquing the dominant neo-Malthusian perspective on population growth and land degradation, which held that as a population grew, people would continue to exhaust natural resources until a threshold was crossed by which further cultivation was impossible or yields significantly reduced. People would then move to a new area and the cycle would continue. But these two perspectives, one of endogenous intensification and thresholds linked to natural resource decline, are not mutually exclusive and can occur simultaneously (Stone 2001).

Intensification is neither inevitable nor an evolutionary schema (Morrison 1996). Processes of agricultural land use change are not linear moving from extensive to intensive land uses (Netting 1993). Furthermore, land uses of varying intensity co-exist and this diversity is fundamental to the internal functioning of an economy (Morrison 1996). Such diversity reflects variable opportunities and constraints facing different individuals and groups (Morrison 1996).

The degree of intensification can be examined in different ways beyond simply fallow length. The most common is the total production per unit time or area (typically per hectare and year), which is measured by total output (Kates, Hyden, and Turner 1993:10). Surrogate measurements include the frequency of cultivation and the type and number of agrotechnologies (Kates, Hyden, and Turner 1993). Morrison (1996) recognizes multiple pathways to intensifying agriculture: 1. Specialization, which reduces practices to a limited and specific technological- or labor-based strategies, 2. Diversification, which expands practices to include multiple cultigens and fallow regimes, spatially diffused fields, and staggered planting times, and 3. Intensification proper, which refers to increasing per unit yield of land and/or labor for an existing resource. Agricultural change can also include expansion, which simply refers to an increase in amount rather than concentration, and therefore does not necessarily reflect intensification.

This thesis investigates the role of labor intensification in influencing productivity and environmental change over time. Labor intensification is a potential pathway of agricultural intensification in which higher productivity per unit time and area is achieved by increasing the input of labor per unit area (Netting 1993). Labor intensification is associated with higher production yields and diminishing returns for labor invested per unit area of farmland (Erickson 2006). It is not the only possible form of agricultural intensification: industrial agricultural systems are characterized by a high degree of labor extensivity with very high yields per unit labor (Netting 1993). Indeed, as labor intensity increases in shifting agricultural systems, labor productivity tends to decrease (Clarke 1966). Labor intensification is common in smallholder agricultural systems where suitable land for agricultural production is limited (Netting 1993). The entire household provides long and skilled labor to enable high and sustainable production on small farms with permanent fields in areas of dense population (Netting 1993).

While Boserup (1965) argued that agricultural intensification occurred due to population changes at a regional scale, Netting (1993) added the timing and nature of agricultural intensification changes reflects households responding to endogenous demographic change. Household size and composition has been tied to farm area and size, the forms of cultivation used, and the labor needs of the agricultural enterprise (Chayanov 1966; Netting 1993). Chayanov (1966) argued that the degree of intensity reflects households minimizing the drudgery of work in the context of demographic changes. When households have many children and few people who can work the fields, represented by a high consumer/worker ratio, the household will increase the amount of labor in order to meet its minimum consumption level. As the ratio decreases due to children becoming labor units, each laborer will decrease its input as the subsistence minimum is met (Chayanov 1966). However, Chayanov’s model only fits certain extensive agricultural systems where markets are underdeveloped, land is abundant, and labor exchange is low (Netting 1993).

The degree of market integration and production of cash crops does not necessarily lead to intensive forms of cultivation. Among the Koyfar, farmers wanted to enter the cash crop market and extensive cash cropping characterized by movement along a frontier was a popular mechanism for doing so. Yet as land availability declined, intensification increased to allow for the maintenance of soil fertility and an increase in surplus food production (Netting 1968). In Laos, smallholder rubber plantations were associated with an increase in shifting agriculture as farmers expanded into forested regions to produce food while they waited for the establishment of the rubber plantation, which takes around 7 years (Hurni et al. 2013).

Investigating processes and patterns of socioeconomic differentiation and inequality can help researchers to understand variation in agricultural strategies and environmental and livelihood outcomes between households. Inequality is associated with greater stress, poorer mental and physical health outcomes, and a shorter life span (Tucker et al 2015). The form of inequality varies both in practice and degree across societies (Tucker et al 2015). Poverty, hunger, and other negative outcomes for farmers are tied to the rural institutions that govern land, labor, and other forms of capital: agricultural change therefore takes place within the context of institutional change rather than simply changes in inputs or technology (Barlett 1984).

Socio-economic differentiation, which refers to the processes by which inequalities emerge over time and are unequally distributed throughout a society, are often driven by forms of surplus extraction that prevent farming households from accumulating resources (Deere and de Janvry 1979). Once capitalist markets enter regions with peasant households, a minority of producers become successful commodity producers who obtain surpluses while the majority oscillate between small-scale farmers and proletariats. Ultimately, the end result is complete differentiation into farmers and wage earners. Surplus extraction can occur via sharecropping, rent via unpaid labor, the sale of labor, usury, rent, taxation and other forms of trade, all of which must be maintained by political, ideological, and economic institutions (Deere and de Janvry 1979).

Different agricultural land uses are often associated with particular land tenure regimes that set farmers' access to use and transfer land (Brown et al. 1990). Early theory on land tenure and agricultural land use often used a Boserupian framework whereby communal over tribal tenurial systems associated with extensive production transitioned to individual and private property tenure are associated with intensive agriculture under increasing population density, market integration, or innovation in agro-technology (Boserup 1965; 1981). Yet tenurial regimes and land use types often vary within an agricultural system. When high quality agricultural land availability is low, permanent and sustainable intensive production in many smallholder systems is maintained by household- and community-level institutions that prevent land fragmentation and consolidation, whereby the timing of land transfer reflects the generational transfer of land from one landowner to a successor (Brown 1990; Netting 1993). In such settings, more marginal land may be held under a communal tenure system for more extensive land uses, such as livestock production (Netting 1993).

During transitions away from intensive smallholder production, due to industrialization or another broad-scale change, the pace of extensification will be tied to the rate by which some households decide to abandon agriculture and sell to other landowners (Coughlan and Gragson 2016). Under the context of colonialism, extensive agricultural systems are created as land within frontiers, either sparsely settled or "cleared" of indigenous populations, is granted to settlers (Edelman 1985); these conditions often lead to agricultural systems associated with plantation agriculture (Pryor 1982).

Shifting Agriculture

Shifting agriculture is a broad category of agricultural systems where fields are cropped for shorter periods than they are fallowed. This type of agriculture is common throughout the tropics and can be associated with both subsistence and commodity production. The specific form of shifting agriculture, also known as swidden or slash and burn agriculture, within a given place depends on the extent of available land, labor, and capital, settlement patterns, degree of integration, and many agronomic conditions and characteristic (Conklin 1961). As shifting agriculture becomes more “extensified”, or as the fallow length increases, it is associated with higher returns per unit labor and simpler forms of technology such as sticks (Clarke 1966). Tillage, irrigation, ditching, the tool usage, the amount of time between clearing, burning, and planting all indicate the degree of intensification within shifting agricultural systems. Often there can be a mix of these techniques. When soil is poor, forest-fallow systems are often more common than grass- or bush-fallow systems. To use a grass-fallow system on such soil, much more labor inputs are required to till and fertilize the crops, with results that lead to large declines in yield per hour of labor (Carneiero 1961; Dumond 1961).

Tropical regions have several environmental challenges that make shifting agriculture an effective strategy as opposed to more permanent styles of cultivation in temperate regions. Soils are often very acidic and fairly poor; cultivation quickly leads to deterioration in the nutrient status and physical condition of soils, erosion of topsoil, and changes in numbers and composition of soil fauna and flora (Clarke 1976). Meanwhile, high rates of precipitation and warm temperatures lead to an increase in weeds and the multiplication of pests and disease. In the tropics, forest nutrients are stored mainly in trees, rather than the soil (Clarke 1976). Therefore, the soil in a secondary forest are the same as the soils in a 3-year-old garden, and burning must be used to unlock those nutrients for agricultural use (Clarke 1976). The need to weed always increases in subsequent years. In Papua New Guinea, trees are allowed to grow within the garden to give them a head start on regeneration, while other growth is pulled. Trees are planted across Africa and the Pacific region, particularly nitrogen fixing varieties (Clarke 1976).

Increasing reliance on chemical inputs is often associated with the abandonment of shifting agriculture toward annual and repeated cropping on the same plots (Humphries 1993). This often occurs in the context of increasing production for national and international markets by peasant producers, such as among Mexican peasants. The movement from "safety-first" to profit maximization often coincides with these decisions. Crop that were important, such as landraces, in subsistence and shifting production are not profitable on markets.

Plantation Agricultural Systems

Plantations represent a fundamental institution of European colonization and expansion throughout the Americas (Tomich 2011). Plantations are institutions characterized by specialized commodity production, the employment of nontrivial numbers of nonfamily workers, and are often associated areas of abundantly available land, the ability to obtain and control unfree labor, and high capital investment (Pryor 1982). Often located within or along land frontiers, where political and economic institutions are weak or absent, plantations become the dominant political-economic institution through which production and export is organized (Mintz 2011).

Early plantations formed in areas where indigenous peoples were moved, enslaved, or killed off, where land was fertile and easily obtained, and from which products could easily be sent to Europe (Thompson 2010; Mintz 2011). Political power in such areas is often weak or absent, and so plantations become the dominant political institution (Mintz 2011). Owners and overseers expected disorder and used violence and other means to maintain control (Mintz 2011). Financial and capital markets are often imperfect or entirely absent, and large-scale plantations are often the only institutions that can obtain credit in these regions (Weiman 1990). Plantations are nearly always part of a dual economy, co-existing with smallholder farmers (Pryor 1982). Land markets associated with plantations may be "stunted", as landowners may hold onto land for prestige purposes rather than putting it into the most productive use or selling it to those who could use it more efficiently (Pryor 1982). Plantation owners may also be able to use their considerable political and economic power to prevent land sales to smallholders, such as occurred in Union County when land sales to freedmen following the Civil War were discouraged (Pryor 1982; Charles 2014). As the economic power of plantation owners declines, due to broader socio-economic or environmental factors, the ability to control the labor supply may decline and the plantation system may no longer be maintainable.

Plantations have often been examined within typological schemas or as a distinct model of production (e.g. Mandle 1973; Pryor 1982). Tomich (2011) critiques such studies as being overly ahistorical and reductionist. Here plantations are placed as a distinct unit of capitalist production, producing commodities that flow consumer regions (Mintz 1985). Such approaches ignore the ways in which the control of land and labor by an elite class is dynamically maintained within a wide range of socioeconomic and ecological conditions and how the emergence and reorganization of plantations over time is locally contingent and a product of evolving social relationships and divisions of labor (Tomich 2011). Likewise, oversimplifying labors as members of a proletariat, entirely dependent on plantation labor and goods imported from elsewhere, while romanticizing past traditional activities, ignores the multiple modes of economic activity, including subsistence, peasant, wage, and urban, that workers are engaged in (Merleaux 2015).

Deforestation & Soil Erosion

Deforestation has become a major target for both research and intervention over the past several decades (Brondizio 2002). Deforestation can jeopardize water quality and availability, soil quality, biodiversity, and the control of greenhouse gas emissions (Jusys 2018). Past societies have commonly been used as cautionary tales of examples of runaway natural resource extraction linked to the “collapse” of social systems, such as among the Classic period Maya, the ancient Rome Empire, Norse colonies in Greenland, and Polynesians at Easter Island (see: Cooke 1931; Culbert 1973; Diamond 2005; Montgomery 2007). Yet despite popular narratives, deforestation does not inevitably result in environmental degradation and widespread socio-economic collapse (McNeil 2011; McAnany and Yoffee 2010). Societies have long avoided Malthusian scenarios of degradation by many means, including intensifying and/or expanding production, increasing fallow periods, and using common pool institutions to manage resource use (McNeil 2011; Netting 1968; Netting 1993). Therefore it is important to understand how institutional, environmental, and topographic processes and characteristics influence individuals’ decisions in managing and responding to environmental outcomes.

Within a shifting agricultural system, deforestation and reforestation are fundamentally related to fallow cycles. In many sub-tropical and tropical regions fallow cycles allow trees to return before clearing the land again, rather than grass fallow cycles which allow grasslands to emerge before clearing (Clarke 1966). Yet other factors can influence the rate and nature of deforestation and reforestation within a larger landscape. Within frontier settings, deforestation is not simply tied to fallow periods (Brondizio et al. 2002). Land use is characterized by cycles of progressive expansion and the coexistence of intensive and extensive systems of production. Therefore the time of settlement, stages of farm consolidation, and infrastructural and institutional variables all influence whether, when, and how households manage fallowing (Brondizio et al. 2002). Deforestation can be cyclical or occur in the context of sudden events. In the case of the former, initial settlers clear land but then intensify the use of that land to claim it and boost productivity in cash crops. For the latter, sudden credit or market opportunities can influence both spikes in deforestation and secondary succession (Brondizio et al. 2002).

Starting with Boserup (1965), social scientists began critiquing the neo-Malthusian narrative that declining soil fertility through erosion and other processes was the result of population growth and a shortage of natural resources. Degradation can occur under many different conditions and land uses, including both extensive and intensive forms of agricultural land use, and the attention of analysis should on how degradation is related to class interest and social struggle (Robbins 2004; Andersson et al. 2011; Goodman 1991). Blaikie (1985) argues that soil erosion a political-economic problem resulting from inequalities of economic opportunities between the majority of poor, rural land-users and more powerful agents and institutions.

The chief mechanism that creates economic inequalities is capital accumulation by elite class interests, either through taxation, land rents, or other forms of resource appropriation (Blaikie 1985). Marginalized farmers enter into a positive feedback loop of soil degradation as they are forced to unsustainably exploit natural resources to meet household needs (Blaikie 1985). Soil erosion thus emerges out of the relationships of producers with landlords, external markets, administrations and cultural orders, exploring the role of power in determining resource access and utilization and the distribution of environmental degradation (Robbins 2004; Blaikie 1985; Blaikie and Brookfield 1987).

The ability to control labor can help some households prevent degradation and intensify production, driving a mosaic of intensified agriculture and increased degradation for households unable to compete (Awanyo 2001). Alternatively, degradation associated with deforestation has been attributed to wealthy, large-holding, and non-resident landowners rather than smallholders or tenants (Miettinen et al. 2012). Degradation is not irreversible, as in the case of deforestation in Brazil where the interaction of particular soil types and historic forms of land use allows some rainforests to re-develop (Lu et al. 2002).

Narratives of deforestation and soil erosion often deny agency to producers both in terms of causing and responding to environmental change (O'Brien 2002). In particular, contemporary forms of shifting agriculture is portrayed as driving tropical land degradation, including the loss of biodiversity and as a main emitter in greenhouse gasses. NGOs and other similar organizations are then positioned as saviors who can educate land users or improve the conditions that may force farmers to deforest or erode their land (O'Brien 2002). The FAO (1984) describes an early state of shifting agriculture as being in balance with nature, due to subsistence orientation and low population numbers, but now it is extremely degrading due to economic inequalities, globalization, international debt, and high population numbers. Within this framework producers are portrayed as passive victims who do not try to innovate but mindlessly use traditions handed down from their ancestors (O'Brien 2002).

3) LAND USE IN THE SOUTHEASTERN PIEDMONT AND UNION COUNTY, 1790 - 1860

The study area represents two historic townships in Union County, South Carolina: Goshen Hills and Cross Keys. Together they represent a contiguous, 33 square kilometer section of Union County. It is bounded by the Enoree River to the south and the Tyger River to the north. Union County is located within the Southeastern Piedmont biogeographic region of the United States. Situated between the coastal plain and the Appalachian Mountains, the Piedmont is the most eroded part of the Appalachian orogeny. It is characterized by broad upland areas that descend into bottomlands, fertile sites that attracted the first Euro-American settlers to Union County (Coughlan and Nelson 2018). As agricultural production expanded from the alluvial bottomlands to drier uplands following Euro-American settlement, soil erosion on the uplands and sloped areas drove a process of deposition in the bottomlands, leading to flooding and influencing agricultural abandonment in many of these areas (Trimble 1974).

Environment & Soils

The Piedmont region is characterized by acidic soils that are easily susceptible to erosion. The most common classification of soils in the South, and the most common in the Piedmont, is ultisols, an order with poor fertility, acidity, and with high rates of nutrient leaching (Majewski and Tchakerian 2007). High acidity is related to low soil aggregation, which decreases the drainage, aeration, and microbiological activity that together promotes nutrient uptake by plants and prevents water from easily transporting soil particles (Helms 2000). Ultisols are particularly deficient in phosphorous. Phosphorous, a critical element for plant growth, is often limited in the granite-derived soils of southern soils (or is combined with aluminum and iron in a form that is not available to the plant) (Helms 2000). Calcium, helps reduce the acidity of soil, and phosphorous often occur together since they concentrate in bones and shells, and are commonly found in limestone and other base-rich materials. Until phosphorous fertilizers became available, not even long fallow periods could completely restore the fertility of the soil once it was cultivated (Majewski and Tchakerian 2007).

Figure 3-1: Map of Union County and Cross Keys and Goshen Hills townships. Map by Michael Coughlan.

Alfisols are the other order of soils that can be found in the South, but mainly in Tennessee and Kentucky and are widespread in the northern states. These soils are blessed with an abundance of phosphorous, potassium, calcium, and other essential plant nutrients. Northern farmers used mixed husbandry to maximize productivity on these soils, including pasturage of livestock and rotations of clover and other legumes to fix nitrogen. In the south, areas with alfisols still didn't have high improved acreage ratios, potentially due to topography; many areas with alfisols were subject to either intense erosion, poor drainage, or were simply inaccessible due to rough topography (Majewski and Tchakerian 2007).

The warm and humid climate of the southern United States contributes to both the poor development of the soil and other issues with cultivating crops and livestock (Stoll 2002; Rubin 1975). While not technically in a tropical region due to frosts, the southeast suffers from several similar disadvantages: The heavy annual rainfall contributes to the leaching of the soil, the long, hot summers and insufficient rainfall stress crops, while the humid environment leads to crops maturing faster, which decreases the quality and yields of several grains, legumes, and tubers including wheat, corn, rye, oats, barley, potatoes, grasses and legumes (Rubin 1975). Fodder crops particularly suffered, due to both acidic soils and risk of rain during mowing and curing periods (Rubin 1975). Additionally, livestock's ability to produce milk and fight pests and infections were compromised in the high humidity and high temperatures (Helms 2000).

In the Piedmont region, the soils best suited for agriculture were the bottomlands. Farmers were attracted to them for their alluvial soils, as they were naturally well-drained and loamy thanks to a mixture of sand, clay, and silt (Rubin 1976; Helms 2000). However, there were shortcomings to bottomland production: The chance of late floods could destroy crops or prevent planting, while the timing of planting arrived later as the wetter soils warmed up later in the spring. Corn was commonly grown there due to its shorter growing season. These alluvial areas could vary in their quality. Clay-heavy areas were farther from the banks where the smallest particles fell out last in the flood (Helms 2000). These areas would be best put in perennial pasture such as canebrakes. These alluvial lands did not require long fallowing as the upland areas did, but an occasional rotation with a legume to supply nitrogen would be necessary to undertake continuous cultivation (Helms 2000).

Shifting agriculture was the dominant agricultural land use strategy on the non-alluvial upland fields of the southeastern Piedmont. Within a shifting agricultural system, burning secondary forests would deposit ash that improved fertility and reduces the acidity of the soil (Nelson 2007; Majewski and Tchakerian 2007). The paucity of phosphorous and other bases in the soil, rather than a labor-saving motivation by planters, influencing decisions to invest in a more extensive land use was the main motivation of this system (Helms 2000). Forest growth would be burned and cultivated for 3 to 6 years, abandoned, and fallowed for 15 to 20 years (Majewski and Tchakerian 2007). In many northern areas and in some regions of the South such as Shenandoah Valley, farmers would use soil-conserving forage crops on the arable land, promoting both the quality of crops and livestock (Stoll 2002). Yet this strategy could not be extended to elsewhere in Virginia and deeper into the piedmont region due to the shortcomings with the soil and climate (Rubin 1975). Ultimately, the reliance on commercial crops in conjunction with declining yields made it hard for all but the wealthiest farmers and planters to manage their debts, particularly during periods of low prices, driving a pattern of environmental degradation and migration (Stoll 2002; Nelson 2007; Ruffin and Kirby 2000).

Agricultural Land Use

Antebellum agricultural regions in the Piedmont region were divided into numerous classes characterized by the institution of slavery. The most politically, socially, and economically dominant, yet smallest, group within the rural landscape was the planter class, who owned both large estates and slave populations (Aiken 1998). Slaves, holding neither land nor possessions and having no autonomy in land use decisions, were subject to a tedious and cruel labor management system (Aiken 1998; David 1976). The majority of farmers in the southeast were yeomen farmers, a group that has been variably defined as farmers owning less than 300 acres (Aiken 1998) or farmers who owned zero to five slaves (Ford 1986). Often characterized as the "poor whites", 30 to 50 percent of the population in the South did not own any land in the period leading up to the civil war, and this group engaged with the few agricultural labor opportunities in the piedmont, were tenant farmers or crossroads merchants, or worked as overseers and slave catchers on plantations (Bolton 1993).

The plantation was the most influential unit of organization in the rural, cotton-producing South. Plantations are centrally administered agricultural estates that are organized to supply large external markets, and in the South, were labor- and capital-intensive agricultural systems that required close supervision and often tedious and cruel management of the workforce to ensure that laborers worked hard (Pryor 1982; Aiken 1998). Given the high availability of land and ownership of labor via slavery, planters could obtain land and labor in proportion, which was unlike farmers in the northern and western United States, where labor was scarce and farmers focused on capital improvements (Pryor 1982). Both small and large farms across the Piedmont were diversified, producing corn, cotton, and numerous other crops as well as a range of livestock animals, as the region was unable to import grains or other foodstuffs until much later in the 19th century (Gallman 1970).

The expansion of agriculture out of alluvial bottomlands to the uplands was associated with shifting agriculture and soil erosion. Across the Piedmont, ultisol soils were of such poor quality that fields would often be abandoned after a few years and another patch of forest would be cleared (Majewski and Tchakerian 2007). In Union County, old fields were described in the 1820s as having "became all-but-forgotten", and by the 1850s the top-soil was allegedly lost along with any remnants of the pre-settlement forests (Charles 2014; Ireland et al. 1939). Once uncultivated land was no longer available, farmers would fallow fields for 8 to 10 years (WPA 1941). Abandoned fields were highly vulnerable to erosion during rainfall events; rapid run-off would strip away the top-soil. As the soil load within local streams increased, flooding became a regular threat to bottom-land fields, often drowning row crops and laying down layers of sediment (Charles 2014). Erosion could lead to the development of gullies, large erosive channels, particularly on slopes where the water from fields drain (Charles 2014). Attempts to stabilize soil and re-direct water resources, such as hillside ditching and terracing, could accelerate the formation of gullies if they were not maintained (Ireland et al. 1939).

Beginning immediately after the Civil War, the postbellum period witnessed the reorganization of the plantation system toward sharecropping and tenant farming. The legal status of sharecropping was altered by state legislatures to make black freedmen laborers rather than tenants, therefore allowing the landlord to own the crop rather than the sharecropper (Aiken 1998). In an environment with little cash available, state legislatures also developed the crop-lien system in order to extend credit to sharecroppers and tenants (Ford 1984). Sharecroppers were laborers whose wages were a share of the crop, usually one half, and had no legal interest in the crop except for their claim for wages (Ford 1984; Fite 1984). They were paid by landlords, while tenants paid the landlord (Fite 1984). Both sharecroppers and tenants would obtain all necessary supplies from local merchants, including food, seed, and fertilizers, usually on credit, which would be paid upon bringing the cotton crop to the merchant, who was responsible for dividing the proceeds of the crop with the landlord (Aiken 1998). Sharecroppers also received the use of farming implements, housing, and livestock from the landlord, further decreasing sharecropper's share of the cotton profits (Aiken 1998).

Centrally managed plantations still existed throughout the south, but the spatial organization and management of the plantation changed as tenants and sharecroppers built or moved their homes near fields, rather than residing in one central location. Many plantation owners moved to the cities and became landlords, or they died and their children had no interest in operating a plantation (Fite 1984; Aiken 1998). Some plantations had managers to oversee work, while in other cases merchants or the landowner would visit sharecroppers, sometimes only once a year or even more rarely. Sharecroppers and tenants were given 20 to 40 acres, about the size that one family could work. Cotton production was maintained by an annual application of fertilizers and sharecroppers' contracts often demanded the maintenance of terraces and restricted workers from harvesting wood from forests (Taylor 1943). Despite gaining freedom, it was still difficult for many black farmers to obtain land or even move up from sharecropping to tenancy. White farmers were more likely than black farmers to be tenants (Raper 1936). Tenants, finding it difficult to move socially upward toward landownership, were nonetheless in danger of moving downward; when livestock died, many tenants could not afford to replace them and would transition downward to sharecropping or wage cotton labor (Raper 1936).

The widespread availability of cheap fertilizers, the development of terracing, and on-going soil erosion and deposition resulted in agricultural production moving primarily to broad, upland ridges. As long as terraces were maintained on these areas and fertilizers were applied annually, cotton cultivation continued. The on-going abandonment of marginal, sloped land and much of the bottomlands continued throughout the early 20th century (Coughlan et al. 2017). U.S. census data indicates that the maximum improved acreage following the Civil War peaked at 5 acres in 1890, while the acreage planted in cotton peaked in 1900. Cotton yields began to increase from 1900 to 1910, likely related to the widespread availability of fertilizers and the abandonment of heavily eroded and least productive lands (Coughlan et al. 2017).

Reforestation, mainly consisting of loblolly pine, began on abandoned land. Industrialization in urban areas began to draw many black laborers north for more lucrative job opportunities. The arrival of the boll weevil in 1921 also influenced the abandonment of agriculture in more marginal areas; managing the boll weevil's impact on the cotton crop was possible but often only occurred on well-managed and capitalized farms (Giesen 2011). Between 1919 and 1924, the harvested cropland in 59 counties across the South dropped 28%, and Alabama, Georgia, and South Carolina lost 75, 72, and 66% of their plantations, respectively (Aiken 1998).

Union County

Euro-American settlement of the county began in the mid-eighteenth century, and by 1800, the county was nearly entirely claimed. The South Carolina colonial government, growing increasingly concerned by both a growing black population and the threat of Native Americans, enticed white settlers by offering land grants of 50 acres per household member (Edgar 1998). The South Carolina's Commons House of Assembly provided money for tools, transportation, and food, and land taxes were waived for ten years (Edgar 1998). In 1755, the land granted increased to 150 acres for the head of household and 50 acres for each household member, including white servants and black slaves. While many early settlers practiced subsistence agriculture, others attempted to produce tobacco with little success due poor soils and an unfriendly climate (Ford 1986).

Union County was settled by a mix of ethnicities and religious identities. Arriving overland from Pennsylvania, Scotch-Irish Presbyterians were likely the first to settle around

1751 (Charles 2014). Later in the 19th century, Quaker and Baptist settlers began to move into Union County and start to construct meeting houses and churches around which their communities were oriented (Charles 2014). The Quakers settled in particularly large numbers in southern Union County, where our study area is located, often arriving from northern counties. Cotton production began in the Piedmont region following 1800 with the invention of the cotton gin, which had revolutionized planters' capacity to separate the cotton seed from lint (Olmstead and Rhode 2008; Aiken 1998). The number of slaves in Union County increased along with the production of cotton. Opposed to the rise of slave-based agricultural enterprises, most Quakers had either migrated northward or converted to Methodist or Baptist religions by 1810 (Charles 2014). Those Quakers who out-migrated would have likely sold their land, located on some of the most fertile land in the county, to their increasingly wealthy neighbors (Charles 2014).

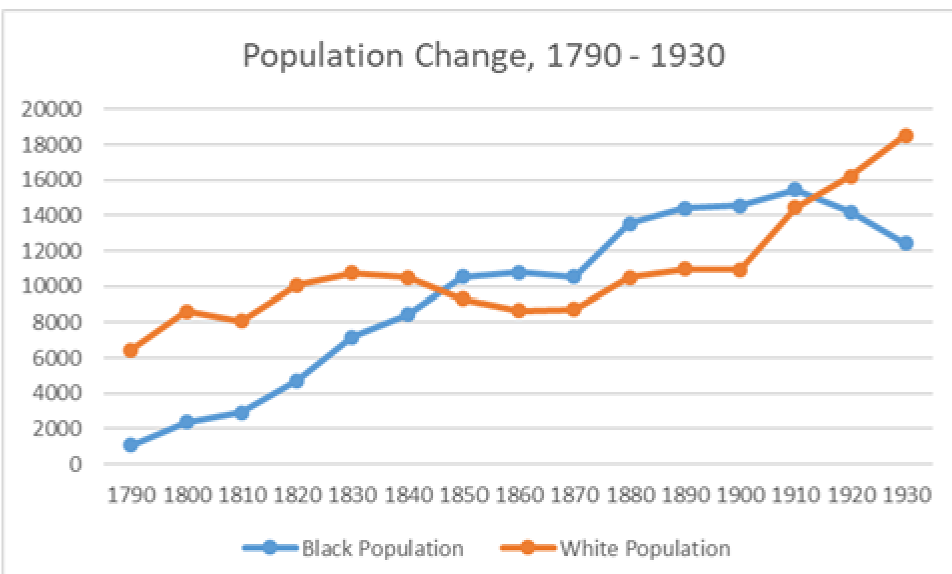


Figure 3-2: Population change in Union County

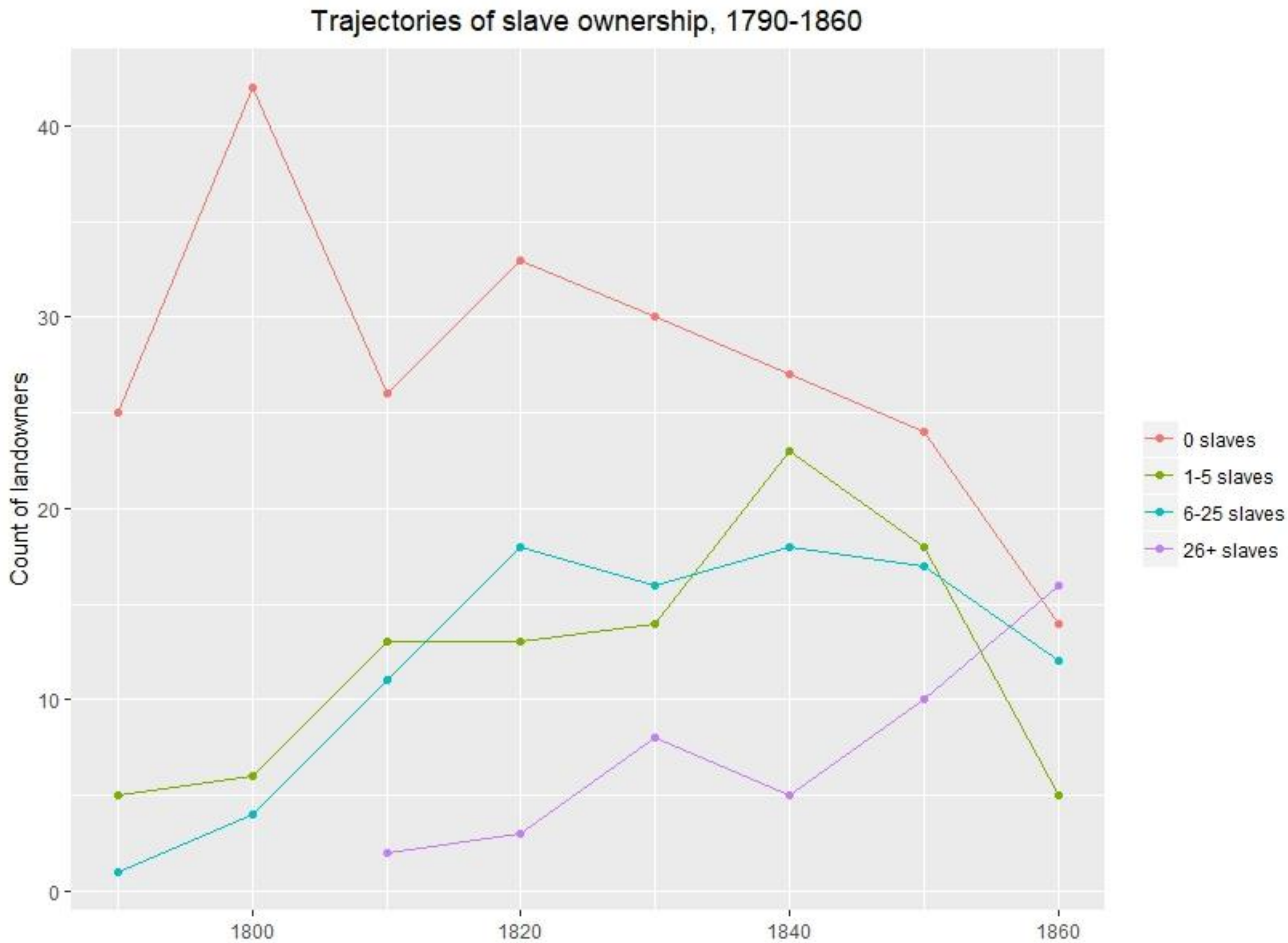


Figure 3-3: Change in the degree of slave ownership among landowners, 1790-1860.

From 1840 until the outbreak of the Civil War the number of large plantations increased as the number of yeomen farmers declined. Figure 3-3 is based on a sample of landowners that lived in either Goshen Hills or Cross Keys. It illustrates the sharp rise in plantations with slave populations of 26 or more slaves, along with the decline in the number of households that did not own slaves or owned fewer than 6. Infrastructural projects made shipping cotton easier throughout this period: The State Road was completed in the 1820s which connected western North Carolina to Columbia and Charleston (Charles 2014), while the first railroad line was built through the town of Union in 1859 (Ireland et al. 1939). Prior to the railroad most cotton shipping occurred by river as Union County was upriver of Charleston (Charles 2014).

As in the rest of Piedmont, soil erosion was a major problem for farmers in Union County. Heavy soil erosion from upland areas was noted as early as 1808, only six years after the first historical note of cotton production in the county (Charles 2014). Farmers attempted to prevent erosion by hillside ditching, which was not very effective and often led to the development of large gullies in their catchments (Charles 2014). The land market reflected the divergent quality of agricultural land as alluvial lands were being sold for five to seven times more than the upland areas (Hall 1949). By the 1850s the loss of topsoil was nearly complete in all of the county's upland regions (Charles 2014). The deposition of such soil led to a series of devastating floods throughout the latter 19th century, burying the fertile alluvial soils and destroyed grist mills and other forms of infrastructure (Hall 1940). Erosion was tied to waves of emigration from 1820 until after Civil War as households abandoned their exhausted lands (Charles 2014).

4) AN AGENT-BASED MODEL OF SHIFTING AGRICULTURE AND ENVIRONMENTAL CHANGE

The degree of labor intensification influences agricultural land use outcomes, including long-term yields and the length of land fallowing and associated change in land cover patterns. Labor intensification refers to the process of increasing the amount of labor applied to a unit of land for agricultural production. Labor intensive agricultural systems, such as small-scale smallholder households, are associated with high and persistent land productivity, while labor extensive agricultural systems, such as in industrial agricultural or long-fallow subsistence systems, are associated with high labor productivity (Netting 1993; Clarke 1966). Yet the link between the degree of labor intensification and long-term land and labor productivity outcomes are linked to the size and dynamic quality of landholdings and labor availability of the household over time (Boserup 1965; Netting 1993).

Frontier areas are often associated with rapid deforestation as farmers and planters engage in a cycle of land acquisition and subsequent land exhaustion for commodity production (Montgomery 2007). Agent-based models of land use and land cover change within frontier areas tend to focus on macro and regional-level explanations of deforestation, including population change, distance to market, market integration, and infrastructure (Parker et al. 2008). While these insights are important, there remains a need to understand how the actions and characteristics of households responding to macro-level processes influences farm-level environmental outcomes (VanWey et al. 2007). This paper presents an agent-based model to investigate how the degree of labor intensification by individual farming households interacts with their available land and labor to influence long-term changes in agricultural land use and land cover outcomes and patterns.

Households are a key unit of analysis in frontier regions, and understanding how their land use reflects both endogenous changes, such as household demography over time, and exogenous changes, such as changes in commodity markets, is essential to understand processes of land use and land cover change within a landscape (Van Wey 2007). Household size and demographic composition is correlated with and sensitive to farm area, cultivation techniques, and household requirements (Netting 1993). Labor availability, the size and quality of landholdings, and the access to other forms of capital strongly influences the opportunities and constraints of individual farmers (Netting 1993; Ellis 1998). Households' production strategies may reflect the consumptive and productive capacities of the household in the context of changing demography (Chayanov 1966; Walker 2003). Households' management strategies, particularly how they balance short-term yields with the long-term sustainability of resources, will have important implications for livelihood security and land use practices over time (Bennett 1982).

By drawing on theories of the relationship between household change and behavior and agricultural land use, I attempt to answer the following question: How does the degree of labor intensification interact with households' land and labor characteristics and demography to influence (1) the rate, magnitude, and pattern of forest cover and soil change, (2) the length of continuous cultivation and fallow periods for individual plots of land, and (3) long-term changes in land and labor productivity?

Agricultural Production in the Piedmont

Yeomen farms and plantations are the two main agricultural production types in the Southeastern Piedmont region prior to the Civil War. Most farms were yeomen producers, a group that has been variably defined as farmers owning less than 300 acres (Aiken 1998) or farmers who owned zero to five slaves (Ford 1986). Plantations were less common, but economically dominated the region. Plantation owners owned a large number of slaves and large quantities of land and had access to financial capital, particularly the ability to obtain funding for important infrastructure for cotton processing and transportation (Pryor 1982). Given the major differences in terms of capital ownership, yeomen farmers and plantation owners varied in terms of decision-making strategies and in the opportunities and constraints in the context of agricultural production.

Plantation owners focused on commodity over subsistence production. The main commodity in the region, cotton, was a labor-intensive crop particularly during harvesting season. The ownership of and ability to coerce large amounts of effort from a large labor force, the ownership of cotton processing technology, and the security of absorbing a bad production year allowed these producers to focus on cotton production. Additionally, plantation owners likely had much lower transaction costs associated with the transportation of cotton.

The ABM focuses only on yeomen households. Due to the differences between yeomen farms and plantations, the model would have become much more complex if both producers were present. Furthermore, land use agent-based models are primarily informed by theory on smallholder households (Magliocca et al. 2013). Modeling households that are sensitive to changes in demography, have limited access to financial capital, and engage in both subsistence and commodity production allow researchers to simplify assumptions about the opportunities and constraints facing household producers.

Yeomen Producers

In the southeast Piedmont, yeomen farmers are small-scale producers largely reliant on family labor or one to five slaves (Ford 1996). Yeomen farmers are characterized as practicing diversified, “safety-first” cultivation, which prioritizes food production to meet household subsistence requirements over commodity production. Yeomen farmers were common throughout the entire Piedmont, including interspersed with plantations in the lower Piedmont region. The upper Piedmont region, whose more rugged topography was not ideal for large-scale cultivation, was almost entirely characterized by yeomen producers. Yeomen farmers closer to plantations likely produced more cotton than the farmers in the upper Piedmont region. As railroads and access to credit spread to more mountainous and rugged areas, transactions costs associated with the production and sale of cotton fell enough that farmers shifted their focus from corn to cotton (Ford 1986).

The ABM presented uses the household life cycle model to simulate yeomen land use decisions in relation to demographic change. Based on the Chayanovian peasant economy model and the developmental cycle of the household, household life cycle model posits that households respond to outside processes, such as changes in commodity or capital markets, differentially depending on the demographic composition of the household (Chayanov 1966; Goode 1958; Walker 2003; Walker and Homma 1996). The changing demographic composition of the household as members give birth, age, and die influence the consumption requirements and production capacity of the household (Chayanov 1966; Hammel 2005). The model assumes that households do not have access to hired labor or capital and focuses production to meet consumption needs, rather than to accumulate capital (Walker 2003; Walker and Homma 1996).

Model Components

Agents

Each agent represents a farming household. Households do not have equal access to or ownership of land and labor. They vary in terms of household size. The quality of landholdings that farmers have access to varies, both in terms of soil fertility and topographic position. There are no interactions between farmers. Table 4.1 describes the attributes of each farmer, each of which is explored in more detail in the remainder of the chapter:

Table 4-1: Agent attribute descriptions

Attribute	**Description**
Household Size	Total household size (consisting of free adults and/or slaves) is randomly allocated. The distribution is based on household size and the mix of ages and gender from demographic data from Union County, South Carolina, 1790 - 1860.
Labor Availability	Labor availability calculates the sum labor capacity of all members of the households.
Household Demography	The age of each household member is tracked. As children age, they contribute more to agricultural labor. Life events such as marriage, childbirth, death, departure of adult children are randomly simulated.
Subsistence Requirements	Each household member requires a certain amount of food per year, expressed in corn bushels, depending on their age. The requirements for each member is summed for the entire household.
Objective Function	Households have one of two objective functions that shape labor allocation and land use decisions.
Plots	Each farm is made up of plots that vary in terms of land cover, land use, soil fertility, and topographic position.

Spatial Units

A relative topographic index and landform analyses were conducted on 10-meter digital elevation models (DEMs) of Cross Keys and Goshen Hill townships to characterize realistic farm-level topographic variability. Based on algorithms developed by Weiss (2000) and was implemented using ArcGIS software, the result was a polygon layer where each polygon represented a particular landform, including broad upland areas, narrow ridges, slopes, and bottomlands. There were 9 total landform classes, which were simplified to 3 topographic positions: flat, upland areas, sloped areas, and broad alluvial bottomland areas. 100 acre farms were formed by placing a square 100 acre grid over the landform layer and extracting the proportion of each landform for each 100 acre grid. At the start of the model, each farmer is allocated a random grid unit from this collection until they have received the necessary number of acres. For instance, a farmer with a 500 acre farm will receive 5 100 acre grids for a total of 500 acres.

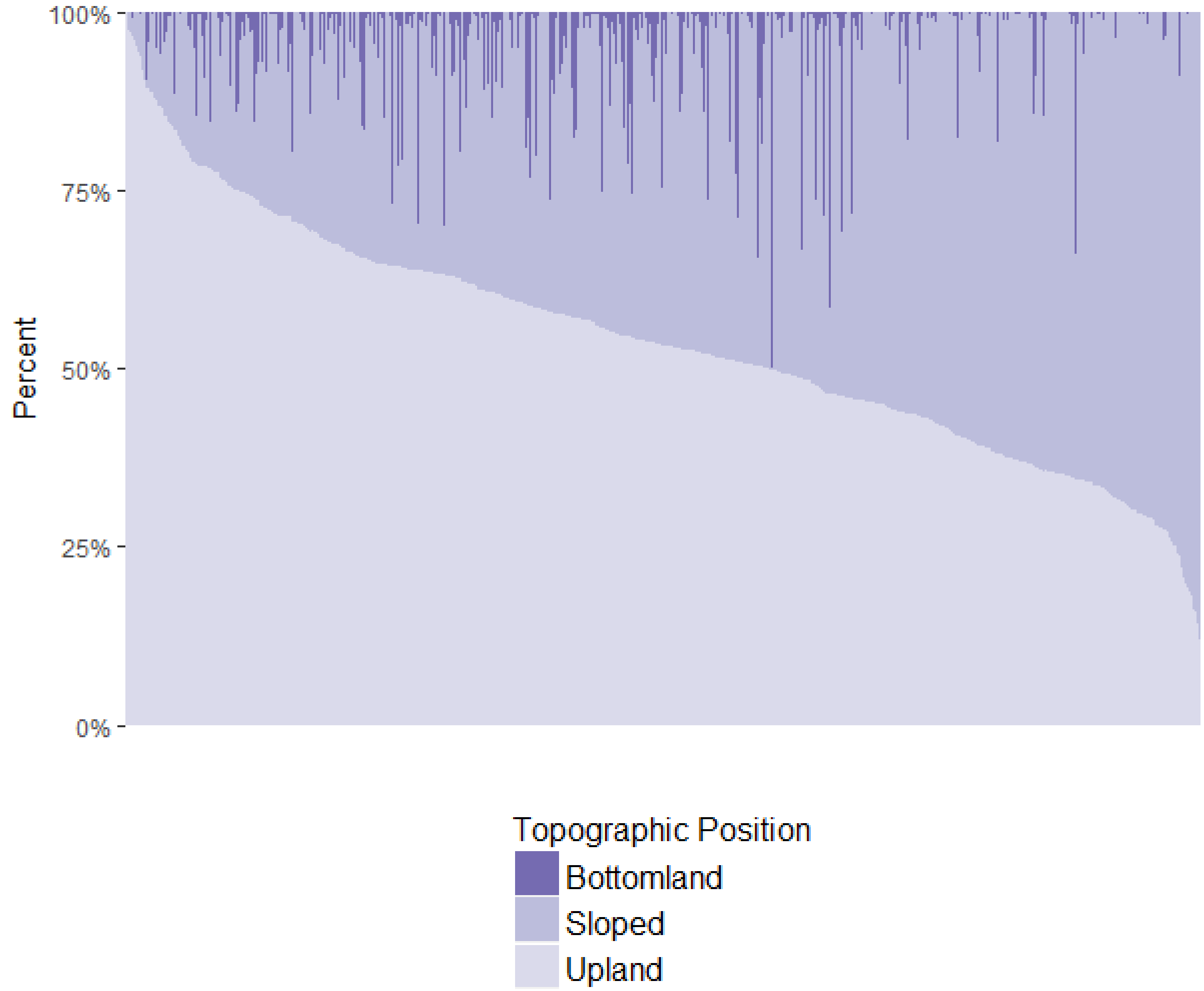


Figure 4-1: Topographic position variability in Union County. Each vertical slice of the plot represents the percentage of the three topographic positions within a 100 acre plot. All of the 100 acre plots developed for Goshen Hills and Cross Keys are represented. Therefore the entire rectangular plot graphically represents the percentage of each topographic position within the two township. Of note: the rarity and low percentage of bottomlands for many 100 acre plots.

Each topographic position influences yields and the rate of soil loss and regeneration. Sloped areas have the lowest starting level of soil quality, the quickest rate of soil loss, and regenerate soil slowly. Upland and bottomland soils start with the same level of soil quality, but the degradation and regeneration rates differ between the two types. Bottomlands lose soil much more slowly and regenerate much faster. Due to the higher moisture content of bottomland soils, cotton yields are reduced while corn yields are not. Upland areas characteristic dryness does not differentially affect corn and cotton yields.

Land cover change is simulated in the model based on land use decisions. All grids are implemented as have a primary, mixed hardwoods forest at the beginning of each model run. Land used for agriculture is classified as tilled land. If land falls out of cultivation, it is classified into a category based on the years since it was last cultivated.

Table 4-2: Land cover change rates

Land Cover	**Model years since cultivation**
Tilled Land	N/A
Pasture	1-4
Early successional	5-9
Young Pine	10-14
Adult Pine	15+

Demography

Households grow and diminish in size over time. Each household begins the model with only two adults and the household life cycle is modeled by simulating changing demography over time. Until model year 20 there is a 20% chance of a newborn being added to the agent household. Once individuals reach age 17 each year there is a 25% chance they leave the household. At model 40, the household is automatically reset back to two adults and there is a

20% of a newborn being added to the household until model year 60. At no point in the model can the total number of adults drop below two.

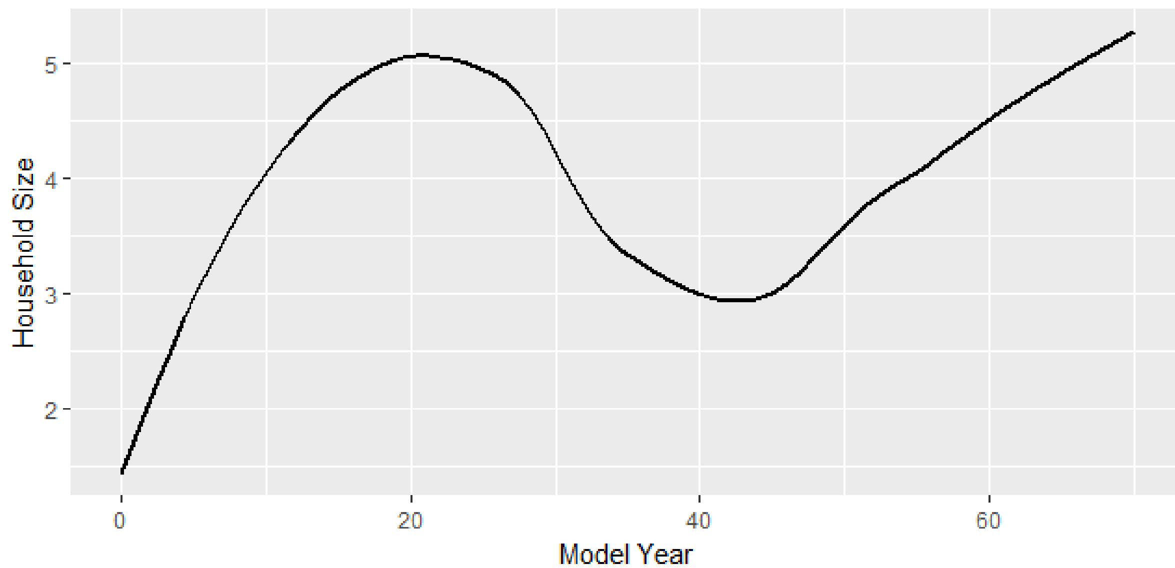


Figure 4-2: Average household size across all model years

Households are assumed to be nuclear households and autarkic, meaning without any connections with wider monetized regional networks as in Chayanovian theory (Chayanov 1966). These assumptions are designed to simplify model procedures, but do not likely reflect actual household dynamics (Hammel 2005). Household members are assigned consumptive and productive characteristics based on their age. Consumption requirements represent a minimum number of corn bushels required for subsistence. Age-specific consumption requirements and productive potential are acquired from corn- and cotton-residual research by Ransom and Sutch (1977; 2001). Piedmont-specific consumption requirements are similar to updated age-based subsistence requirements based on Chayanovian theory (Hammel 2005). The productive characteristic reflects how much labor the member contributes to agricultural land use.

Table 4-3: Age-based consumption requirements and labor contribution of household members

Age range	Consumption requirements per year (corn bushels)	Labor productivity
0-4	5	0
5-8	10	0
9-14	15	.5
15+	20	1

Demographic trends in households were parameterized based on Union County demographic census data from 1810 – 1860. Demographic data collected at the household level includes the age range and overall size of each household, which represents the sum number of free white individuals. The overall distribution of household sizes was assumed to represent the range of possible family sizes at different time periods within a households' demographic development. The probabilities described above were developed to create demographic profiles that reflect historical trends in household demography.

Yeomen households could own slaves. The typical definition of a yeomen farmer for the southeast piedmont defines it as a household that owns 0 to 5 slaves (Ford 1986). Any more would constitute a plantation. As for most slave-owning households, the nature of slave-ownership among small-scale producers is highly complex and variable. Slaves may or may not have had spouses, and may or may not have been able to have and raise offspring (Kaye 2009). Their children, or any adult slave, could be sold at any time (Kaye 2009. This project assumes that modeling demography for slave families owned by yeomen households is both beyond the scope of the model and unfeasible. To understand how slaves may have augmented the land use activities of yeomen households, model scenarios will be conducted that initialize households with additional adult laborers.

Land Use Decision-making

To pick a land use strategy for a given year, agents must decide how much labor to allocate toward corn and cotton, how much labor to invest per acre of production, and evaluate the capacity of each option to meet household subsistence requirements. These decisions are made based on the expected prices for commodities, the objective function of the farmer, and the expected yields of a potential strategy to meet household requirements. Land use strategy refers to the number of 1 acre grids that will be cultivated, the type of crop (corn or cotton) that will be cultivated on the grid, and the amount of labor that will be allocated toward cultivating the grid. The agent will ultimately pick between one of two potential land use strategies.

The first step is to decide how much labor to allocate toward to both cotton and corn. Agents will only increase the cultivation of cotton at the expense of corn if they believe the returns of cotton will equal or surpass the cost of purchasing corn on the market. Agents estimate the farm-gate price of cotton, or how much they expect to receive per acre of cotton sold at the end of the growing season. These estimates are influenced by both expected transaction costs and the price of the commodity at regional markets. They predict how much corn they would be able to purchase in the local market with the cotton income and evaluate how that amount compares to the amount of corn they could have grown per acre (if they substituted cotton for corn). If the ratio is very high, for example they could buy a much higher level of corn than they could have grown, they will increase the amount of labor allocated toward cotton. Farmers are assumed to be risk averse to commodity production and will only increase the allocation if the ratio is much higher than 1.

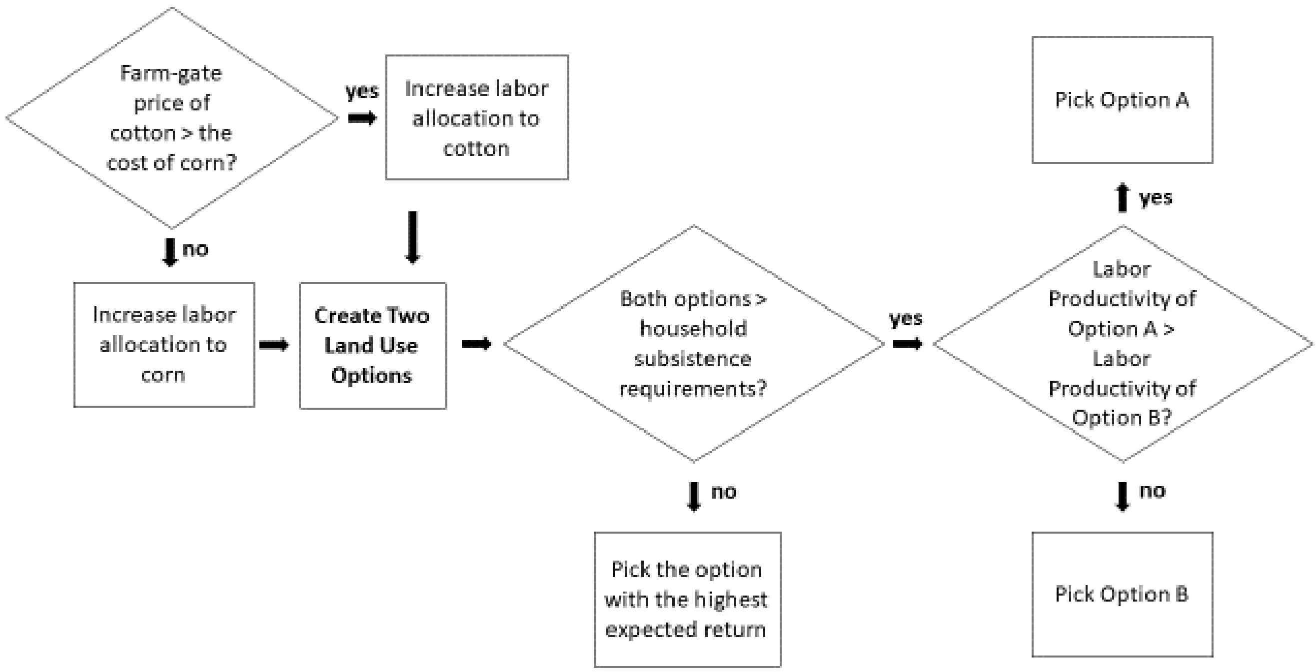


Figure 4-3. Decision tree for labor extensive farmers making land use decisions

Each farmer forms two potential land use strategies. The first strategy applies the maximum amount of labor to each one acre plot cultivated, while the second applies the minimum amount of labor to each one acre plot cultivated. Therefore, the latter option will tend to increase the area cultivated, while the former option will limit the amount of land cultivated. There are trade-offs between the two options: maximizing the amount of labor applied to each plot will decrease soil loss as the overall land under cultivation decreases, but the overall level of production will be lower than minimizing the amount of labor per plot. This is based on a review of antebellum-era agriculture in the Piedmont region: intensive methods, whether they involved the application of manure and other compost materials, ditching, heavy weeding, or rotations with grasses, did not boost annual or year-over-year levels of production per laborer higher than more extensive land uses as occurred in more northern or alluvial regions (Rubin 1975).

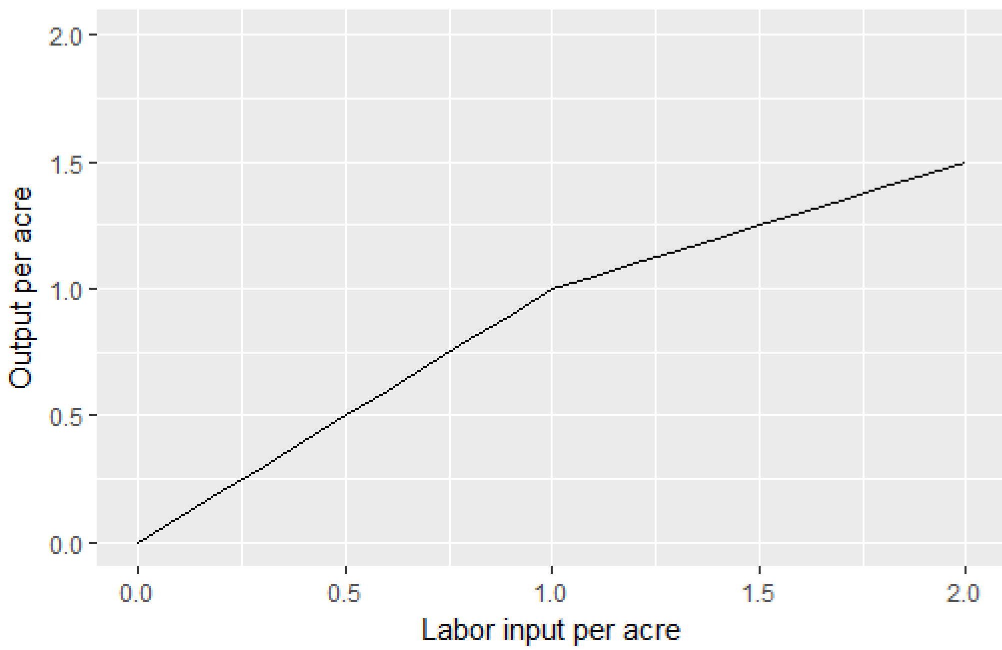


Figure 4-4: The model's simplified relationship between labor input and output per acre. Output per acre drops by 50% for a one unit increase in labor unit per acre when one labor unit has already been invested.

Crop and Labor Parameters

Crop-specific yields are parameterized based on joined Union County agricultural and demographic census data. By joining demographic and agricultural census data collected at the household-level for the 1850 and 1860 U.S. censuses, labor productivity estimates were generated. The interquartile range was assembled for both labor productivity for corn (bushels per laborer) and cotton (pounds per laborer) and all values outside this range were thrown out. The interquartile range represents all values between the 25^{th} and 75^{th} quartiles in the data. The resulting estimates for labor productivity are assumed to represent possible yields per unit labor given particular arrangements of soil fertility, labor intensification, topographic position, crop type, and randomness. The yield for any given plot is determined by:

$$Y = LI * SF * CT * TP * r ,$$

where Y is yield, LI represents the degree of intensification, SF represents the quality of soil for that plot, CT is a coefficient to adjust the yield to the correct crop unit, TP represents the topographic position of the plot, and r is a small, random generated factor. All possible yields fall into the bounds derived from the historic census data.

Historic agricultural journals, farmers' almanacs, journals, and contemporary sources have been used to parameterize how soil fertility and labor influence yields. This includes *Affleck's Southern Rural Almanac and plantation and garden calendar* (Affleck 1851), *Piedmont Farmer: David Golightly Harris 1855-1870* (Harris and Racine 1997), *The Southern Cultivator* (Jones and Jones, 1843), *History of Agriculture in the Southern United States, Volume I & Volume II* (Gray 1941), and *Nature's Management: Writings on Landscape and Reform, 1822-1859* (Ruffin and Kirby 2000).

Objective functions

Each agent is assigned one of two objective functions: land productivity maximizer or labor productivity maximizer. Each strategy helps the agent to decide between two potential agricultural land use strategies. Land productivity maximizers will pick the option that maximizes the output per acre cultivated. This option broadly represents a more labor-intensive strategy that limits the amount of soil loss per yield by investing more labor per acre. Labor productivity maximizers pick the option with the highest return per labor unit applied. In general, this will represent the more extensive land use.

The ability to meet livelihood requirements also influences the objective function. If none of the agent's options are expected to meet their minimum livelihood requirements, they will pick the option that maximizes their returns. If only one option meets or exceeds the minimum livelihood requirements, they will pick that option. Otherwise they will use their pre-determined objective function to pick between the two options. Agents do not switch between the two objective functions.

In general, each of the potential land use options will reflect the two objective functions assigned to the farmers. The “labor intensive” strategy that applies the maximum amount of labor to each plot will often be the strategy of the per acre productivity maximizer, while the “land intensive” strategy will often be the strategy of the per labor unit productivity maximizer. The reason both options are available to agents are for conditions where the farmers’ standard objective function does not meet household requirements, due to soil fertility decline and/or household demography. In those cases, farmers may switch to a different land use option.

Simulating Agricultural Land Use and Environmental Change

To illustrate model processes, the following section tracks the land use activities, demographic changes, and environmental trajectories of one farming household (agent 49). Agent 49 has 100 acres and begins the simulation with a household size of two, both adults. The model simulates 70 years. Figure 4-5 illustrates the trends in agricultural production, household size and labor availability, land cover, and overall soil fertility throughout the modelled time frame:

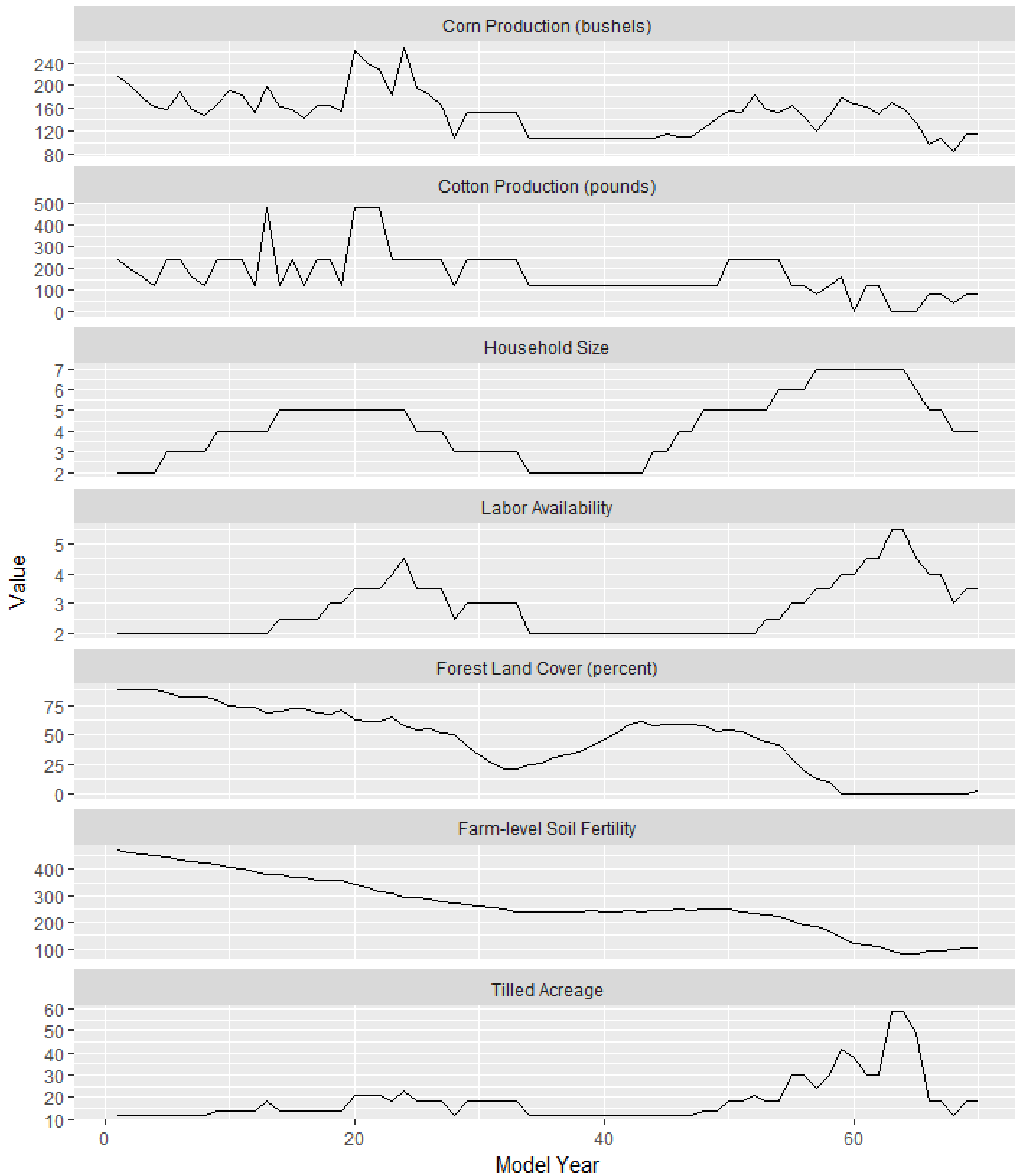


Figure 4-5: Household, agricultural, and environmental outputs over time

Of the above plots, only the household size and labor availability charts are "pre-determined" via model code. Agricultural land use decisions, production output, and resulting environmental changes emerge from agent responses to feedbacks originating from previous land use decisions in the context of unique land, labor, and decision-making characteristics. Figure 4-6 visualizes the topographic variability of the agent's 100 acre farm.

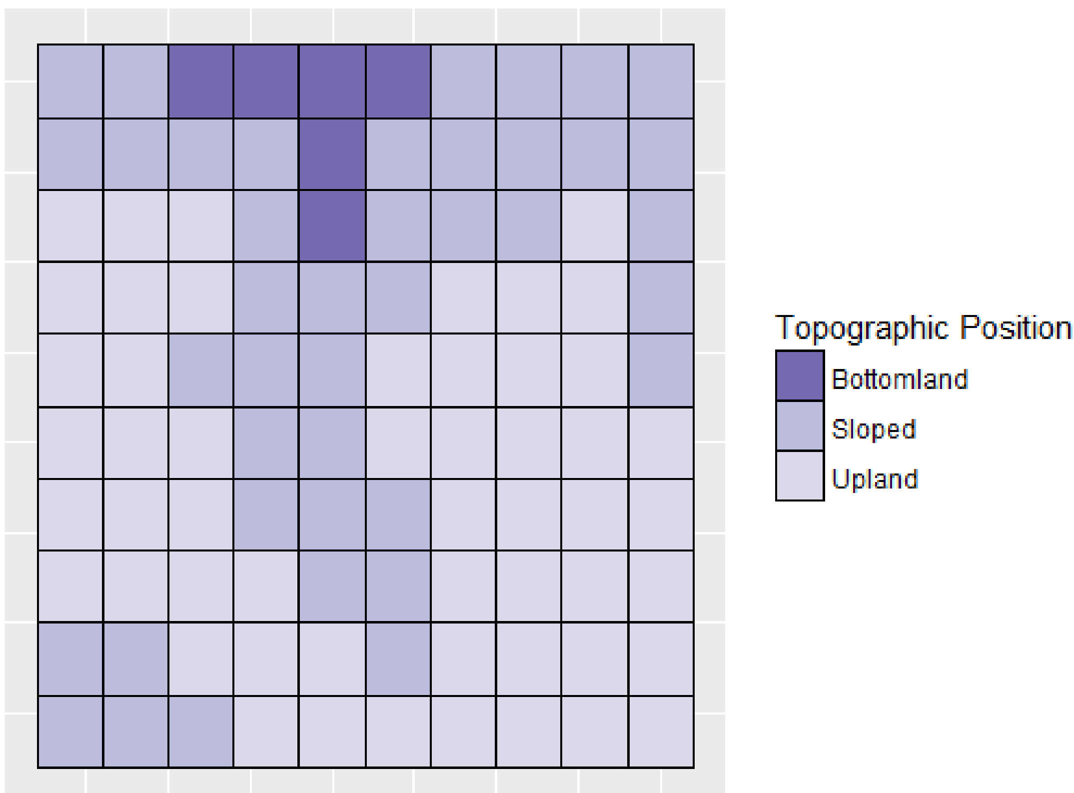
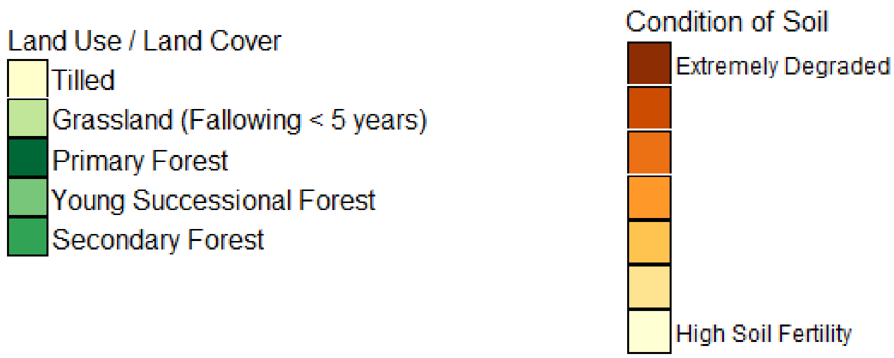
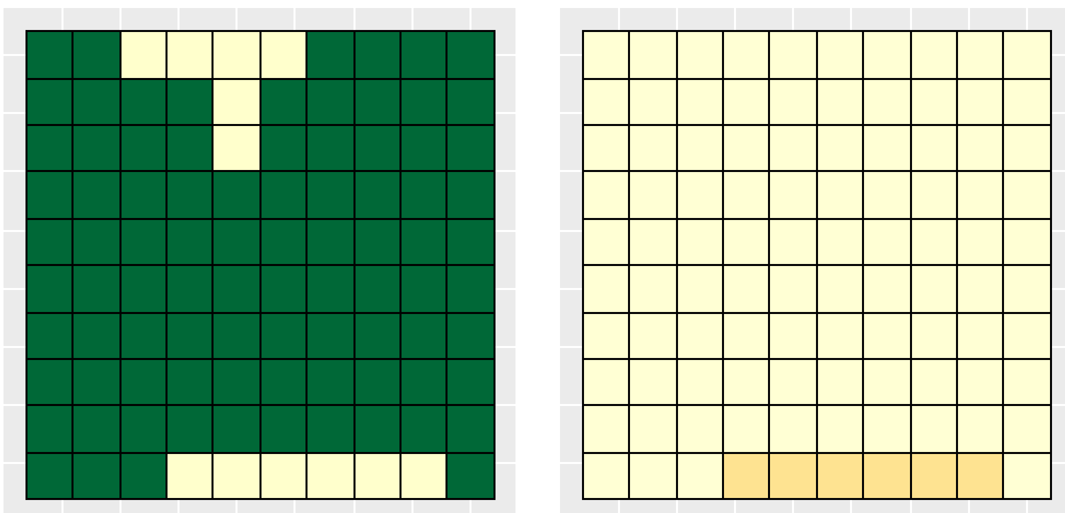


Figure 4-6: A visual representation of topography on agent 49's 100 acre farm

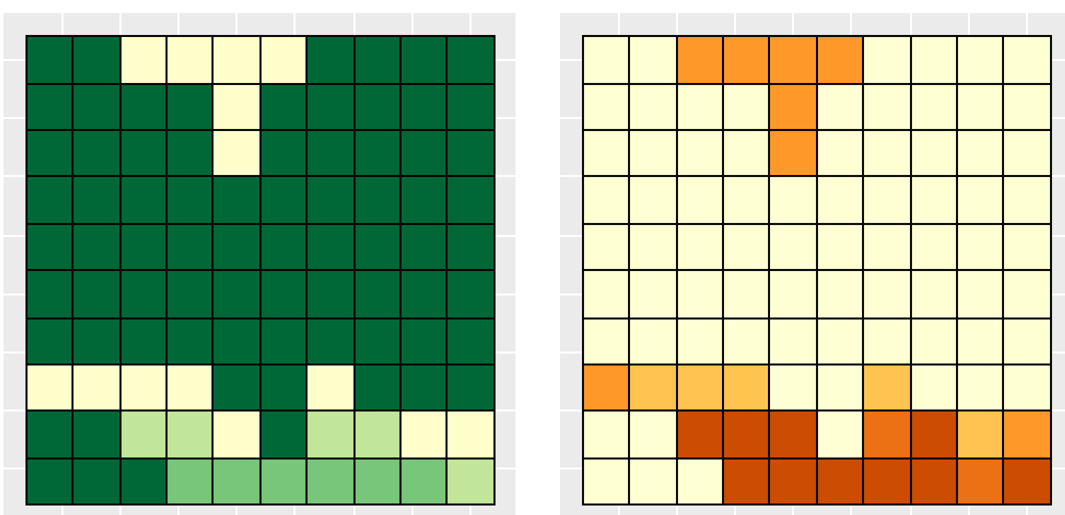
Land use decisions influence environmental changes that farmers must respond to in subsequent years. Land use legacies, or the influence of past land use actions, influence the nature and pattern of soil quality and land cover across the farm. Farmers respond to these legacies by managing fallow periods and the deforestation of new land for cultivation. The following section visualizes land use/land cover and soil quality change for an agent at multiple time periods to illustrate the temporal processes land use and environmental change within the model:

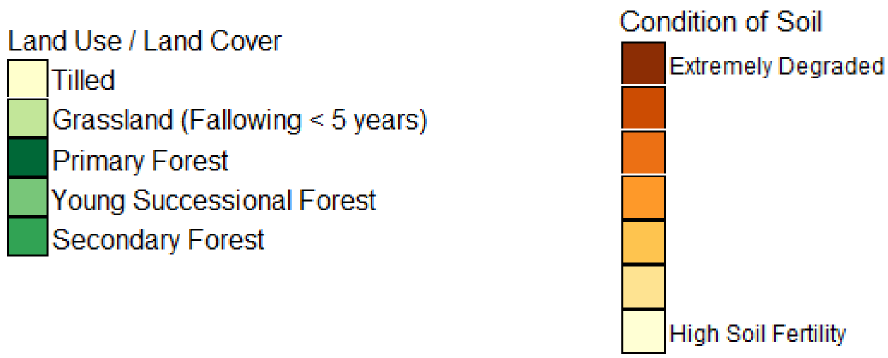


Year 1

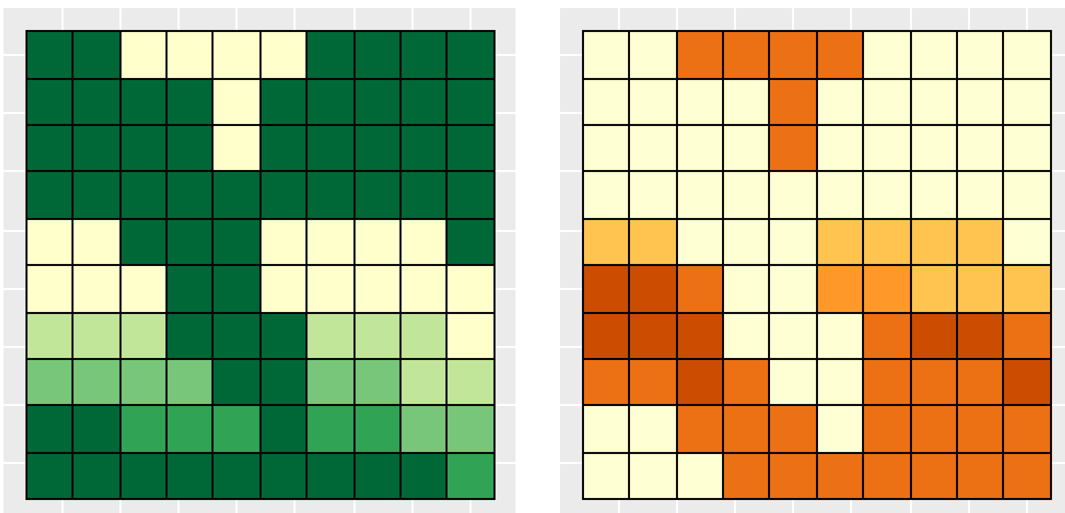


Year 10

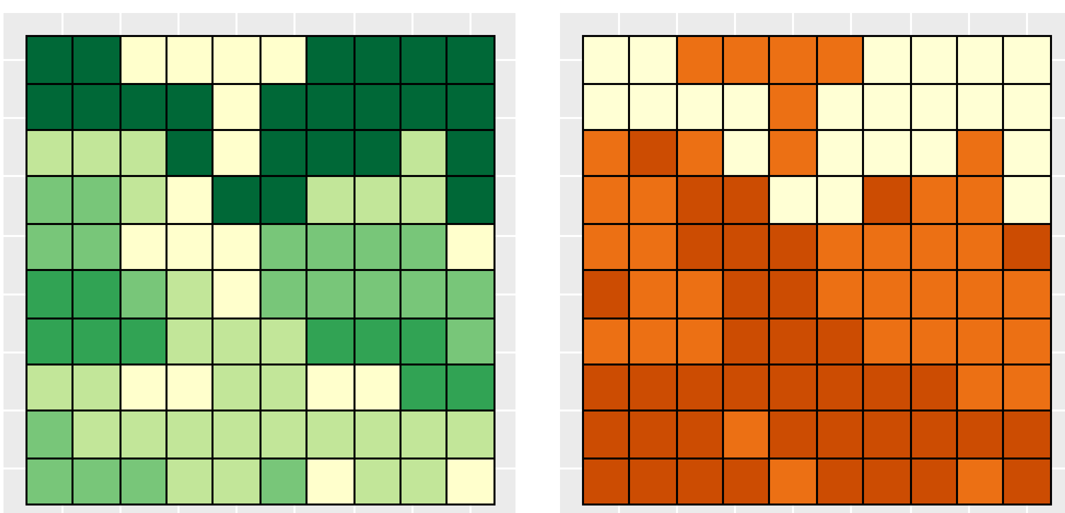


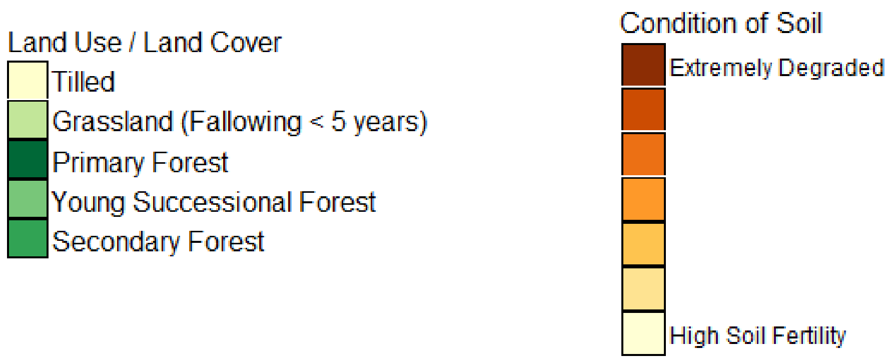


Year 20

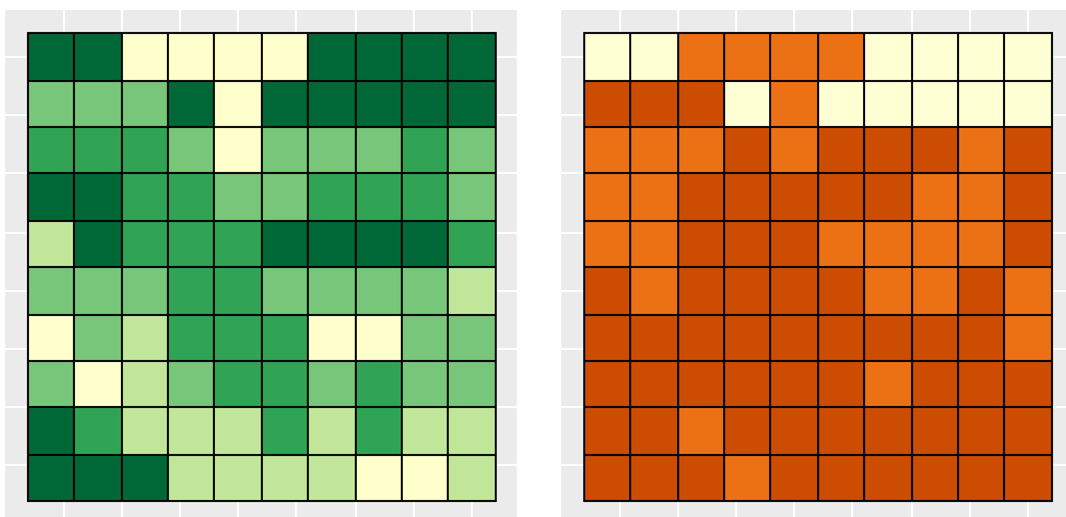


Year 30

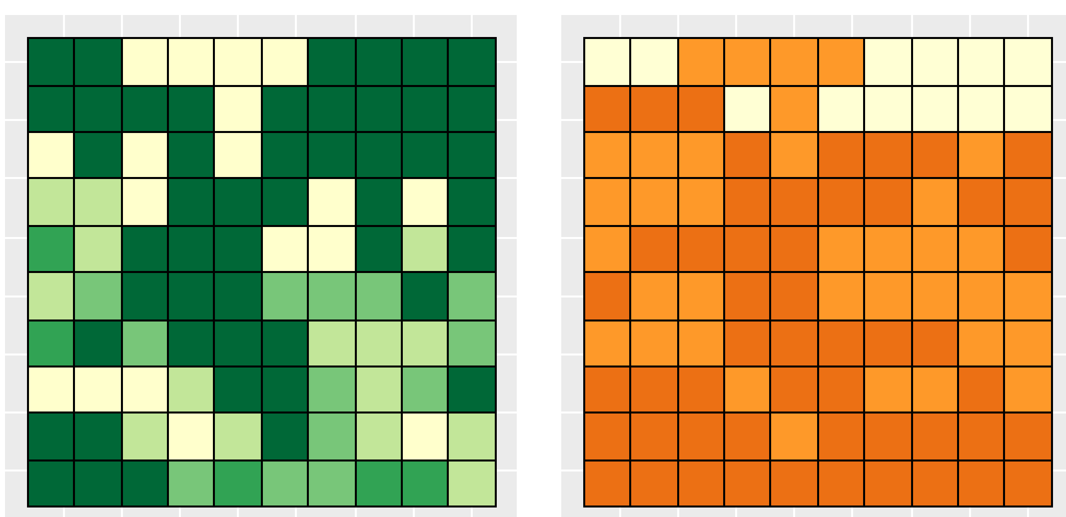


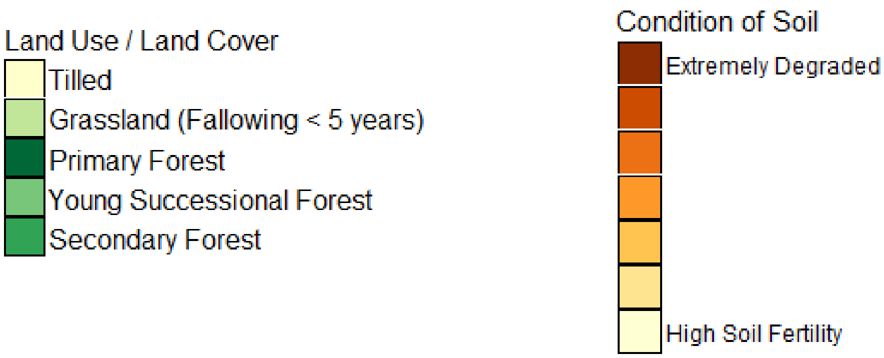


Year 40

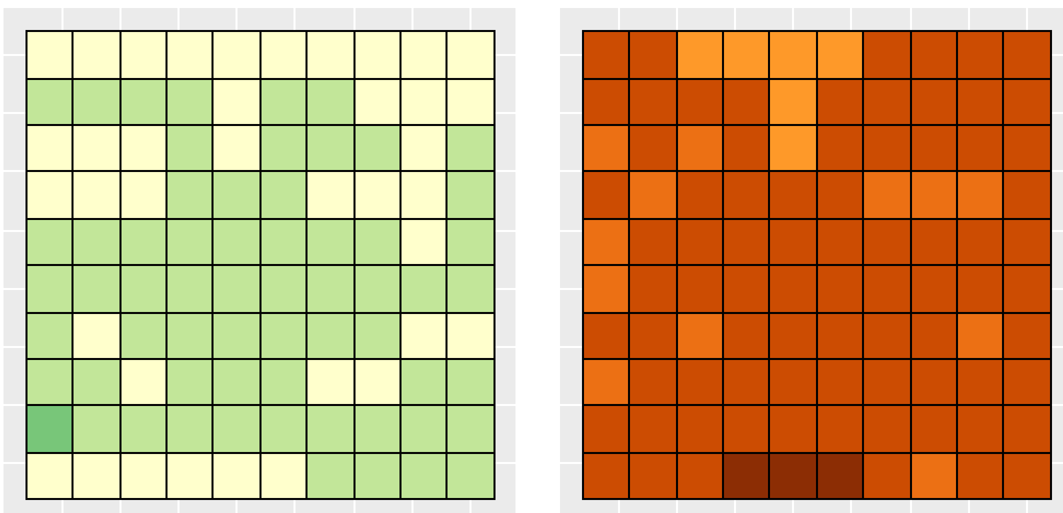


Year 50





Year 60



Year 70

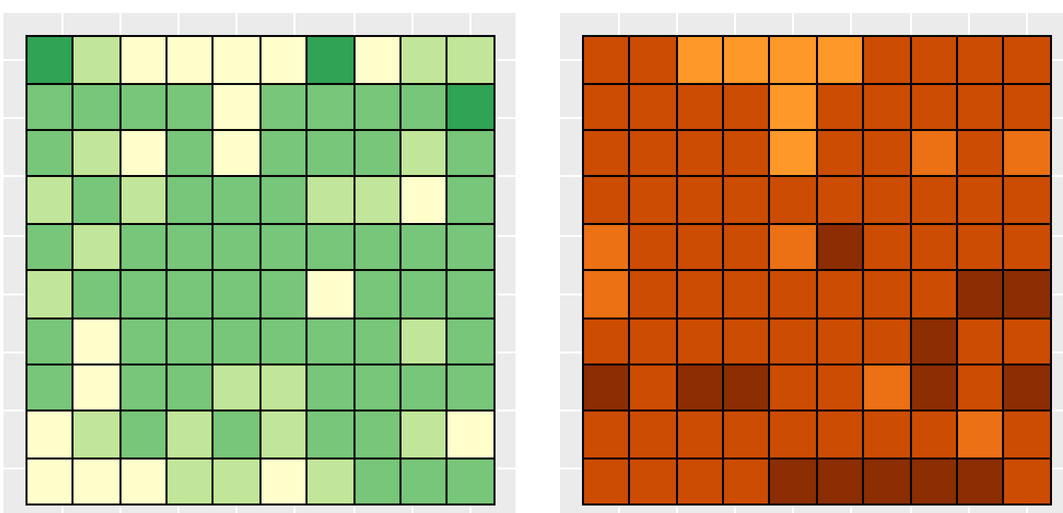


Figure 4-7: Example of the simulation of land use, land cover and soil fertility change

In a shifting agricultural system, 100 acres provides severe land constraints for a farmer. The farmer initially relied on cultivating the bottomlands and practiced shifting agriculture on the upland regions. As soil fertility declined, cultivation expanded into the more marginal sloped topographic positions. It is very likely that the extremely degraded nature of the farm at model year 60 and 70 would necessitate expansion or farm abandonment; the model does not consider the ability of production to meet income requirements and therefore cannot cut off agricultural production at low levels of soil quality. The proceeding chapter investigates how model runs consisting of 500 agents under different land, labor, and decision-making objective functions influence the rate and timing of changes in fallow management, agricultural productivity, and environmental change.

5) MODEL OUTCOMES AND RESULTS

The factors that influence the relationship between agricultural land use and the nature and rate of environmental changes, such as deforestation and soil fertility loss, extend from the household to global markets (Burgi et al. 2004). The availability of land along a frontier, institutions such as slavery, advancing railroads, and the international demand for cotton all shaped the opportunities and constraints facing farmers. Agent-based modeling presents an opportunity to investigate how hypotheses relating macro-structure to individual agency, motivation, and opportunity shape how land use and land cover change unfolds locally (Overmars et al. 2007). This chapter investigates how two farmer strategies, labor intensification or extensification, interact with land and labor constraints and demographic change to differentially influence the rate, magnitude and pattern of fallow management, agricultural productivity, and forest cover and soil change. Each model run consists of 500 agents, each with identical acreage totals, starting labor availability, and objective functions. However, topographic conditions of each farm will vary. Multiple model runs are conducted, with each potential combination of acreage, objective function, and starting labor availability represented.

Model Outcomes

How does the degree of labor intensification influence the annual rate of forest cover and soil fertility change? The following data models labor intensive and labor extensive households with no slave labor. Each farm is 300 acres. Given the differences in land use decision-making between labor intensive and labor extensive farmers, we'd expect differences in rates of forest and soil change. Extensive farmers should have cultivated more acres, which must result in more soil loss and likely will lead to a higher rate of deforestation.

Figure 5-1: Mean annual rate of deforestation (left) and mean acreage of forest land cover (right)

Figure 5-2: Mean annual rate of soil change (left) and mean percent of soil fertility (right)

Labor intensive households experience a much more stable experience of environmental change. Besides the expected jump at the beginning of the model run that represents initial land clearance, deforestation rates hover around 1 to 1.25 acres deforested per year. Labor extensive farmers experience a mean level of deforestation that is roughly double that of the other group, which much more annual variability. Altogether, labor intensive farmers maintain more forest land cover and soil fertility at the farm-level than labor extensive farmers. Changes in household demography primarily influence the rate of change by mediating the amount of available household labor. Decreasing household sizes related to the departure of adults from the household and the lack of new offspring from model year 30 to 40 are associated with decreasing rates of soil loss, positive gains in soil fertility from model year 40 to 50, and reforestation throughout this period.

Table 5-1: Average rates of deforestation and soil fertility for farmers with 300 acres

Model Year	Labor Intensive Farmers		Labor Extensive Farmers	
Range	Deforestation (acres)	Soil Unit Rate	Deforestation (acres)	Soil Unit Rate
1-2	2	-2.474	4	-5.324
3-19	0.797	-2.793	1.962	-6.827
20-49	0.878	-1.242	1.950	-2.622
50-70	1.121	-0.756	2.045	-1.604

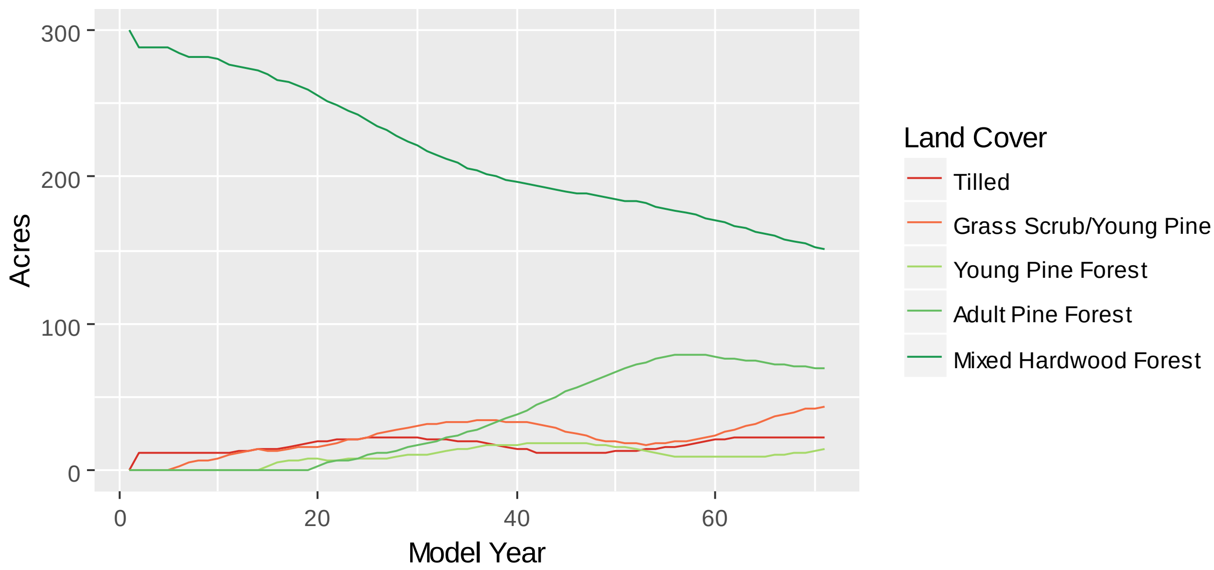


Figure 5-3: Mean land cover changes for labor intensive agents

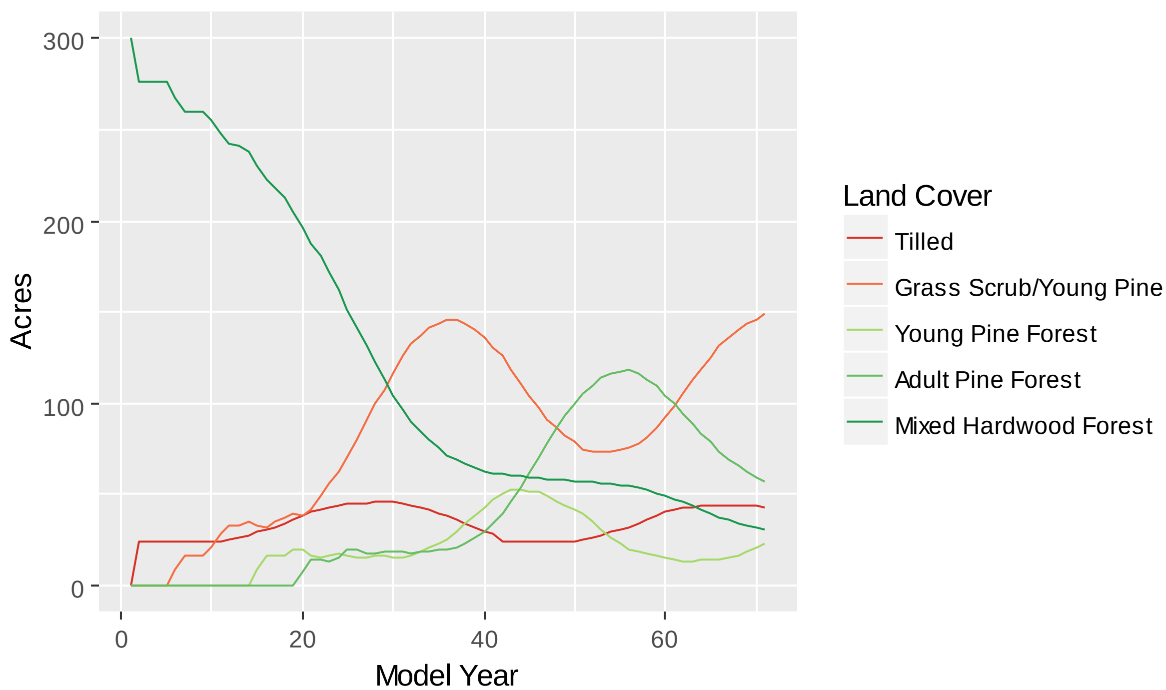


Figure 5-4: Mean land cover changes for labor extensive agents

Labor intensive farmers maintain, on average, 50% of the original forest over a 70 year period. However, labor extensive farmers maintain less than 50 acres, or around 17%, of original forest cover. This is likely located on marginal land ill-suited to cultivation. The above graphs clearly demonstrate major differences in recently fallowed and pine land covers between the two types of farmers. It is possible that fallow regimes vary due to the higher spatial extent of cultivation by extensive farmers.

How does the degree of labor intensification influence fallow management? The decision to clear new land or cultivate on old fields is inherently related to land use legacies. Previous cultivation decisions shape the distribution of land cover types and degree of soil fertility loss across the farm. If plots cultivated in the prior year do not have adequate soil fertility to support a crop or the labor supply of the household increased, then farmers will convert other land cover types. As the quality of high quality land decreases, farmers may be forced to shorten fallow periods. The shorter a fallow period is shortened, the less soil fertility recovery will occur on the plot. This section investigates how fallow periods vary across topographic positions and between labor intensive and extensive farmers. The following figures chart both the average length of continuous cultivation and fallow periods. Values of zero represent years in which either no plots were moved from cultivation to fallow or from fallowing to cultivation.

Figure 5-5: Mean uplands cultivation length (left) and fallow length (right)

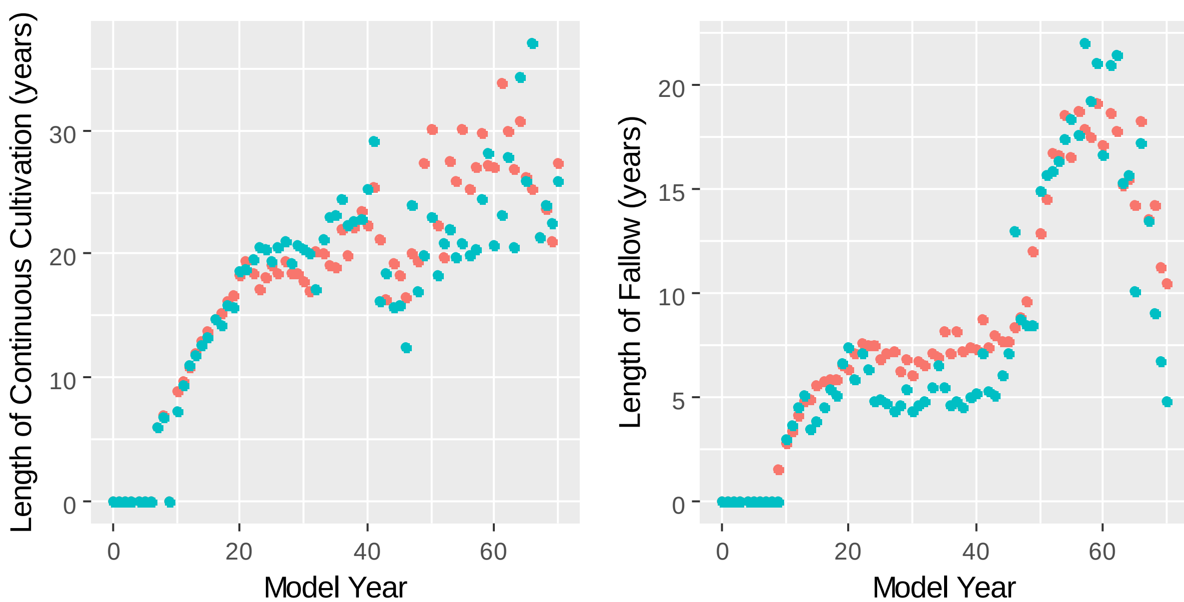


Figure 5-6: Mean bottomlands cultivation length (left) and fallow length (right)

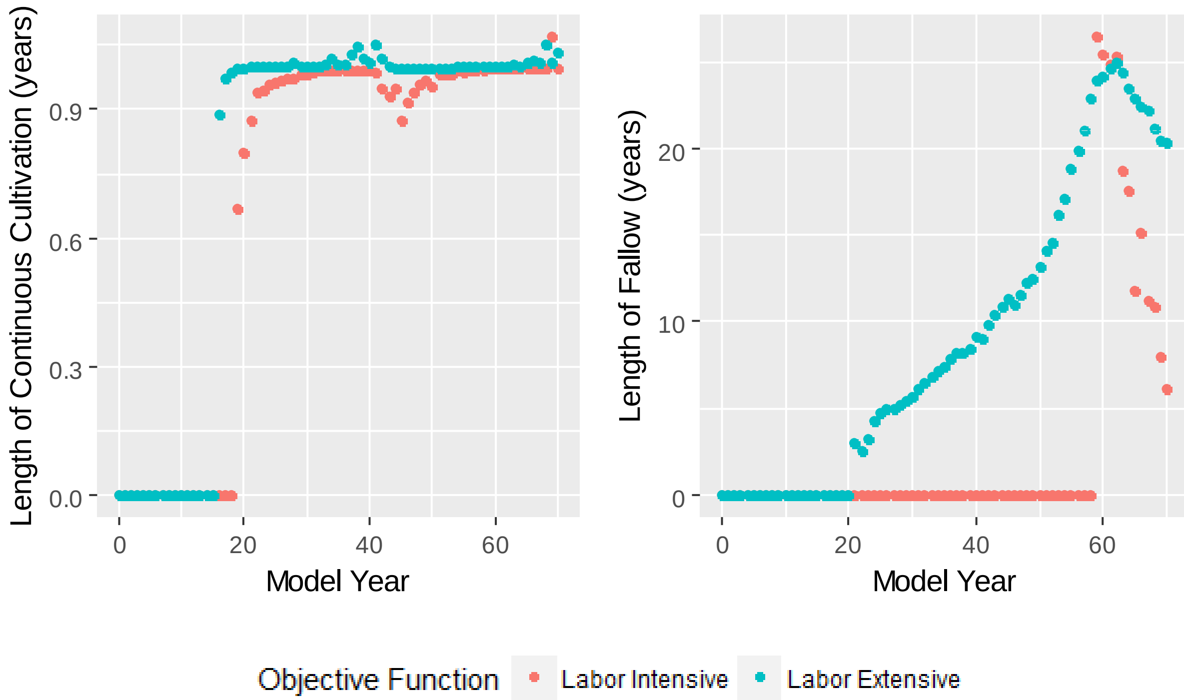


Figure 5-7: Mean steep slope cultivation length (left) and fallow length (right)

There are dramatic differences between labor intensive and extensive agents on the upland topographic positions. The length of continuous cultivation declines rapidly for labor extensive farmers from model years 10 to 30. By model year 40 labor extensive farmers are cultivating a plot for around one year before moving on, which represents a significant loss of soil. Labor intensive farmers maintain longer cultivation and fallow periods. Bottomland cultivation and fallowing is similar for both groups; bottomlands are cultivated for very long periods and have relatively short fallow periods. Sloped areas, the most marginal land, are cultivated for one year before being fallowed; once cultivated by labor intensive farmers they are often left fallowed, while labor extensive farmers are more likely to bring them back into cultivation.

Based on fallow and cultivation lengths and the percent of soil fertility loss, it appears that labor extensive agents face a highly degraded environment more quickly than labor intensive agents.

How does the degree of labor intensification influence long-term production, land, and labor productivity? If farmers with different objective functions and equal labor availability are cultivating fields with equivalent level of soil fertility, the labor extensive farmer will have a higher level of production. Labor intensification is associated with a decline in yields for the extra unit of labor assigned to an acre-sized plot. Yet if soil fertility levels vary, the production outcomes facing farmers become uncertain. Over long time frames, land use legacies reflecting different topographic characteristics and objective functions shape the environmental quality of plots, constraining production in unexpected ways.

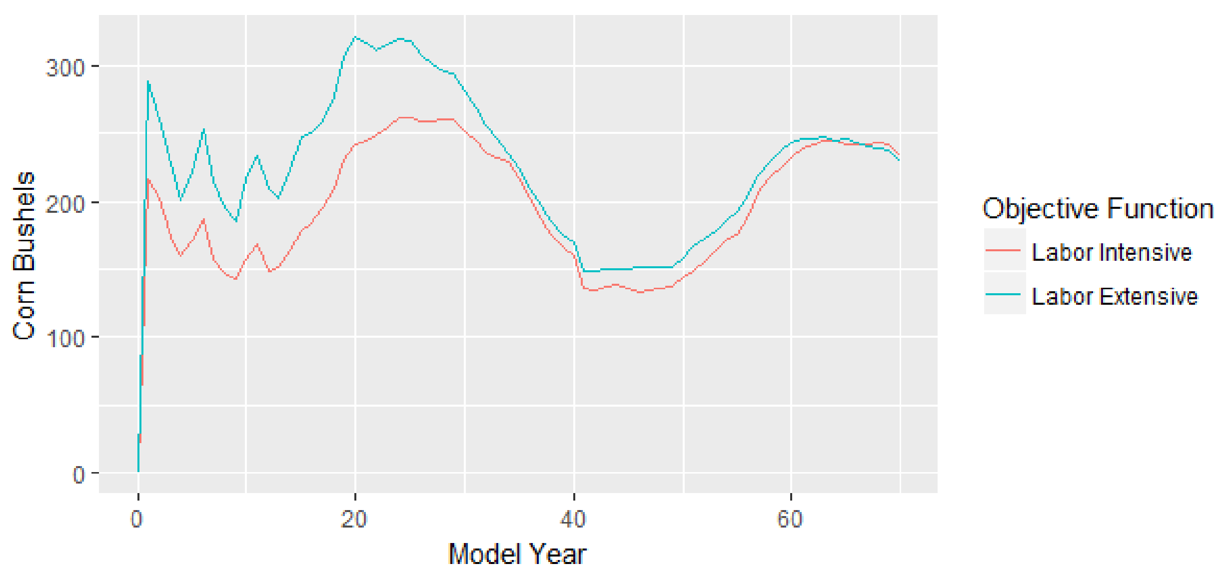


Figure 5-8: Mean annual corn production

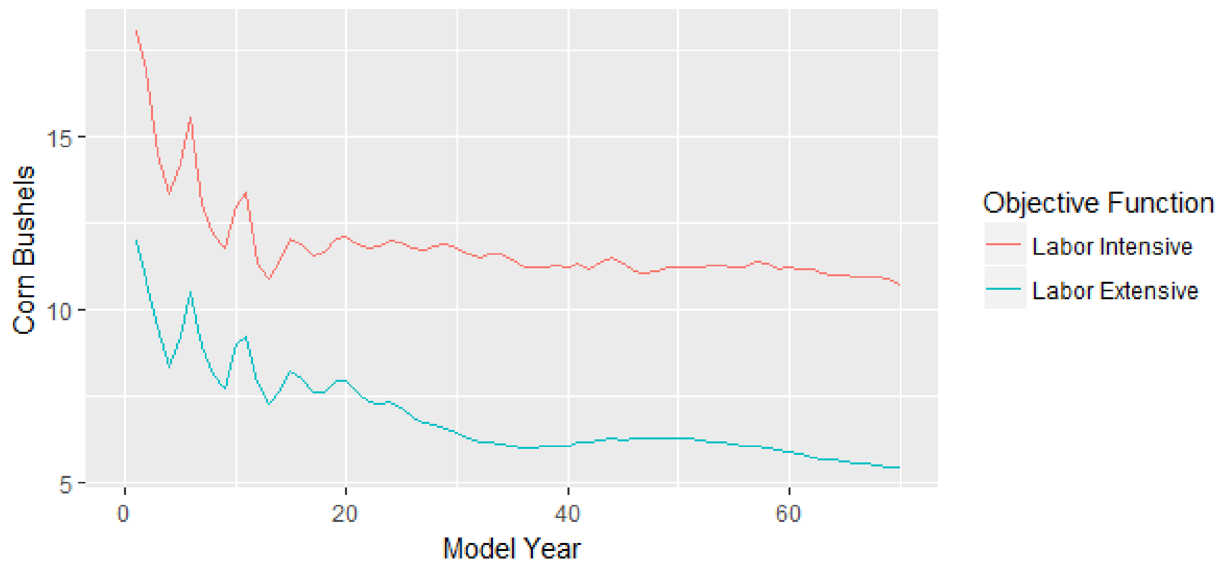


Figure 5-9: Mean annual per acre corn productivity

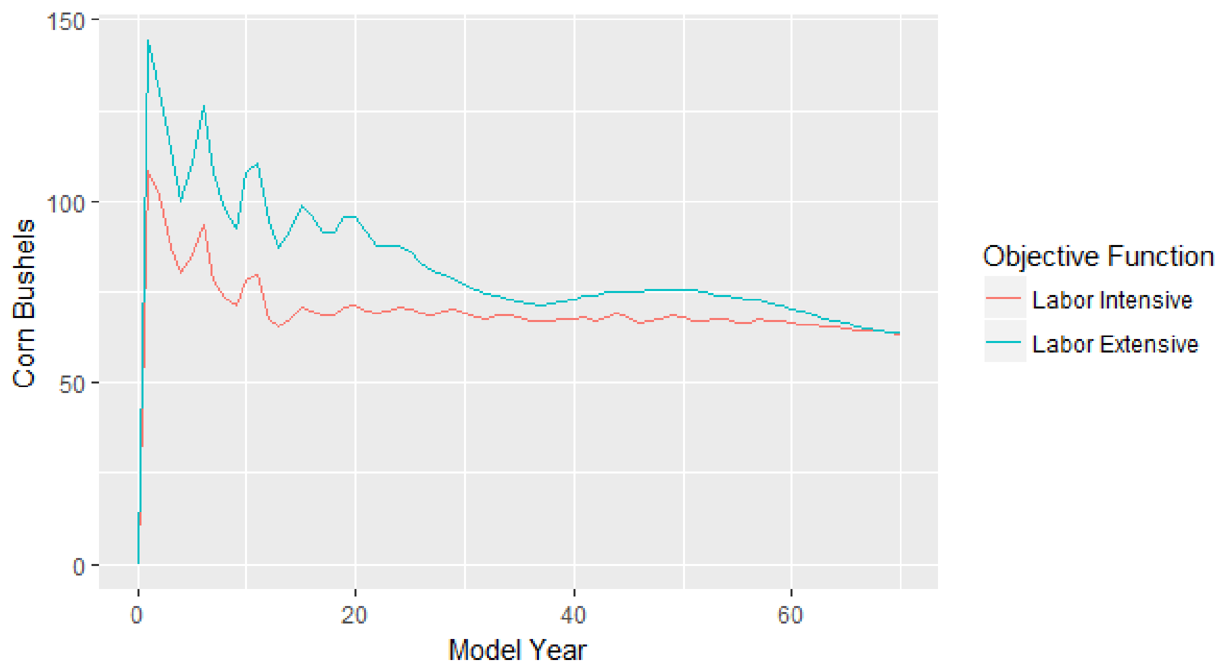


Figure 5-10: Mean annual per laborer corn productivity

Labor extensive farmers obtain a higher level of corn production until around model year 30, at which point the overall level of production converges with labor intensive farmers. The convergence is reflected in changing labor productivity. Beginning at model year 20, the difference between labor productivity begins declining for the two types of agents. The high labor productivity of extensive producers therefore is a short-term benefit, only lasting on average around 20 years for 300 acre farmers.

How do varying amounts of labor and acreage influence the rate of environmental change, fallow periods, and agricultural production? The degree of labor intensification influences how farmers respond to environmental feedbacks. The preceding section detailed these processes for farmers who relied only on immediately household members for labor and had 300 acre farms. Different sets of labor amounts, such as the ownership of slaves, or different farm sizes will influence how the degree of labor intensification influences environmental changes, fallow cycles and agricultural production by changing the opportunities and constraints facing farmers through time.

One-way ANOVA tests were conducted to compare the group means of labor productivity from model years 21-70 for individual model runs. Each model run represents a different combination of total farm acreage, labor, and objective functions. One test was run for all combinations of land and labor for labor intensive farmers and another for labor extensive farmers. Due to a statistically significant F-test, Tukey HSD tests were conducted to determine what pairs of groups were statistically significant. The results are presented in two tables below. Each cell below the middle diagonal contain the difference between the row group and the column group. Each cell above the middle diagonal provides a visual color to represent this difference between the column group and the row group. Blank cells represent pairwise comparisons where the difference in means was statistically insignificant.

Table 5-2. Tukey HSD tests comparing multiple one-way comparisons between group means of LABOR INTENSIVE farmers at different acreages and levels of additional labor.

Slaves		0	1	3	0	1	3	0	1	3	0	1	3	0	1	3
	Acreage	100			200			300			400			500		
0																
1	100	-8.03														
3		-14.86	-6.83													
0		21.72	29.75	36.58												
1	200	13.26	21.29	28.12	-8.46											
3			9.43	16.26	-20.31	-11.86										
0		28.81	36.84	43.67	7.10	15.55	27.41									
1	300	23.15	31.18	38.01		9.88	21.74	-5.67								
3		13.95	21.98	28.81	-7.77		12.55	-14.86	-9.20							
0		30.52	38.55	45.38	8.80	17.26	29.12		7.37	16.57						
1	400	26.21	34.24	41.07	4.49	12.95	24.81	-2.60	3.06	12.26	-4.31					
3		21.45	29.48	36.31		8.19	20.05	-7.36		7.50	-9.07	-4.76				
0		30.85	38.88	45.71	9.14	17.59	29.45		7.71	16.90	0.33	4.64	9.40			
1	500	27.56	35.59	42.42	5.85	14.30	26.16		4.42	13.62	-2.95		6.11	-3.29		
3		24.16	32.19	39.02	2.45	10.90	22.76	-4.65		10.21	-6.36		2.71	-6.69	-3.40	

Table 5-3: Tukey HSD tests comparing multiple one-way comparisons between group means of LABOR EXTENSIVE farmers at different acreages and levels of additional labor.

Slaves		0	1	3	0	1	3	0	1	3	0	1	3	0	1	3
	Acreage	100			200			300			400			500		
0																
1	100	-6.55														
3		-12.48	-5.93													
0		21.79	28.35	34.27												
1	200	10.27	16.83	22.75	-11.52											
3			5.42	11.35	-22.92	-11.41										
0		39.25	45.80	51.73	17.45	28.97	40.38									
1	300	25.27	31.83	37.75		15.00	26.40	-13.98								
3		7.60	14.15	20.08	-14.19		8.73	-31.65	-17.67							
0		49.86	56.42	62.34	28.07	39.59	50.99	10.61	24.59	42.26						
1	400	38.37	44.92	50.85	16.57	28.09	39.50		13.09	30.77	-11.50					
3		19.96	26.52	32.44		9.69	21.09	-19.29	-5.31	12.36	-29.90	-18.40				
0		55.09	61.64	67.57	33.30	44.81	56.22	15.84	29.82	47.49	5.23	16.72	35.13			
1	500	45.68	52.23	58.16	23.89	35.41	46.81	6.43	20.41	38.08	-4.18	7.31	25.72	-9.41		
3		30.46	37.01	42.94	8.67	20.18	31.59	-8.79	5.19	22.86	-19.40	-7.91	10.50	-24.63	-15.22	

The productivity of labor from model year 21-70 varies widely between different groups. The higher farm acreages and lower labor sizes is associated with higher labor productivity for farmers. Within acreage classes, farmers with less labor tend to have higher mean labor productivity. Labor extensive farmers tend to have much higher productivity as the acreage total increases, while labor intensive farmers have less extreme differences as labor and land increases.

Table 5-4: Mean deforestation rate (acres) of labor intensive farmers

	100 Ac	**200 Ac**	**300 Ac**	**400 Ac**	**500 Ac**
0 Slaves	0.7767564	1.2079633	0.9922294	0.8416290	0.7492753
1 Adult Slave	0.5609844	1.0628687	1.1315675	0.9569774	0.8037106
3 Adult Slaves	0.3336044	0.6887934	1.0377353	1.0860495	1.0111733

Table 5-5: Mean deforestation rate (acres) of labor extensive farmers

	100 Ac	**200 Ac**	**300 Ac**	**400 Ac**	**500 Ac**
0 Slaves	0.8850877	1.5838527	2.0966330	2.1018944	1.9136559
1 Adult Slave	0.5992415	1.2001462	1.6774920	2.0456119	2.2143650
3 Adult Slaves	0.3423287	0.7637110	1.1366916	1.4691891	1.8250923

The rate of deforestation is not stable across each respective objective function. Deforestation rates per year are low for small farms and increase with larger acreages. For lower acreages, the deforestation rate tends to decrease with an increasingly higher labor supply. This reflects the time-dependent nature of deforestation: The rate of deforestation is likely very high for these farmers at the beginning of the model, resulting in the rapid loss of the original forest cover. For the remainder of the model very little trees are lost because plots are not allowed to return to forest. The following figures demonstrate how the rate of deforestation declines faster under lower farm acreages. Labor intensive farmers with 300 acres or more do not experience the same dramatic drop off in deforestation rate.

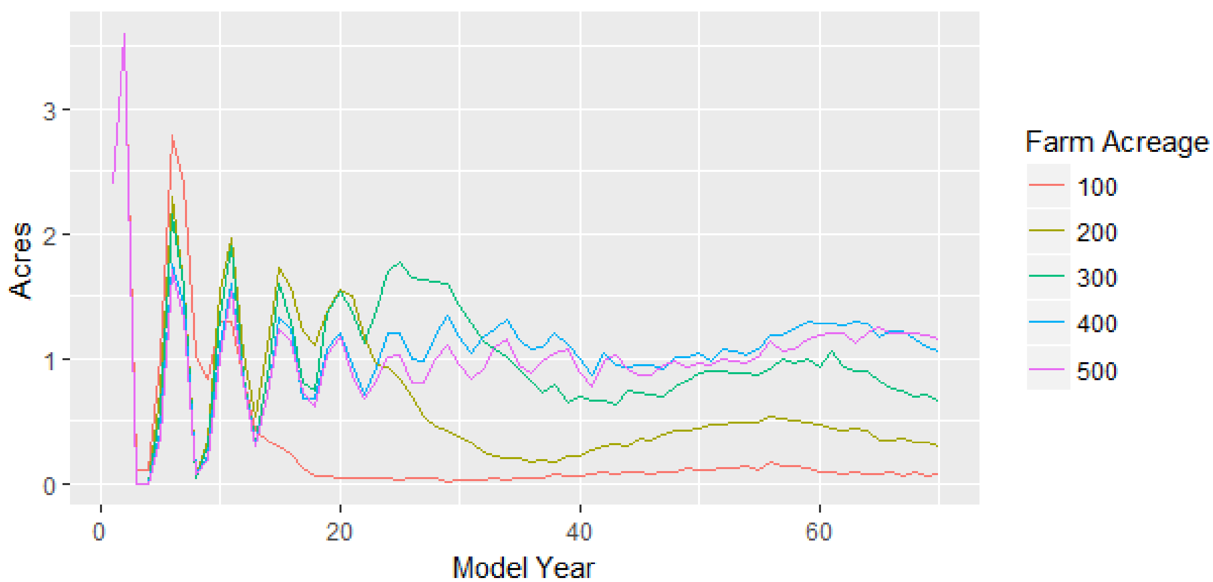


Figure 5-11: Annual mean deforestation rate for labor intensive farmers with 3 slaves

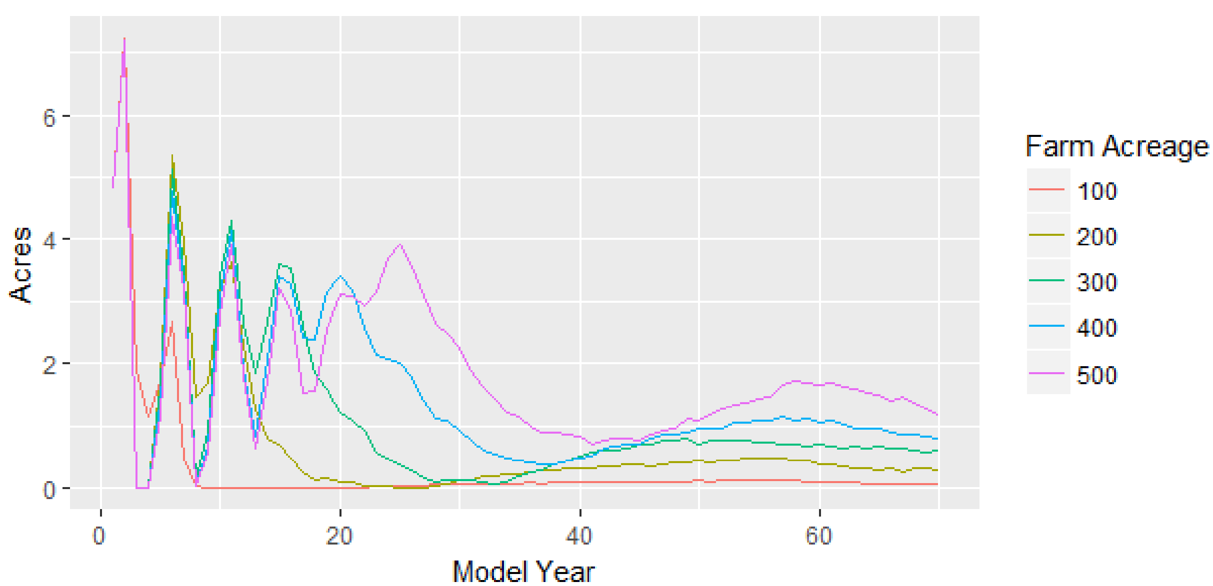


Figure 5-12: Annual mean deforestation rate for labor extensive farmers with 3 slaves

Given this, we would expect fallow periods to vary dramatically under different labor and land characteristics. For labor intensive farmers, only non-slave owners maintain average fallow periods of 15 or more years at 300 or more acres on upland plots. For labor extensive farmers, only non-slave owners maintain long fallow periods (just under 15 years) at 500 acres. In general, fallow periods increase with more acreage and declines with each additional laborer. For bottomland plots fallow lengths tend to be similar although farmers with three additional laborers have much lower fallow periods at lower acreages.

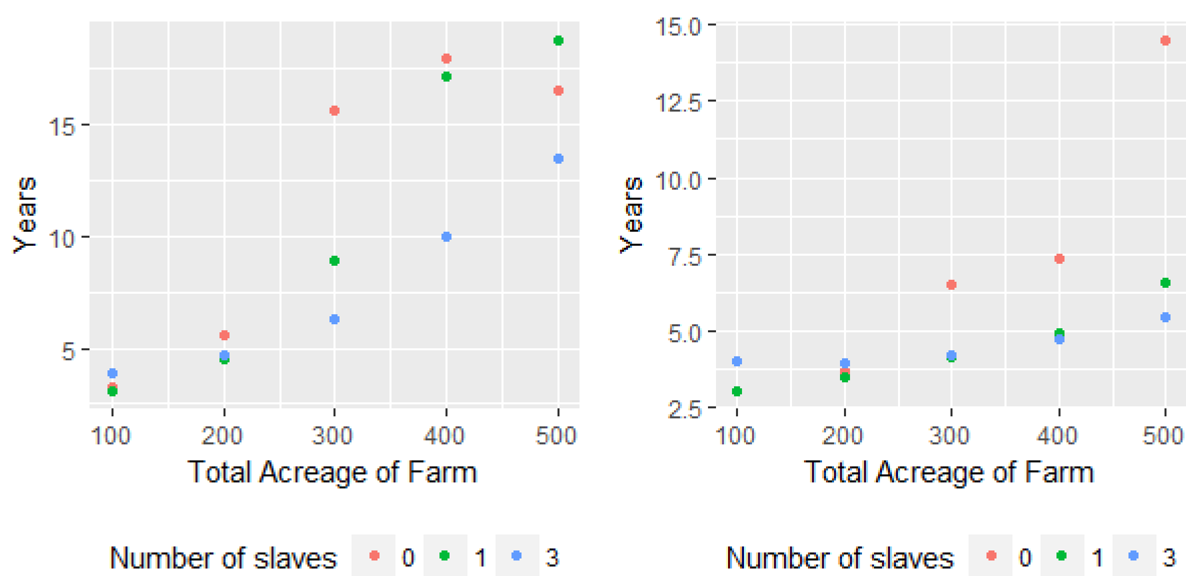


Figure 5-13: Mean length of fallowing on upland plots,
labor intensive (left) and labor extensive (right)

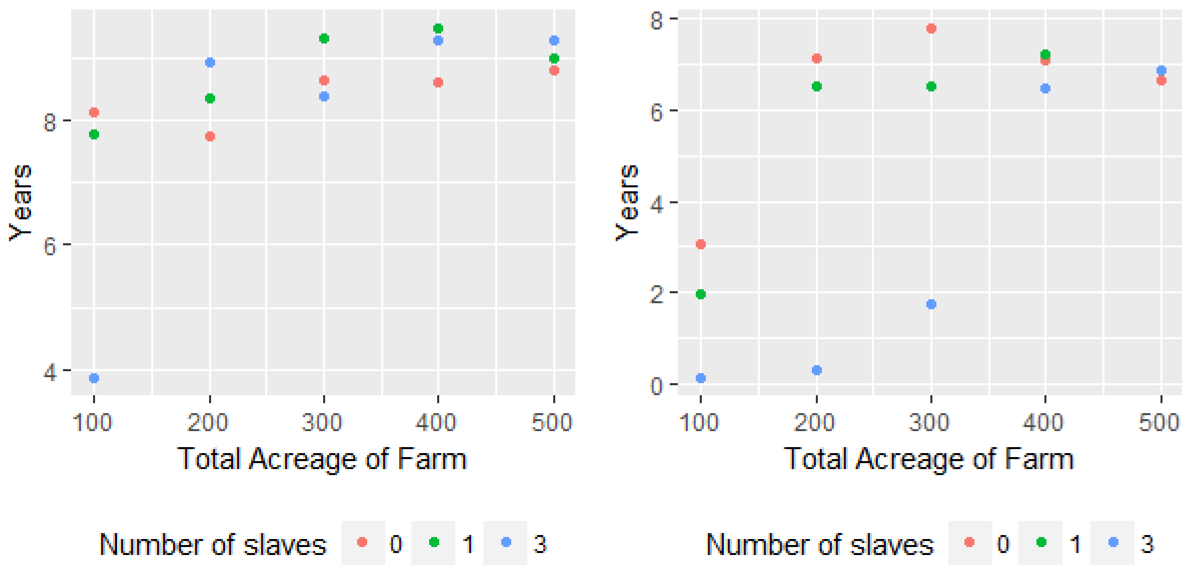


Figure 5-14: Mean length of fallowing on bottomland plots,
labor intensive (left) and labor extensive (right)

How does topographic position variability influence forest cover and long-term changes in agricultural productivity? Increased farm size is associated with longer fallow periods and prevent the loss of land and labor productivity. Yet there is varaibility within each model run at different total acreages. Topographic variability likely influences farm-level outcomes related to land use and environmental change. In particular, access to bottomlands, the least common of the three topographic positions in Goshen Hills and Cross Keys townships, may allow farmers to decrease the rate of forest and soil loss by concentrating agricultural production on alluvial areas that allow for persistent yields. The following graphs visualize the average deforestation rate and land productivity of labor intensive farmers at different total farm acreages:

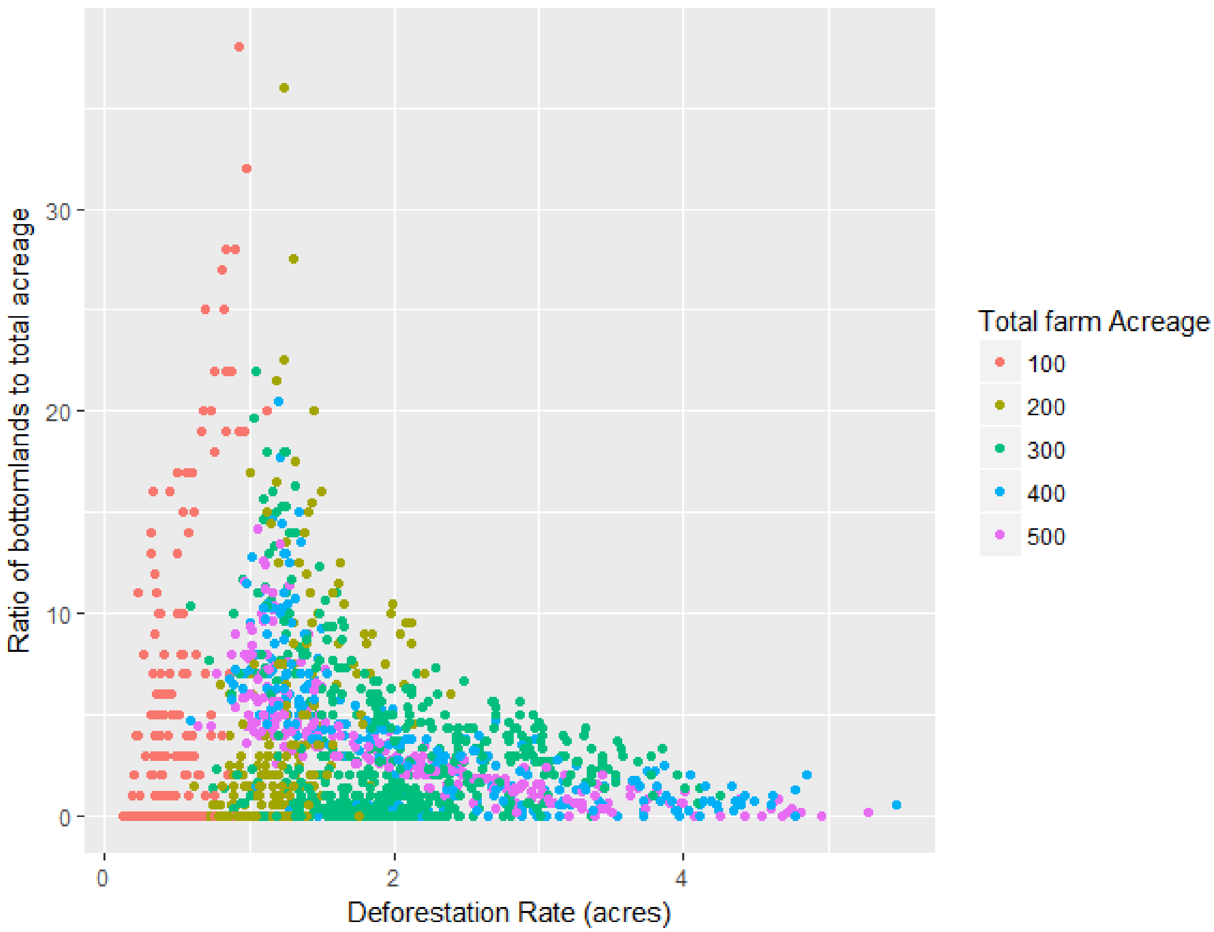


Figure 5-15: The relationship between deforestation rate and the ratio of bottomlands to total farm acreage

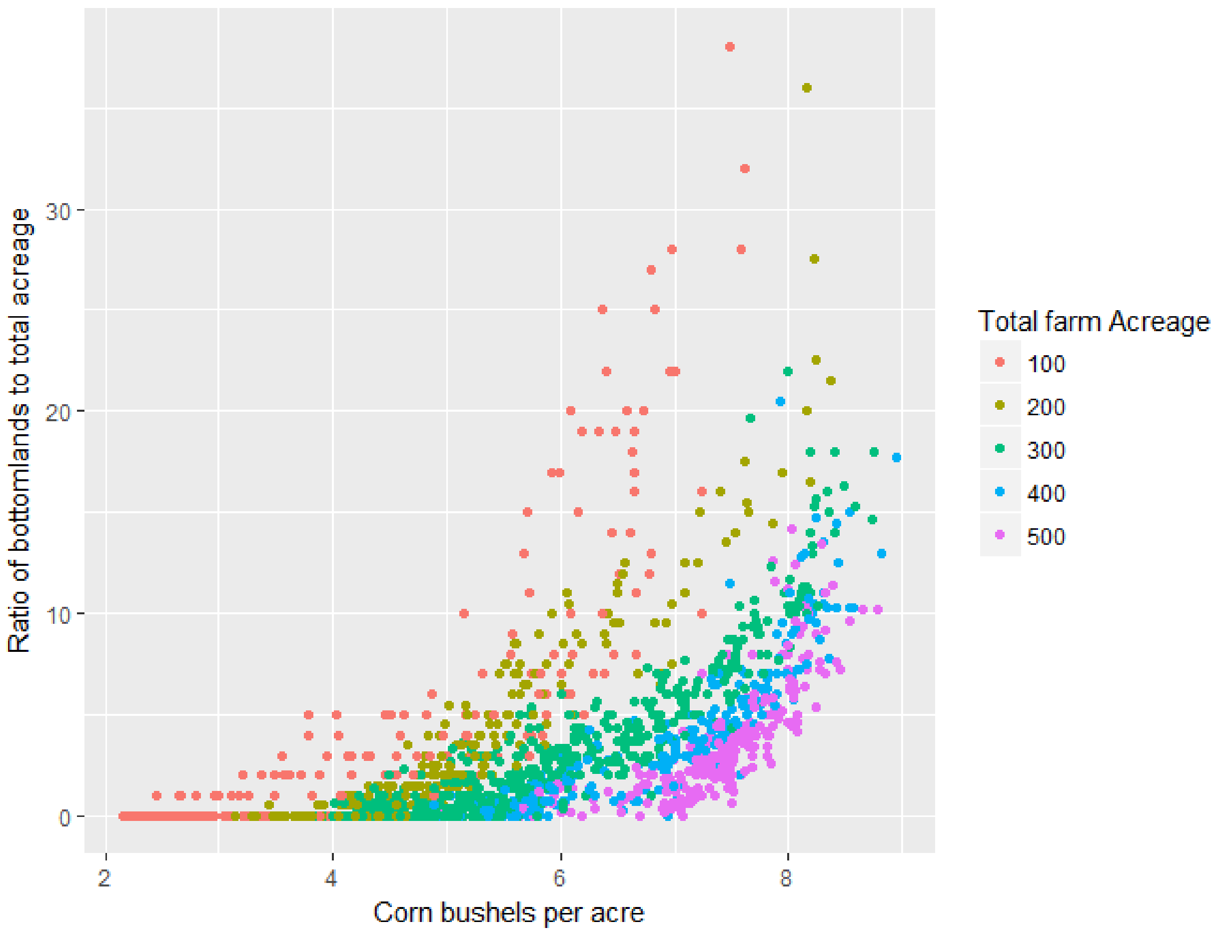


Figure 5-16: The relationship between land productivity and the ratio of bottomlands to total farm acreage.

There is a clear negative relationship between deforestation rate and the ratio of bottomlands to total acreage and a positive relationship between land productivity and the ratio of bottomlands to total acreage. As farm acreage increases the deforestation rate declines and land productivity increases, yet the number of bottomland acres that farmers have access to plays an important role to mediate the variation of environmental and agricultural changes within given farm acreages.

6) CONCLUSION

A wide range of conditions may influence farmers to engage in unsustainable forms of agriculture. Extra-local conditions, such as commodity markets, widely available land along a frontier, or national institutions relating to labor and land tenure, influence what opportunities and constraints face farmers and how they weigh trade-offs between short- and long-term production outcomes on their land (Bennett 1982). Declining labor intensification is common in agricultural systems where farmers are not induced to conserving soil resources for sustainable, long-term production (Netting 1993). While this project does not investigate how specific exogenous condition influence land use decisions, it provides an experimental laboratory to investigate how different assumptions related to the interaction of labor intensification with other land and labor characteristics influence agricultural land use and environmental change outcomes.

Shifting agriculture is characterized as a labor extensive system with long fallow periods and high labor productivity (Erickson 2006). Maintaining adequate returns on the same land in shifting agriculture requires allowing plots to undergo a full fallow period (Clarke 1966). Under acreages commonly associated with yeomen farmers in the southeastern Piedmont, a high degree of labor extensivity failed to maintain adequate forest-fallow cycles during model runs. While labor extensive farmers obtain initial higher levels of agricultural production and labor productivity than labor intensive farmers on uncleared and fertile land, they rapidly degrade soil resources and are forced to bring fallowing plots back into production much sooner than more labor intensive farmers. Short fallow periods coincide with declining agricultural production and labor productivity, and labor extensive farmers quickly converge to the level of production and labor productivity associated with labor intensive farmers.

Frontier environments are often associated with widespread deforestation as agricultural land use rapidly spreads into large regions (Brondizio et al. 2002). The model provides evidence that the degree of labor extensivity will influence whether deforestation is associated with the degradation of soil resources. Long-term rates of deforestation are highest under labor extensive farmers with adequate total farm acreages. This suggests that if farmers have either large tracts of land or the ability to move to uncultivated lands following the exhaustion of other land, deforestation rates and the loss of soil resources will both occur at higher rates than with labor intensive farmers. Labor intensive farmers maintain lower and stable deforestation rates, around 1 acre per year, even as labor availability increases, and maintain high soil quality by fallowing.

Topographic variability plays an important role in influencing long-term patterns of environmental and agricultural change. The highest quality agricultural lands in the region was alluvial bottomlands (Helms 2000). In the model, farmers with access to these alluvial regions are associated with higher overall agricultural productivity across total farm acreage and labor categories. Because bottomlands are relatively rare in the two townships, the ability for farmers to maintain agricultural production over long-term periods may have been tied either to the ability to acquire new lands or to control alluvial areas (Coughlan et al. 2017). The model presented here did not take into account processes of soil deposition on alluvial areas, which began decreasing agricultural productivity of these areas in the mid-nineteenth century. This process may have influenced accelerated upland expansion as farmers abandoned once highly productive areas.

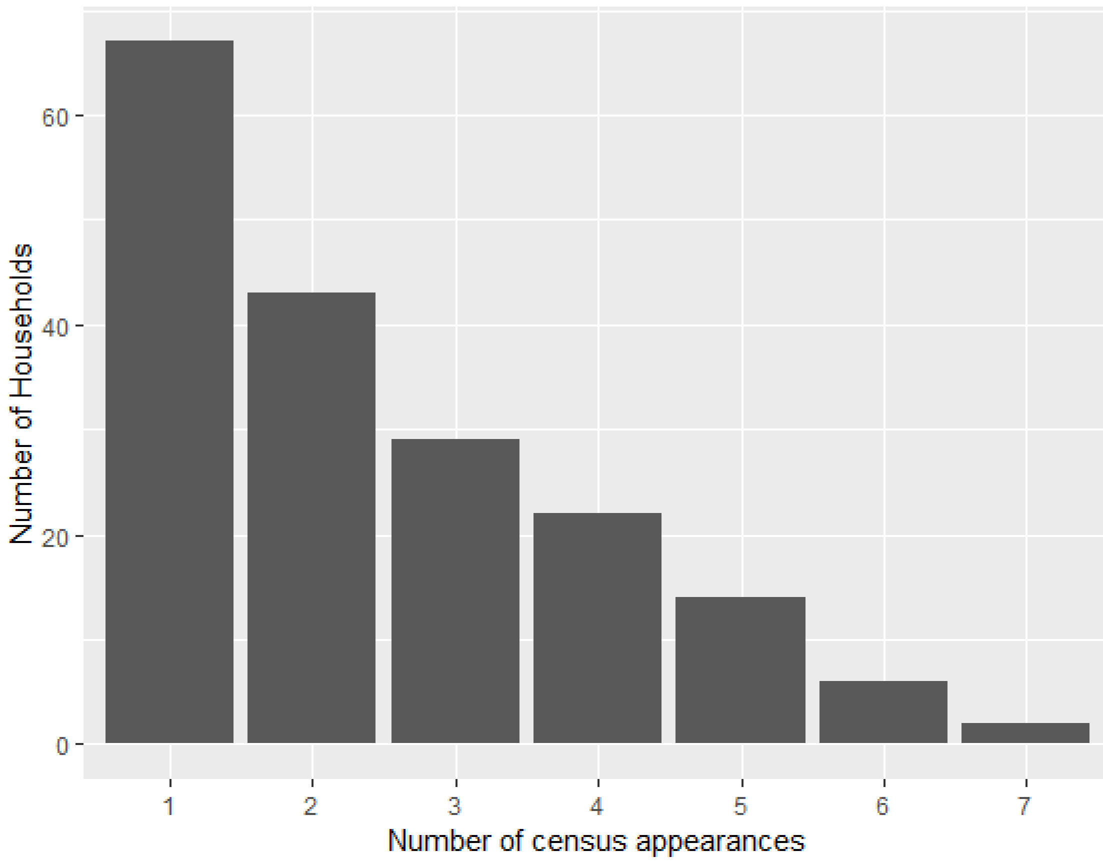


Figure 6-1: The number of appearances in decadal demographic census schedules by households located in Goshen Hills and Cross Keys.

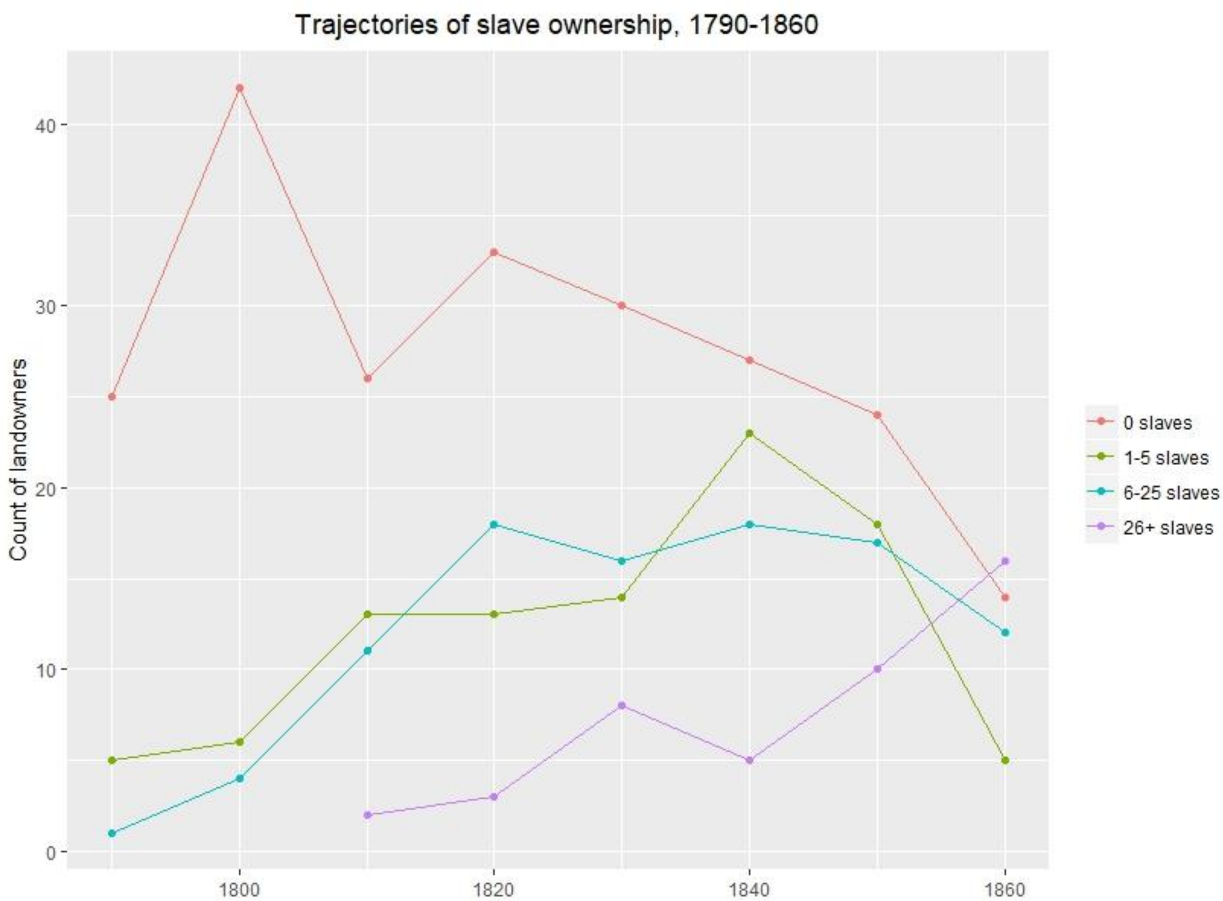


Figure 6-2: Change in the degree of slave ownership among landowners, 1790-1860.

The Antebellum-era southeastern Piedmont region was characterized by a high degree of land availability that may have induced farmers to engage in a highly extensive mode of production (Montgomery 2007). Model results demonstrate that extensive farmers would have experienced many of the outcomes predicted by historians, particularly rapid soil quality loss quickly resulted in declining agricultural yields. The model predicts that labor extensive farmers who owned slaves or had less than 500 acres would suffer rapidly declining yields within 20 to 40 years. Figure 6-1 illustrates the persistence of household heads in Goshen Hills and Cross Keys townships and suggests that the majority of households disappear within one to two censuses, representing anywhere from one to 29 years of residence in Union County. Figure 6-2 suggests that yeomen households experienced declining membership throughout the period of 1790-1860. While this could be due to heightened mortality, land concentration by plantations, or other factors, it is possible that extensive agriculture production by yeomen farmers allowed for a short window of residence. Future research can test which model scenarios best represent real-world processes by validating model output with historical data sources, including agricultural and demographic census data and forest composition change records (Grimm et al. 2005).

The model provides an experimental environment to test how different assumptions related to decision-making, labor availability, and the size and quality of landholdings would influence the nature and pattern of agricultural land use activities and outcomes, as well as environmental change. Farmers who are more labor extensive will, for a short-period, experience high labor productivity and overall yields than labor intensive farmers before land degradation will limit their production. In frontier settings, farmers are often characterized as extensive producers who move on to fresh lands once the soil fertility drops to a certain point. Netting (1967) describes how smallholders extensity along a frontier and begin to intensify their application of labor as land shortages begin to occur. There are certain limitations with this approach. There were likely important socioeconomic connections between yeomen households and plantations that may have influenced land use decisions, such as plantation-based labor opportunities, local sales of food or cotton between these production types, or the ability to rent or otherwise obtain land by yeomen farmers. Some sets of parameters, meaning the arrangements of labor, land, and decision-making strategies at the farm-level, may not have been realistic or present for the period being investigated, while others may have been far more common.

Widespread soil erosion and declining agricultural production are not due to farmer mismanagement or ignorance (Blaikie 1985). Farmers may engage in highly labor extensive production due to widespread land availability or to meet increased production needs due to surplus extraction (Netting 1993; Blaikie 1985). The model demonstrates that farmers engaged in these practices would have quickly experienced negative outcomes related to soil quality decline and declining agricultural production. Labor intensive farmers, however, maintained soil quality and agricultural production by engaging in a forest-fallow cycle that allowed for the regeneration of soil fertility. In an environment characterized by socio-economic inequality, it is likely that farmers varied in their degree of labor intensity or switched between them due to changing environmental and socio-economic conditions (Bennett 1982; Blaikie 1985; Netting 1993). Such variation in agricultural strategies would have led to a heterogeneous spatio-temporal pattern of environmental and agricultural land use change across the Piedmont landscape.

BIBLIOGRAPHY

Affleck, Thomas. 1851. *Affleck's Southern Rural Almanac, and Plantation and Garden Calendar*. New Orleans.

Aiken, Charles S. 1938-. 1998. *The Cotton Plantation South since the Civil War /*. Creating the North American Landscape. Baltimore: John Hopkins University Press.

Andersson, Elina, Sara Brogaard, and Lennart Olsson. 2011. "The Political Ecology of Land Degradation." *Annual Review of Environment and Resources* 36 (1): 295–319.

Awanyo, Louis. 2001. "Labor, Ecology, and a Failed Agenda of Market Incentives: The Political Ecology of Agrarian Reforms in Ghana." *Annals of the Association of American Geographers*, 2001.

Barlett, Peggy F. 1980. *Agricultural Decision Making: Anthropological Contributions to Rural Development*. Studies in Anthropology. New York: Academic Press.

Beier, C. M., A. L. Lovecraft, and F. S. Chapin Iii. 2009. "Growth and Collapse of a Resource System: An Adaptive Cycle of Change in Public Lands Governance and Forest Management in Alaska." *Ecology and Society* 14 (2).

Bennett, John W. 1982. *Of Time and Enterprise*. Minneapolis, MN: University of Minnesota Press.

Biersack, Aletta. 1999. "Introduction: From the 'New Ecology' to the New Ecologies." *American Anthropologist* 101 (1): 5–18.

Blaikie, Piers M. 1985. *The Political Economy of Soil Erosion in Developing Countries*. Longman Development Studies. London ; New York : Longman, 1985.

Blaikie, Piers M., and Harold Brookfield, eds. 1987. *Land Degradation and Society /*. New York: Methuen.

Bolton, Charles C. 1993. *Poor Whites of the Antebellum South: Tenants and Laborers in Central North Carolina and Northeast Mississippi*. Durham: Duke University Press Books.

Boserup, Ester. 1966. *The Conditions of Agricultural Growth; the Economics of Agrarian Change under Population Pressure*. Chicago: Aldine Pub. Co.

Brondizio, Eduardo S. 2002. "The Colonist Footprint: Toward a Conceptual Framework of Land Use and Deforestation Trajectories among Small Farmers in the Amazonian Frontier." In *Deforestation and Land Use in the Amazon*, edited by Charles H Wood and Porro. Gainesville: University Press of Florida.

Brown, Paula, Harold Brookfield, and Robin Grau. 1990. “Land Tenure and Transfer in Chimbu, Papua New Guinea: 1958–1984—A Study in Continuity and Change, Accommodation and Opportunism.” *Human Ecology* 18 (1): 21–49.

Carneiro, Robert L. 1961. *Slash-and-Burn Cultivation Among the Kuikuru and Its Implications for Cultural Development in the Amazon Basin*. Editorial Sucre.

Charles, Allan D. 2014. *The Narrative History of Union County, South Carolina*.

Chayanov, A.V. 1966. *The Theory of Peasant Economy*. The American Economic Association Translation Series. Homewood, Ill.

Clarke, William C. 1966. “From Extensive to Intensive Shifting Cultivation: A Succession from New Guinea.” *Ethnology* 5 (4): 347–59.

———. 1976. “Maintenance of Agriculture and Human Habitats within the Tropical Forest Ecosystem.” *Human Ecology* 4 (3): 247–59.

Conklin, Harold C. 1961. “The Study of Shifting Cultivation.” *Current Anthropology*. 2 (1): 27–61.

Cooke, C. Wythe. 1931. “Why the Mayan Cities of the Petén District, Guatemala, Were Abandoned.” *Journal of the Washington Academy of Sciences* 21 (13): 283–87.

Cote, Muriel, and Andrea J. Nightingale. 2012. “Resilience Thinking Meets Social Theory: Situating Social Change in Socio-Ecological Systems (SES) Research.” *Progress in Human Geography* 36 (4): 475–89.

Coughlan, Michael, and Ted Gragson. 2016. “An Event History Analysis of Parcel Extensification and Household Abandonment in Pays Basque, French Pyrenees, 1830-1958 AD.” *Human Ecology* 44 (1): 65–80.

Coughlan, Michael R., Donald R. Nelson, Michael Lonneman, and Ashley E. Block. 2017. “Historical Land Use Dynamics in the Highly Degraded Landscape of the Calhoun Critical Zone Observatory.” *Land* 6 (2): 32-64.

Crowley, Eve L., and Simon E. Carter. 2000. “Agrarian Change and the Changing Relationships Between Toil and Soil in Maragoli, Western Kenya (1900–1994).” *Human Ecology* 28 (3): 383–414.

Culbert, T. Patrick. 1973. *The Classic Maya Collapse*. School of American Research Advanced Seminar Series. Albuquerque, University of New Mexico Press [1973].

Cumming, Graeme S. 2014. “Theoretical Frameworks for the Analysis of Social-Ecological Systems.” In *Social-Ecological Systems in Transition*, edited by Shoko Sakai and Chieko Umetsu, 3–24. Tokyo: Springer.

David, Paul A., ed. 1976. *Reckoning with Slavery: A Critical Study in the Quantitative History of American Negro Slavery*. New York: Oxford University Press.

Deadman, Peter, Derek Robinson, Emilio Moran, and Eduardo S. Brondizio. 2004. "Colonist Household Decision-Making and Land-Use Change in the Amazonian Rainforest: An Agent-Based Simulation." *Environment and Planning B: Planning and Design* 31: 693–709.

Deere, C.D., and A. de Janvry. 1979. "Conceptual-Framework for the Empirical-Analysis of Peasants." *American Journal of Agricultural Economics* 61 (4): 601–11.

Diamond, Jared. 2005. *Collapse: How Societies Choose to Fail or Succeed: Revised Edition*. New York: Penguin Books.

Donnelly, Shanon, and Tom P. Evans. 2008. "Characterizing Spatial Patterns of Land Ownership at the Parcel Level in South-Central Indiana, 1928–1997." *Landscape and Urban Planning* 84: 230–40.

Duit, A., V. Galaz, K. Eckerberg, and J. Ebbesson. 2010. "Governance, Complexity, and Resilience." *Global Environmental Change* 20 (3): 363-546.

Dumond, D. E. 1961. "Swidden Agriculture and the Rise of Maya Civilization." *Southwestern Journal of Anthropology* 17 (4): 301–16.

Edelman, Marc. 1985. "Extensive Land Use and the Logic of the Latifundio: A Case Study in Guanacaste Province, Costa Rica." *Human Ecology* 13 (2): 153–85.

Filatova, Tatiana, Peter H. Verburg, Dawn Cassandra Parker, and Carol Ann Stannard. 2013. "Spatial Agent-Based Models for Socio-Ecological Systems: Challenges and Prospects." *Environmental Modelling and Software* 45 (July): 1–7.

Fite, Gilbert Courtland. 1984. *Cotton Fields No More: Southern Agriculture, 1865-1980*. Lexington, Ky: Univ Pr of Kentucky.

Ford, Lacy K. 1986. "Yeoman Farmers in the South Carolina Upcountry: Changing Production Patterns in the Late Antebellum Era." *Agricultural History* 60 (4): 17.

Gallman, Robert E. 1970. "Self-Sufficiency in the Cotton Economy of the Antebellum South." In *The Structure of the Cotton Economy of the Antebellum South*. Washington: The Agricultural Historical Society.

Giesen, James C. 2011. *Boll Weevil Blues: Cotton, Myth, and Power in the American South*. Chicago: University of Chicago Press.

Goodman, David. 1991. *Refashioning Nature : Food, Ecology, and Culture*. New York: Routledge.

Grimm, Volker, Uta Berger, Donald L. DeAngelis, J. Gary Polhill, Jarl Giske, and Steven F. Railsback. 2010. "The ODD Protocol: A Review and First Update." *Ecological Modelling* 221 (23): 2760–68.

Grimm, Volker, Eloy Revilla, Uta Berger, Florian Jeltsch, Wolf M. Mooij, Steven F. Railsback, Hans-Hermann Thulke, Jacob Weiner, Thorsten Wiegand, and Donald L. DeAngelis. 2005. “Pattern-Oriented Modeling of Agent-Based Complex Systems: Lessons from Ecology.” *Science* 310: 987.

Hammel, E.a. 2005. “Chayanov Revisited: A Model for the Economics of Complex Kin Units.” *Proceedings of the National Academy of Sciences of the United States of America* 102 (19): 7043–46.

Harris, David Golightly, and Phillip N. Racine. 1990. *Piedmont Farmer: The Journals of David Golightly Harris, 1855-1870*. University of Tennessee Press.

Helms, Douglas. 2000. “Soil and Southern History.” *Agricultural History* 74 (4): 723–58.

Hornborg, Alf. 2013. “Revelations of Resilience: From the Ideological Disarmament of Disaster to the Revolutionary Implications of (p)Anarchy.” *Resilience: International Policies, Practices and Discourses* 1 (2): 116.

Humphries, Sally. 1993. “The Intensification of Traditional Agriculture among Yucatec Maya Farmers: Facing up to the Dilemma of Livelihood Sustainability.” *Human Ecology* 21 (1): 87–102.

Hurni, Kaspar, Cornelia Hett, Andreas Heinimann, Peter Messerli, and Urs Wiesmann. 2013. “Dynamics of Shifting Cultivation Landscapes in Northern Lao PDR Between 2000 and 2009 Based on an Analysis of MODIS Time Series and Landsat Images.” *Human Ecology* 41 (1): 21–36.

Ireland, H. A., Dolan Hoye Eargle, and C. F. Stewart Sharpe. 1939. *Principles of Gully Erosion in the Piedmont of South Carolina*. Technical Bulletin, United States Department of Agriculture; No. 633. Washington: U.S. Dept. of Agriculture.

Jones, J.W., and W.S. Jones. 1843. *Southern Cultivator*. Augusta, GA: J.W & W.S. Jones.

Jusys, Tomas. 2018. “Changing Patterns in Deforestation Avoidance by Different Protection Types in the Brazilian Amazon.” *PLoS ONE* 13 (4): 1–16.

Kates, Robert W, Goran Hyden, and B.L II Turner. 1993. “Beyond Intensification.” In *Population Growth and Agricultural Change in Africa*, edited by B.L II Turner, Goran Hyden, and Robert W. Kates. Gainesville: University Press of Florida.

L. C. Gray (Lewis Cecil). 1941a. *History of Agriculture in the Southern United States to 1860, Volume I*. Carnegie Institution of Washington. Publication No. 430. New York.

———. 1941b. *History of Agriculture in the Southern United States to 1860, Volume II*. Carnegie Institution of Washington. Publication No. 430. New York.

Leslie, Paul, and J. Terrence McCabe. 2013. “Response Diversity and Resilience in Social-Ecological Systems.” *Current Anthropology* 54 (2): 114–43.

Lu, D., E. Moran, and P. Mausel. 2002. “Linking Amazonian Secondary Succession Forest Growth to Soil Properties.” *Land Degradation & Development* 13 (4): 331–43.

Majewski, John, and Viken Tchakerian. 2007. “The Environmental Origins of Shifting Cultivation: Climate, Soils, and Disease in the Nineteenth-Century US South.” *Agricultural History* 81 (4): 522–49.

McAnany, Patricia Ann, and Norman Yoffee. 2010. *Questioning Collapse : Human Resilience, Ecological Vulnerability, and the Aftermath of Empire*. Cambridge ; New York : Cambridge University Press.

McNeil, Cameron L. 2012. “Deforestation, Agroforestry, and Sustainable Land Management Practices among the Classic Period Maya.” *Quaternary International* 249 (February): 19–30.

Merleaux, April. 2015. “Sweetness, Power, and Forgotten Food Histories in America’s Empire.” *Labor: Studies in Working Class History of the Americas* 12 (1/2): 87–114.

Michael R. Coughlan, Donald R. Nelson, Michael Lonneman, and Ashley E. Block. 2017. “Historical Land Use Dynamics in the Highly Degraded Landscape of the Calhoun Critical Zone Observatory.” *Land, Vol 6, Iss 2, p 32 (2017)*, no. 2: 32.

Miettinen, Jukka, Aljosja Hooijer, Chenghua Shi, Daniel Tollenaar, Ronald Vernimmen, Soo Chin Liew, Chris Malins, and Susan E. Page. 2012. “Extent of Industrial Plantations on Southeast Asian Peatlands in 2010 with Analysis of Historical Expansion and Future Projections.” *GCB Bioenergy* 4 (6): 908–18.

Mintz, Sidney W. 2011. “Plantations and the Rise of a World Food Economy: Some Preliminary Ideas.” *Review (Fernand Braudel Center)* 34 (1/2): 3–14.

Mintz, Sidney Wilfred. 1985. *Sweetness and Power : The Place of Sugar in Modern History /*. New York: Viking,.

Montgomery, David R. 2007. *Dirt : The Erosion of Civilizations /*. Berkeley: University of California Press.

Morrison, Kd. 1996. “Typological Schemes and Agricultural Change - Beyond Boserup in Precolonial South India.” *Current Anthropology* 37 (4): 583–608.

Nelson, Lynn A. 2007. *Pharsalia: An Environmental Biography of a Southern Plantation, 1780-1880*. Environmental History and the American South. Athens: University of Georgia Press.

Netting, Robert McC. 1968. *Hill Farmers of Nigeria: Cultural Ecology of the Kofyar of the Jos Plateau*. University of Washington Press.

———. 1993. *Smallholders, Householders : Farm Families and the Ecology of Intensive, Sustainable Agriculture*. Stanford, CA: Stanford University Press.

O'Brien, William E. 2002. "The Nature of Shifting Cultivation: Stories of Harmony, Degradation, and Redemption." *Human Ecology* 30 (4): 483–502.

Olmstead, Alan L., and Paul W. Rhode. 2008. "Biological Innovation and Productivity Growth in the Antebellum Cotton Economy." *Journal of Economic History* 68 (4): 1123–71.

Overmars, Koen P., Wouter T. de Groot, and Marco G.A. Huigen. 2007. "Comparing Inductive and Deductive Modeling of Land Use Decisions: Principles, a Model and an Illustration from the Philippines." *Human Ecology* 35 (4): 439–52.

Parker, Dawn C., Steven M. Manson, Marco A. Janssen, Matthew J. Hoffmann, and Peter Deadman. 2003. "Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review." *Annals of the Association of American Geographers*, no. 2: 314.

Pryor, Frederic L. 1982. "The Plantation Economy as an Economic System." *Journal of Comparative Economics* 6 (3): 288–317.

Ransom, Roger L., and Richard. Sutch. 1977. "One Kind of Freedom : The Economic Consequences of Emancipation" New York: Cambridge University Press.

Ransom, Roger L., and Richard Sutch. 2001. "One Kind of Freedom: Reconsidered (and Turbo Charged)." *Explorations in Economic History* 38 (1): 6–39.

Raper, Arthur Franklin. 1971. *Preface to Peasantry: A Tale of Two Black Belt Counties*. New York: Ayer Co Pub.

Robbins, Paul. 2004. *Political Ecology*. Malden, MA: Blackwell Publishing.

Rubin, Julius. 1975. "The Limits of Agricultural Progress in the Nineteenth-Century South." *Agricultural History* 49 (2): 362–73.

Ruffin, Edmund, and Jack Temple Kirby. 2000. *Nature's Management : Writings on Landscape and Reform, 1822-1859*. Athens : University of Georgia Press.

Steven M. Manson, and Tom Evans. 2007. "Agent-Based Modeling of Deforestation in Southern Yucatán, Mexico, and Reforestation in the Midwest United States." *Proceedings of the National Academy of Sciences of the United States of America*, no. 52: 20678.

Steven. Stoll. 2002. *Larding the Lean Earth: Soil and Society in Nineteenth-Century America*. 1st ed.. New York: Hill and Wang.

Stone, Glenn Davis. 2001. "Theory of the square chicken: advances in agricultural intensification theory." *Asia Pacific Viewpoint* 42 (2–3): 163–80.

Taylor, Rosser H. 1943. "Post-Bellum Southern Rental Contracts." *Agricultural History* 17 (2): 121–28.

Thompson, Edgar T., Sidney W. Mintz, and George Baca. 2010. *The Plantation*. Southern Classics Series. Columbia, S.C. : University of South Carolina Press.

Tomich, Dale. 2011. "Rethinking the Plantation: Concepts and Histories." *Review (Fernand Braudel Center)* 34 (1/2): 15–39.

Trimble, Stanley. 1974. *Man-Induced Soil Erosion on the Southern Piedmont*. Ankeny, IA.: Soil and Water Conservation Society.

Tucker, Bram T, Elaine Lill, Tsiazonera, Jaovola Tombo, Rolland Lahiniriko, Louinaise Rasoanomenjanahary, Pirette Miza Razafindravelo, and Jean Roger Tsikengo. 2015. "Inequalities beyond the Gini : Subsistence, Social Structure, Gender, and Markets in Southwestern Madagascar." *Economic Anthropology* 2 (2).

Weiman, David F. 1990. "Staple Crops and Slave Plantations: Alternative Perspectives on Regional Development in the Antebellum Cotton South." In *Agriculture and National Development: Views on the Nineteenth Century*, edited by Lou Ferleger, 119–61. Henry A. Wallace Series on Agriculture History and Rural Studies.

WPA. 1941. *South Carolina: The WPA Guide to the Palmetto State*. University of South Carolina Press.