Gender and Land Resource Management in Southern Ghana[*]

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September 7, 1999

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[*] The authors would like to thank the Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana for providing a vibrant and stimulating research environment. We thank J.K. Amaktakpor, Fred Magdoff, Foster Mensah, Edwin Gyasi, Kojo Amanor and seminar participants at ISSER and IFPRI for valuable comments. Valuable research assistance at Yale was provided by Rikhil Bhavnani. We thank the National Science Foundation (SBR-9617694), the Fulbright Commission, the World Bank Research Committee, the International Food Policy Research Institute, the Institute for the Study of World Politics, the Social Science Research Council, and the Institute of Industrial Relations, UC Berkeley for funding this research. Most of the research was conducted while both authors were visiting fellows at ISSER and the second author was at the Northwestern University Economics Department. We owe a great debt to the data collection team, which was lead by Ernest Appiah and consisted of Robert Ernest Afedoe, Patrick Selorm Amihere, Esther Aku Sarquah, Kwabena Moses Agyapong, Esther Nana Yaa Adofo, Michael Kwame Arhin, Margaret Harriet Yeboah, Issac Yaw Omane, Peter Ansong-Manu, Ishmaelina Borde-Koufie, Owusu Frank Abora, and Rita Allotey.

1 Introduction

The alleviation of rural poverty and the enhancement of food security are central policy goals in sub-Saharan Africa. Technological innovation and agricultural intensification are important aspects of almost any strategy designed to meet these goals. As technologies change and land use intensifies, farmers must make decisions regarding the management of their land resources. This paper begins an examination of the incentives faced by individual farmers as they manage the fertility of their land in a region characterized by environmental stress and rapid technological change in agriculture.

We focus on southern Ghana. As in many agricultural systems, famers here engage in a system of shifting cultivation. These farmers also face the opportunity to produce potentially profitable crops for export. They are working with land where the natural resource base and the historical pattern of agricultural has created a fragile agro-ecological envvironment. They also face fractured credit markets, with the near absence of formal lending and scattered and diffuse informal sources of credit. Property rights can be uncertainboth within and across households. This paper offers a preliminary examination of farmers' decision making with respect to fertility management within this environment.

1.1 Agriculture in Akwapim

Historically, the farming systems of the study area have undergone a series of significant changes. In the 19th century, oil palm production sparked the first inflow of migration to the area. This district was at the heart of Ghana's cocoa revolution at the turn of the 20th century (Hill, 1963). In 1930, swollen shoot disease devastated cocoa production and farmers adopted a system based on intercropped cassava and maize. Most recently (since the early 1990's), farmers in the area have moved towards intensive pineapple production for export. While pineapple provides much higher cash earnings, the majority of farms in the area are still planted to the staple food crops of maize and cassava.

Throughout these shifts in crop emphasis, the intensity of agricultural activity has increased. The entire southern Ghanaian forest-savanna transition zone, of which the survey area is part, has seen a dramatic reduction in forest cover since the 1970s (the evidence is from aerial photography (Gyasi et al. 1994) and satellite imagery (Hawthorne and Abu-Juam 1995)), important reductions in fallow lengths over the same period (Gyasi et al. 1994, Amanor 1994), and increased evidence of soil deterioration and infestation by pests (particularly the virulent weed known locally as akyeampong) (Gyasi 1990; Amanor 1994). There is also evidence (Amanor 1994) that patterns of rainfall in the region have changed, but this is disputed by many geographers. Among the primary challenges in the transition to more intensive export crop production, according to the farmers and their extension agents, is finding techniques which will maintain soil fertility under the new cropping system.

In the current system of pineapple or maize and cassava, initial analysis of our data indicates that pineapple is significantly more profitable than the staple crops. Table one indicates that pineapple plots yield close to 1.6 million cedis per hectare more over a year and a half period than comperable plots plnated to maize and cassava.[1] Not only is pineapple more profitable, but there is no evidence that it is more risky to cultivate than maize or cassava (Goldstein and Udry 1999). The export market for pineapple in Ghana has grown significantly in the last few years and there is indication that the demand for fruit for domestic processing is also growing.[2]

1.2 Capital Markets

Land is a vessel: it is filled with nutrients, then those nutrients are extracted in the form of crops. This analogy (related by Marcel Fafchamps) is clearly understood by farmers in the study area. In informal interviews, many farmers explicitly argued that they were drawing down soil fertility in order to expand production. 'Mining the soil' is fundamental to any farming system based on cycles of fallow and cultivation, as in the study area. Decisions regarding the maintenance of soil fertility have an intertemporal dimension, so they are affected by the capital market environment within which farmers operate.

There are a variety of capital markets available to cultivators in the study area. Virtually no one interviewed during the preliminary fieldwork transacted with formal sector financial institutions, but many borrowed or lent informally. Informal financial transactions occur in many forms - between family and friends, with susu collectors or susu companies, and (to a limited extent) with merchants and moneylenders (Aryeetey 1993, Aryeetey and Udry 1995). There is also a degree of contract farming in pineapple cultivation (and rarer forward sales of onion and tomato), which may contain a credit component. The structure of contracts in the study area, however, appears to differ from that found in other African contract farming schemes (Grosh 1992, Little and Watts 1994, Mackintosh 1989, Porter and Phillips-Howard 1995) because farmers in the study area claim that the contract only provides a guaranteed price, with virtually no credit (the only input provided by the exporter is a spraying of a forcing agent (NAA)). In fact, most pineapple exporters acquire the fruit from farmers on a consignment basis, resulting in a large net flow of finance from pineapple farmers to exporters. Does the diffuse and fractured nature of the credit market affect the fertility management decisions of the individual farmers?

1.3 Property Rights and the Household

There is a close relationship between property rights over particular plots and incentives to apply techniques for soil fertility maintenance. Only in rare circum-

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[1] The median plot size is approximately one quarter hectare, and individuals farm an average of about four plots. The 1.7 million cedi difference in median profits generated by the choice to cultivate pineapple on all the plots farmed by an individual is roughly two and a half times Ghana's per capita GDP.

[2] The market is currently small but a set of new entrants may lead to increased demand.

stances are rights over a plot of land in the study area vested in a conventionally-defined household. Moreover, decisions regarding the application of fertility-enhancing techniques to particular plots are made by the individual cultivating that plot. If the efficient household model is not correct, then these individual decisions are conditioned by individual as well as household, economic circumstances.

We now turn to our examination of how these factors impact the fertility management decisions of the individual farmers. Our goals in this paper are to:

1. document the available data and discuss the survey research methodology (section 2);
2. describe the relevant economic and agronomic context, and to discuss the main patterns in the data regarding soil fertility and its management (section 3) ;
3. set out the economic theory which can frame this empirical analysis (section 4);
4. evaluate the potential of this data for constructing and testing empirical models of land resource management (section 5)

2 Survey Research

2.1 Survey Area

This research was conducted in the Eastern Region of Ghana near the large towns of Aburi and Nsawam, along the Akwapim Ridge. This area is where the forest belt that covers the middle of Ghana meets the scrub plain of the coast. The Akwapim ridge provides a physical boundary between these two ecosystems, as one climbs 1300 feet from the coastal plain to the town of Aburi.

We worked in four village clusters. These four areas were selected due to their participation in the growth of fruit and vegetable production in the region, as well as their variety of agronomic, market and geographic conditions. "Village 1" is a pair of adjacent villages a few miles from the large market town of Nsawam. Both villages were settled by Ashanti migrants during the 1850s. "Village 2" is also a pair of adjacent villages on an old road joining the two large towns. One of the pair was settled about 150 years ago; the other about 80 years ago. They joined together about 50 years ago. This village has the largest population of the four clusters with about 2030 people.[3] Five miles north of village 2 (and a 45 minute journey by vehicle) lies village 3, which consists of a main small village (population is around 340) and a pair of adjacent hamlets. The main village is quite young, settled in 1939. However, one of the hamlets

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[3] Population figures are calculated using the number of houses multiplied by the average household size (5.6) in our data adusted for a joint occupancy rate of 37% (GSS, 1995) in this region.

(pop. 110) was settled about 200 years ago. With limited access to non-farm income opportunities, village 3 is far and away the most agriculturally active community among the four. About a mile from the main road from Aburi to the capital of Accra is village 4. Settled in 1821, it has a population today of around 990 people. Twenty five years ago, cocoa farming was the major livelihood in village 4, and the village was fairly well off. Today no one is growing cocoa and farming has shifted to food crops. Despite this shift in agricultural income, the village has continued to grow, nearly doubling in size since the early 1970s.

2.2 Survey Operations

We initiated the survey in late November 1996. After taking a census of married couples and triples, we selected 60 in each village at random to participate. A pair of enumerators lived near or in each village cluster. The male enumerator interviewed the men and the female was responsible for the women. Before finishing in September 1998, these enumerators interviewed each respondent 15 times, at 5 to 6 week intervals. After an individual round of questions was completed, the file would be returned to the base office for data entry and review by either Udry or Goldstein, who supervised the first and second years, respectively. Field supervision was conducted by Ernest Appiah of the Institute of Statistical, Social and Economic Research (the host institution).

In addition to the village-based enumerators, another enumerator (actually two who alternated), rotated among the villages conducting a detailed plot questionnaire and mapping each plot. This plot data was complemented by soil samples drawn from each plot. The first soil samples were drawn from the plots by the village-based enumerators in November and December of 1996. In November and December of 1997, a second soil sample was taken from each plot by field staff under the direction of the village-based enumerators. These samples were analyzed by the department of soil science at the University of Ghana, Legon.

2.3 The Survey Instruments

In order to provide a comprehensive picture of agricultural production we collected an extensive set of data on farm activities. These questionnaires formed the core of each round and were repeated during all visits. In addition, we rotated in other, modular questionnaires. These modules allowed us to address a variety of issues and also for the evolution of questions as we repeated them. A complete list and copies of all survey instruments is available on the project website: http://www.econ.yale.edu/~udry/ghanadata.html. The following questionnaires are the most relevant for this discussion:

Plot Activities and Work on Spouse's Plot - The plot activities form provides the basic agricultural input and output data. Data on all labor and non-labor inputs and on all harvests from each plot cultivated by each respondent is requested. After it became clear that we were not achieving good coverage of the labor inputs by spouses on respondents' farms, we added the Work on Spouse's Plot questionnaire.

Output Sales and Sales from Spouse's Plot - These track the sale of output. Forward sales are recorded, as are the more common sales on consignment. In these cases, "continuation" forms follow the transaction until it is completed. In round 8 we began administering Sales from Spouse's Plot in order to track better the intrahousehold allocation of the proceeds from crop sales. In addition to plot activities, plot sales are part of the core set of questionnaires which were administered each round.

Plot Ranking - This questionnaire asks the respondent to rank all household plots in the order of fertility. It was administered in Rounds 8 (Oct. 1997) and 10 (Feb. 1998) before the results of the respective year's soil tests were provided to respondents.

Plot Questionnaire - Administered only once, this gathers extensive information on plot rights and features. It includes basic agronomic information such as the soil type, toposequence and recent crop history. It also asks for detailed information on the current contract and ownership history. Finally, it identifies the responsible party for a number of property rights (e.g. the right to sell output or the right to pledge the land).

2.4 Characterizing Soil Fertility

We mapped each plot using a Global Positioning System and Geographical Information Software.[4] We can use this data for a fairly accurate measurement of plot area. In addition to this geographic information, each plot was also tested for organic matter/carbon and pH.[5] Samples were collected by project staff from five locations on the plot, mixed and then a smaller sample was drawn. This soil was tested in the laboratories of the soil science faculty at the University of Ghana, Legon.

The ideal soil test would have been a complete assessment of all major nutrients, as well as micro-nutrient availability and a soil horizon profile. Given the sheer number of plots (we sampled 750 in the first year and over 1100 in the second), this was not feasible. Organic matter, however, should provide a good overall indicator of soil fertility because of its multifaceted impact on the soil and plant growth processes. While organic matter is not itself a plant nutrient, it is an important source of the nutrients which crops do consume. In addition, it is quite important for soil fertility in a number of other ways. First, it increases the cation exchange capacity, the soil's ability to absorb critical elements. Asadu, et.al (1997) estimate that organic matter accounts for about 60 percent of the soil's effective cation exchange capacity in sub-Saharan Africa.

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[4] The mapping was conducted using a Trimble GeoExplorer GPS receiver and a Community Base Station for post-processing differential correction. This procedure results in pointwise accuracies in the 1 to 5 meter range.

[5] Organic carbon was determined using the Walkley-Black wet oxidation method. Organic carbon multiplied by a constant (1.72) yields organic matter. Note that this test does not reveal the presence of fertilizers, which are inorganic compounds.

Organic matter also affects soil structure into particles that allow for improved aeration and water retention, as well as increasing the stability of soil particles which can help stem erosion . Finally, organic matter can absorb toxins (both naturally occurring and human-applied) that accumulate in the soil (Woomer, et. al. 1994). In some respects (such as the provision of cation exchange capacity) organic matter is more important in tropical soils than in temperate, as tropical soils are more weathered and have a lower level of available minerals (Duxbury et. al. 1989)

One way to gauge the relevance of organic matter as a proxy for overall fertility was to ask the farmers to rank their plots in terms of overall fertility and to compare this ranking with one based on organic matter. Under the null hypothesis of no correlation between the two measures of fertility, $s \equiv \sum_j (n_j - 1) \cdot \rho_j$ is distributed approximately $N(0,1)$, where n_j is the number of plots cultivated by farmer j and ρ_j is the spearman rank correlation between own rank and organic matter rank for each farmer with at least 5 plots. In our sample, $s = 10.83$, firmly rejecting the null hypothesis. Our measure of organic matter is correlated with the respondents' own assessments of plot fertility.

The test for pH provides a complement to that for organic matter. Not only is pH important for the growth of one of the major crops in this area (pineapple), it is also correlated with the nutrient availability. Acidic soils enhance the availability of trace elements for plant growth. Indeed, Duxbury, et. al. (1989) cite results that show the cation exchange capacity of soils increasing in direct proportion to pH above 5.0. Note though, that below 5.5, the exchange sites for the important trace elements can be blocked by aluminium or iron molecules. We discuss the particular pH needs of different crops below.

The soil tests were repeated after one year on the plots cultivated by our respondents. In the first year (1996-97), 738 plots were tested. In the next year we tested 1148 plots, including 626 which had been tested in the first year. Most of the increase in the sample size between the two years is accounted for by the fact that fallow plots were not tested in the first year, but were in the second.[6] In addition, some plots were missed by error in the first year. Of the 112 plots which were tested in the first year but not the second, about a third were dropped by error and the rest passed to individuals who were not in the sample.

3 The Agronomics of the Research Area: The Determinants of Organic Matter and pH

Organic matter and pH are determined by a diverse set of processes and factors. For the purpose of this analysis, we can divide these into two basic groups: anthropogenic and environmental. Anthropogenic changes stem mostly from the farming system: what is planted, how it is planted, the time between and dura-

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[6] The difficulty of reaching fallow plots was a significant obstacle to our enumerators in the first year. We hired additional staff in the second year for this specific task.

tion of fallows, and like factors. The physical environment, through topography, soil texture, climate, vegetation and rainfall, is also a key determinant. In this section, we briefly describe the features of the environment and farming systems of our study area which are the most important determinants of the soil fertility process.

The rainfall pattern is bimodal in the study region and agricultural activity tends to be concentrated around the major and minor cropping seasons defined by this rainfall pattern. However, pineapple can be produced during all months of the year in Ghana. Table 2 gives an overview of the annual pattern of agricultural production. There are two main harvest seasons, the minor season in December and the major in July-August.

The farmers in this area practice shifting cultivation, with fields left fallow after a period of cultivation in order to restore their fertility. The associated fertility cycle, with land fertility diminishing through a period of cultivation and then being restored during the fallow period, is the centerpiece of the theoretical model discussed in section 4.

The main tool for clearing at the end of a fallow is the cutlass, which also serves as the main overall agricultural implement. There is minimal use of hoes and almost no use of mechanical implements. However, the data we shall examine below indicates that the intensity with which land is being farmed is increasing, with obvious ramifications for long term fertility management. In order to set the context for a more formal discussion of the dynamics of fertility management, we now describe the current agronomic situation.

3.1 Soil

The main soil in this area can be classified as alfisols (USDA), which are well weathered, mineral soils. Table 3 provides the organic matter and pH results by year. The mean organic matter for both years is slightly higher than the 3.0% that Brady (1990) cites as representative of this type of soil.

In a system of shifting cultivation, soil fertility on continuously cultivated plots declines until it reaches a critical level at which it is fallowed. This pattern is observed in our data: for the 626 plots that were tested for both years, there was a 9 percent decline in OM over the year. pH also declined, by about 5 percent.

Geographic variables play an important part in the determination of organic matter and pH. Table 4 reports the organic matter and pH of plots by village. The soils around each village are quite different from each other, as we can see from the difference in organic matter. Village 2 has far and away the lowest fertility. The level of pH is also indicative of the geographic differences, witness village 1's much higher pH. Village 1 is relatively far from the other villages, so it is quite possible that the soils there are different on many levels from the others. These geographical factors combine with different farming systems to affect the way that fertility and pH change over time. Both OM and pH are declining most rapidly in village 3. We shall look at some possible reasons for this below.

Within each village, variation could be caused by many things: drainage, topography, soil type, and the like. We have data on topography classified into three categories: flat, slope, steep slope. Table 5 shows the organic matter and pH of these different toposequences. Steeper slopes have higher initial organic matter, yet experience a faster rate of decline than other areas. In terms of pH the steep slopes seem to be more stable than the others. This is in line with Ahn's (1993) observation that in the forest areas of Ghana some farmers choose to farm lithosols over rocks containing weatherable minerals since they are more fertile. This may also be responsible for the higher rate of OM decline, as the soil layer is thinner than elsewhere. One alternate explanation for this correlation would be that since steeper land entails more strenuous labor, it is farmer less intensively. We shall examine this in the context of fallow patterns, below.

We have classified the respondents' local names of their soil types into sand, loam and clay, according to the U.S. textural classification system. Table 6 provides the organic matter and pH of different soil types. Loamy soils are much closer to neutral pH and have marginally higher organic matter. When looking at the difference over the two year period, loamy soils tend to be more stable in organic matter with a much smaller change than the other types.

These geographic variables vary significantly across villages as well. For example, 69 percent of the land in village 1 is flat, while 22 percent of the land in village 4 is on a steep slope. Table 6 shows the distribution of soil types by villages. Again, the moutainside soils of village 4 set it apart.

3.2 Crops

The crops themselves use and contribute to organic matter in different ways. Maize and cassava are the main food crops, and they are often intercropped (with no crop clearly dominant), so we combine these plots into a single "maize, cassava and cocoyam" category which includes all combinations of these crops. Table 7 shows the organic matter and pH, by year, of the different crops.[7]

The difference in plot characteristics between pineapple and other crops is stark. Pineapple is planted on much more acidic land. Pineapple is also planted on soil with lower levels of organic matter. However, these differences in organic matter are driven almost entirely by villages. If we look at the difference in organic matter between pineapple and non-pineapple plots, the only place in which the difference is significant (at the 99 percent level) is village 1. The result that pineapple is planted on more acidic soil, however, is statistically significant for each village. The pH result is probably due to the fact that farmers recognize pineapple's need for more acidic soil, or as a by-product of the fertilizer used on these fields. In fact, each crop has a different optimal pH.

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[7] We used the plot activities form (administered each round) to categorize the crops grown on each plot. Thus, we only count a crop on that plot for the year if there was some activity (this includes harvesting and planting). Then we categorized the main crop on the plot using rules based on field observation (e.g. cassava can be intercropped with pineapple, but it is almost always planted only on the border of the plot).

Table 8 shows the number of plots in each village planted to the major crops where the pH level is too high, optimal, or too low.[8] The results indicate that the majority of fields planted to pineapple are too basic for that crop. The situation with maize is more varied. In village 1, the majority of maize fields had a pH that was above optimal. Village 2 had the problem of maize plots planted on plots that were to acidic. Villages 3 and 4, on the other hand, had plots planted on both ends of the spectrum. Given cassava's tolerance for a wide range of pH (5-8), almost all plots fell within the optimal values.

The central dynamic of the fallow system of fertility maintenance is evident in Table 9, which reports the changes in OM and pH on plots cultivated with the same crop in the two sample years. Organic matter and pH decline on all plots; significantly so on the plots devoted to the two main farming systems of the region. The decline in OM is quite large: for pineapple, the annual decline is equivalent to about 1/3 to 1/4 the cross-sectional standard deviation of plots planted with pineapple; for the maize/cassava system the decline is 1/4 to 1/5 the cross-sectional standard deviation.

3.3 Gender

Men are much more likely to grow pineapple then women. 90% of the plots cultivated by women are based on the maize/cassava farming system, while more than a third of the plots cultivated by men are devoted to pineapple (see Table 10). Women's plots appear to be less fertile than those of men: the median OM of maize/cassava plots cultivated by women is 3.10, while for men it is 3.38.[9] There is no significant difference in the pH of the maize/cassava plots cultivated by men and women. About half of the difference in the median OM of plots cultivated by men and women is accounted for by village effects. The remaining difference is .13 and statistically significant at the 10% level.

The rate at which fertility declines is lower on plots cultivated by women. The median decline in the pH of maize/cassava plots of women is identical to that of similar plots cultivated by men. However, the median decline in OM is lower on women's maize/cassava plots: -.06 compared to -.31 on men's maize/cassava plots.[10] Controlling for village effects, the difference is even more striking: the OM on men's maize/cassava plots declines much more rapidly than that on women's maize/cassava plots (the difference is .28 (p=.07)).

Gender differences in fertility decline (though not fertility) persist even when we examine differences within households. Within households, the median OM of maize/cassava plots cultivated by men and women are virtually the same (the difference is .03). However, the median decline in OM is much smaller on plots cultivated by women than on plots cultivated by their husbands (the difference is .33 (p=0.10)).

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[8] Note that for this table, intercropped fields were counted twice, once under maize and once under cassava.

[9] The p-value of the null hypothesis that these medians are equal is 0.02.

[10] The p-value of the null hypothesis that this difference is zero is 0.12.

Women cultivate plots which are less fertile than those of men, but the rate at which fertility declines on plots cultivated by women is less than on those cultivated by men. The gender differences in fertility and (especially) fertility decline are large, even within households.

4 A Simple Model of Fertility Dynamics

Soil fertility is a dynamic system which affects and is affected by crop growth. Our crucial hypothesis is that the relevant aspects of soil fertility can be represented as a single index $\phi(t)$. Obviously there are a host of factors that enter into what we call "soil fertility"; our working hypothesis is that these can be aggregated into a scalar index. It might be the case that different crops, soils or topographies might involve different functional relationships between $\phi(t), \dot{\phi}(t)$ and output, but in each case we hypothesize that the index itself is unchanged (Barrett 1991). We incorporated the assumption that this hypothesis is correct into the design of the fieldwork by asking our respondents to rank the fertility of their own and their spouses' plots.

We first describe some of the reduced form relationships between cropping patterns, fallow periods, and organic matter content that would be expected to hold if farmers optimally manage fertility. We describe the difficulties which arise if there are different forms of unobserved heterogeneity in the characteristics of different plots, and if households do not face complete markets. Finally, we discuss extensions of the model which permit an analysis of fertility choice on multiple plots within a household.

Most discussions in the economics literature of the management of soil fertility in developing countries treat the decision problem as one of the optimal extraction of a renewable resource (e.g. Donovan and Casey, 1998; Clay et al. 1998; Krautkraemer, 1994; Barrett, 1991. The source of the model is Lewis and Schmalensee 1977). Let $\tilde{\phi}$ be the maximum fertility obtainable, and normalize ϕ so that the minimal level of fertility (such that land degradation has become irreversible) is 0. Let $g(\phi)$ be the natural rate of regeneration so that on fallow land $\dot{\phi}(t) = g(\phi(t))$, where $g(\tilde{\phi}) = g(0) = 0$, with $g()$ concave.

The control variable is the anthropogenic change in fertility, which we denote by s. Profits can be increased by increasing the rate of soil deterioration, so profits at time t are $\pi(\phi(t), s(t))$ where π is increasing in both arguments. The cost of extracting resources from the soil, of course, is diminished fertility in the future: $\dot{\phi}(t) = g(\phi(t)) - s(t)$. We assume that $s \geq 0$.[11]

If the farmer has access to capital markets at an interest rate δ, his or her problem is to choose a function $s(t)$ to solve

$$\max \int_0^\infty e^{-\delta t}\pi(\phi(t), s(t))dt \tag{1}$$

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[11] This is not an entirely sensible assumption in a farming system of managed fallow. One would want to permit $s < 0$ to incorporate the notion that farmers might find it optimal to use costly resources on fallow plots to speed the regeneration of fertility (Amanor, 1994). For our current purposes, however, little is lost by this simplification.

subject to

$$\dot{\phi}(t) = g(\phi(t)) - s(t) \tag{2}$$

given an initial level of fertility $\phi(0)$. If both $\pi()$ and $g()$ are strictly concave and the discount rate is low enough (relative to $g'(\phi)$) then there will be a steady-state solution with a constant level of fertility ϕ^* such that

$$\frac{\pi_\phi(\phi^*, g(\phi^*))}{\pi_s(\phi^*, g(\phi^*))} + g'(\phi^*) = \delta, \tag{3}$$

where subscripts indicate partial derivatives with respect to the indicated argument.

This is not a sensible model for an agriculture based on repeated fallows, of course. Lewis and Schmalensee (1977) suggest that nonconvexities in $g(.)$ or in $\pi(.)$ can lead to optimal exhaustion of a renewable resource. In particular, there may be increasing returns to depleting soil resources, at least at low rates of resource depletion. For example, in order to keep a plot under cultivation it is necessary to disrupt natural processes of soil regeneration. Alternatively, cultivation may entail fixed costs (for example, a minimal amount of weeding) which can be avoided only by leaving the plot fallow. It may well be the case that the fixed cost is a function of the level of fertility, but that extension is not essential. Let F be the level of the fixed cost associated with $s(t) > 0$. The instantaneous profit function is now

$$\pi(\phi(t), s(t)) - F1(s(t)) > 0), \tag{4}$$

where $1(.)$ is the indicator function and F is the level of the fixed cost. When fertility is low enough, it may now be optimal to abandon the plot. The farmer's problem is now to chose T and the function $s(t)$ to maximize

$$V_a(\phi_0) = \int_0^T e^{-\delta t} \pi(\phi(t), s(t)) dt \tag{5}$$

subject to (2). Lewis and Schmalensee (1977, proposition 6) provide sufficient conditions for the existence of a unique $(T_a, s_a(t))$ solving (5).

A second fixed cost associated with resuming cultivation after a period of fallow can generate an optimal cycle of fallow and farming. In southern Ghana, this cost is the labor expenditure required to clear and prepare a fallow plot for cultivation. Let R be this cost. Lewis and Schmalensee (1977) provide a very simple set of sufficient conditions under which a cycle of land use associated with deteriorating fertility followed by a period of soil regeneration under fallow is optimal.[12] These conditions are that: (a) steady state profits at ϕ^* as defined in (3) are less than F; (b) there are levels of $\phi < \tilde{\phi}$ such that $s > 0$ can be chosen to make $\pi - F$ positive; and (c) $\exists \phi_s < \tilde{\phi}$ such that $V_a(\phi_s) > S$, that is, it is more profitable to return and farm the land rather than to abandon it.

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[12] Krautkraemer (1994) discusses the same set of conditions.

4.1 Empirical Implications

The reduced form implications of this model are very strong if markets are complete, plots are identical (conditional on observables) and OM measures (perhaps with error) ϕ. If these assumptions are correct, then the optimal path of soil depletion is identical across plots, enabling us to write the profits of currently cultivated plots as a function only of current fertility, which itself is only a function of the time since the plot was last fallowed. Hence, looking at the cross section of plots:

1. OM falls on the plots cultivated between the two OM measurements. The rate of this fall depends only on the time since last fallowed.
2. OM on cultivated plots is a monotonically declining function of time since last fallowed, with measurement error in OM as the only source of variation around the function.
3. Plot profit is a monotonically decreasing function of time since last fallowed.
4. There is a critical level $\hat{\phi}$ at which the plot is abandoned to fallow. Although OM measures ϕ with error, on average plots left fallow in year 2 will have lower OM than plots which continue to be cultivated.
5. All plots are cultivated for the same number of years before being fallowed.

4.1.1 Incomplete Markets

It is not the case that markets are complete in our sample villages. In particular, financial markets are imperfect and it is likely that different households face different trade-offs between present and future consumption. We will provide a formal treatment of financial markets and liquidity constraints in future work, but for now the main points are clear if we allow λ to vary across households. In equation (1) λ is replaced by λ_h, otherwise the problem is unchanged. The optimal time path of resource extraction $s^*(t)$ obviously depends on λ_h, weakening the implications noted above. Many of the empirical implications now depend on conditioning on λ_h.

1. OM falls on cultivated plots. However, the rate of the fall depends on λ_h.
2. Conditional on λ_h,OM is a monotonically declining function of the time since last fallowed. With strong but intuitive conditions on $\pi(.)$ and $g(.)$, the rate at which OM declines is a decreasing function of $\lambda_{h.}$
3. Plot profits have no simple unconditional relationship with the time since last fallowed.
4. Remains unchanged.
5. The number of years between fallows increases with λ_h.

4.1.2 Intrahousehold Issues

If the intrahousehold allocation is Pareto efficient, then each cultivator within a household shares a common λ_h, and the implications discussed in section 4.1 hold for within household comparisons. A rejection of those implications then implies either that the model of fertility management is incorrect, or that intrahousehold resource allocation is not Pareto efficient.

4.1.3 Plot Level Heterogeneity

Unobserved heterogeneity at the plot level can make the derivation of reduced form restrictions more difficult, depending upon the form of this heterogeneity. If the heterogeneity takes the form of (either permanent or transitory) plot specific variation in fertility which is uncorrelated with measured OM, then most of the implications above continue to hold because this can be interpreted as measurement error in OM. If, however, the heterogeneity enters into the determination of profits or the evolution of fertility in a more general way, then the reduced form restrictions are weakened. For example, suppose instantaneous profits are

$$\tilde{\pi}(\phi(t), s(t), \varepsilon) \equiv \pi(\phi(t), s(t), \varepsilon) - F1(s(t)), \tag{6}$$

where ε is a time-invariant plot effect. Letting the subscripts h indicate households and p plots, the optimal path of soil depletion on cultivated plots will be a function $s^*(t; \varepsilon_{hp}, \lambda_h)$. During the period of cultivation, $\dot{\phi}^*(t; \varepsilon_{hp}, \lambda_h) = g(\phi^*(t; \varepsilon_{hp}, \lambda_h)) - s^*(t; \varepsilon_{hp}, \lambda_h) < 0$. If $\partial\pi/\delta\varepsilon > 0$, then under restrictive but intuitive conditions we have the result that conditional on λ_h and current fertility ϕ, the rate of depletion is increasing in ε. Consequently, plots with high unobserved productivity (ε) will have lower fertility (ϕ) for any given time since last fallowed. On any given plot, the time path of profits remains downward sloping. However, even conditional on λ_h the cross-sectional correlation between profits and time since last fallowed cannot be signed: plots with high unobserved ε will have high profits and long periods between fallows, mitigating or reversing the expected inverse relationship between time since fallow and profitability.

5 Preliminary Findings

The purpose of this section is to examine the survey data in the light of the primary implications of the simple model of optimal fertility management presented in section 4.

5.1 The Decline in Fertility on Cultivated Plots

Perhaps the most important assumption we have made is that the dynamics of soil fertility can be summarized along a single dimension, and that soil organic matter is a measure (perhaps afflicted by classical measurement error) of fertility.

If fertility is one-dimensional, then in a farming system characterized by cycles of cultivation and fallow, fertility declines during cultivation and is restored during fallow. In section 3.1 we noted that the first half of this pattern is observed in our data. In Figure 1, we show the distribution of changes in soil OM for plots cultivated between the two soil testing dates, separately for pineapple and other crops. The median decline in OM on cultivated plots is -.22 (the median level of OM at the first observation on these plots is 3.14); there is no significant difference in the decline in organic matter on plots cultivated with different crops. Nor is there any difference in the decline in OM across villages, but as can be seen in Table 11, there are important differences according to physical features of the plot. In particular, OM declines very rapidly on steep slopes and much less rapidly on loamy soil. There is no reason to expect that the rate of fertility decline is constant over the period of cultivation, but we find no significant variation in the rate of OM decline according to the length of time since the plot was last fallowed.

It is not possible to use the same method to test the hypothesis that soil OM increases during periods of fallow, because we do not have repeated soil measurements on fallowed plots.

The next important implication of our simple model of fertility dynamics is that fertility is a declining function of the years since the plot was fallowed. If capital markets are complete, this relationship is conditional only on physical characteristics of the plot; if different households face different opportunity costs of current consumption, then this relationship is conditional on λ_h. Figure 2 summarizes the main patterns in the data. This figure is a kernel regression of the relationship between the number of years since a plot was last fallowed and its soil OM measure.[13] There is some evidence of a decline in soil OM in the first few years after a plot is brought into cultivation, but equally strong evidence of a *rise* thereafter. In either case, the changes are tiny; the annual changes are several orders of magnitude smaller than those estimated when using repeated observations on the same plot. This pattern recurs in other specifications, including specifications that attempt to condition on λ_h. In the first pair of columns in Table 12 it can be seen that conditional on the wealth of a household, there is a significant decline in OM with increases in the number of years since a plot was last fallowed. This decline continues through the first 9 years after a plot is brought back into cultivation for a household with median wealth holdings; only 1 percent of the sample plots have been cultivated for more than 10 years. But the size of this decline is very small. The point estimates imply that after 2 years of cultivation, a plot cultivated by a household with median wealth holdings will have an annual decline in OM of -.06, just over 1/4 the size of the decline estimated when using repeated observations on the same plot.

There are three straightforward explanations for this pattern of results. First, it may be the case that the measure of fallow history is contaminated

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[13] This is a partial linear model with linear controls for village, soil type and toposequence dummy variables. In the nonlinear componant, the Epanechnikov kernel is used, with a bandwidth of 1.2.

by a significant amount of measurement error. The complexity of the region's farming system makes responding to this question more difficult than might at first be apparent. Plots are cleared from thick secondary forest and brush, their boundaries change over time, and different parts might be cleared or left fallow at different times. The smaller estimates of the decline in fertility over time in the cross-section than in the panel estimates could be an artifact of this measurement error.

Second, the large decline in OM on those plots cultivated in 1996 might reflect an unusual year effect. The second pair of columns in Table 12 provides some evidence of the strength of this effect: plots tested in the second year of our survey have a significantly lower OM than plots tested in the first, conditional on the number of years since the plot was last fallow. Soil OM responds to environmental factors like rainfall, hence aggregate shocks to OM are possible. Our estimate of the decline in OM based on repeated measurement of OM on cultivated plots cannot distinguish between an aggregate shock to OM and the general decline caused by cultivation.

Third, it might be the case that OM is not an estimate of soil fertility, or that fertility is multi-dimensional. The fallowing/cultivation cycle may be driven by consideration such as those which were incorporated into the model of section (4), but soil OM might not be an estimate of ϕ. For example, it might be the case that the primary determinant of cultivation and fallowing decisions is the micro-ecology of the plot, primarily the composition and extent of weed growth.[14] Alternatively, both OM and other dynamic characteristics of the plot might be important dimensions of soil fertility, in which case the simple model of section (4) with a single state variable is inappropriate. The dynamics of the fallow/cultivation cycle would be altered in important ways by appropriate changes in the model, and it would in general no longer be the case that a monotonic decline in OM over the period of cultivation would be optimal.

5.2 The Decline in Profits with Cultivation/Fertility

The next important implication of the model is that annual profits decline as cultivation proceeds. Table 13 presents an examination of this hypothesis. The determinants of profits on pineapple plots are described in the first pair of columns. Per hectare profits on these plots are increasing in the number of years since the plot was fallowed. This increase is large and statistically significant: an additional year since last fallowed is associated with an increase in per-hectare profits of over 600,000 cedis; median per-hectare profits on pineapple plots are slightly less than 4 million cedis. Similarly, per-hectare profits increase with increases in the number of years since fallowed on maize and cassava plots. The point estimate of the annual increase is about 90,000 cedis, while median per-hectare profits on these plots are about 95,000 cedis.

In section (5.1) we concluded that the number of years since a plot was fallowed could be measured with substantial error. Hence we also investigate

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[14] Amanor (1994) argues that this is an important consideration in a nearby region of Ghana.

the direct relationship between fertility and profitability. These results are summarized in Figures 3 and 4 show the nonlinear component of the partial linear model

$$\pi_{hp} = X_{hp}\beta + f(OM_{hp}) + \upsilon_{hp},$$

where X_{hp} is a vector consisting of village, toposequence and soil indicators, and initial soil pH. The regression is estimated separately for pineapple and maize/cassava farms. There is no strong positive relationship between measured OM at the start of the farming season and per-hectare profits for either pineapple or maize/cassava farms. There is some evidence that the per-hectare profits are inversely related to initial OM on maize/cassava farms, but the confidence intervals are quite wide. On pineapple plots, there appears to be no strong relationship between profitability and OM, except that profits might increase with initial soil OM on the approximately five percent of plots with OM greater than 5%.

There is no evidence in this data that profits decline with cultivation, nor that they are affected by our measure of soil fertility. As noted in section (4), some forms of unobserved heterogeneity in plot characteristics imply that there is no determinate cross-sectional relationship between the number of years of cultivation and profitability. Unobservably "good" plots might have high profits and be cultivated for long periods of time, mitigating or reversing the expected inverse relationship between the number of years since a plot was fallowed and its per-hectare profits.

We have hypothesized that soil OM is an error-ridden estimate of ϕ, plot fertility. The estimated relationship between plot OM and profit, therefore, is expected to be more flat than the hypothesized positive relationship between ϕ and profit. Our estimates of a zero or negative slope, however, is disappointing and implies that there is a substantial amount of measurement error intervening between ϕ and OM.

5.3 Fertility and Fallow Choice

Plots are left fallow when their fertility falls below a critical level. In our sample, however, there is no evidence that plots left fallow have lower soil OM than plots continuing in cultivation. Consider only plots cultivated in the first year of our sample, and the soil tests conducted at the end of that first year. The mean OM of plots left fallow in the second year is 3.01, while the mean OM of plots which were cultivated in the second year is 3.03, a tiny and statistically insignificant difference ($t = 0.09$).[15] Nor is there a significant difference in the OM of plots which are left fallowed and those which continue in cultivation once we condition on other plot characteristics. Table 14 reports the results of a probit of the second-year fallow choice. The sample includes all plots which were cultivated

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[15] There is a similarly small and statistically insignificant difference in the median OM of the two types of plots. Plots left fallow have a median OM of 2.85, while plots continuing in cultivation have a median OM of 2.88 ($t = 0.13$, $p = 0.90$).

in the first year of the survey and one of the dependent variables is the plot soil OM at the end of the first year of cultivation. There is no evidence that plots with lower OM are more likely to be left fallow than plots with higher OM, conditional on other plot characteristics. The point estimate implies the opposite, but the coefficient is very small and statistically insignificant.

6 Implications

It is not appropriate to draw policy or substantive economic conclusions from this preliminary analysis. We find, for example, that women cultivate plots with a lower proportion of soil organic matter than men, and that the rate of decline of soil organic matter is lower on women's plots (even looking within households). Given the rich literature on the important role of soil organic matter in the determination of soil fertility in fallow farming systems, it is tempting to conclude that women are cultivating plots with lower fertility than men, but that they are husbanding soil resources more carefully. However, the results presented in section (5) provide no support for treating measured soil organic matter as an estimate of an underlying unidimensional factor corresponding to soil fertility, even conditioning on other observable plot attributes.

This paper examined the reduced form implications of a single model of fertility management. The fact that the empirical results do not match the reduced form implications of the model can be understood in two different ways:

1. The model of section (4) might be correct, but soil organic matter might be a poor measure of ϕ. For example, it may be the case that certain areas face different limiting nutrients. Many soil nutrients affect plant growth in a non-continuous fashion and may present the binding constraint on plant growth. If this constraint is binding, then additional organic matter will be virtually useless, as the plant cannot utilize this (and other nutrients) until the limiting nutrient is supplied. . If this interpretation is correct, then our future work on land resource management will have to rely on more indirect inference. While the ideal way to deal with the mismeasurement problem would be to obtain an in-depth soil profile for each plot, our GIS information can be used to manage much of the spatial heterogeneity. This can be coupled with our data on agronomic choices such as cultivation intensity, fallowing, and investment in land improvements to test models of resource management, but we cannot rely on what we hoped would be a direct measure of current soil fertility.

2. The model of section (4) might be incorrect. In particular, our assumption that soil fertility can be summarized by a single state variable might be inappropriate. It might be the case that soil organic matter is a good measure of one dimension of soil fertility, as it is an underlying stock from which many of the nutrients in a fallow farming system are derived. However, other dynamic aspects of the plot (for example, soil depth or nature

and extent of weed growth) might also be important for the overall current and future productivity of the plot. If this interpretation is correct, then a new model of optimal fertility management is required, one which accommodates multiple dimensions of fertility. Some of these dimensions would be unobserved, so it will be necessary to derive implications for that subset which is observed.

6.1 Further Work

The most immediate task is to incorporate property rights more explicitly into this model. There are a number of ways through which the rights over the plot will affect the path of fertility. First, there is the form of the contract. We observed that the rent was often crop-contingent, thereby indicating that the landlord often took into account the impact of the crop on the soil in setting the terms. Different contract types, be they share cropping, cash rents, or conditional loans, all have different incentives for the farmer regarding fertility. Obviously, the time horizon of the contract will affect the discount rate of the farmer. However, any uncertainty over the security of the contract will also affect the farmer's decision. Furthermore, the residual or long-term rights that the farmer has over the plots are also important. One can imagine a farmer treating land on loan from a family member quite differently when she knows she will inherit it than when she knows she will not. The promixity and involvement of the landlord is also important, for in cases where the landlord cannot monitor fertility drawdown, the farmer may behave differently than in cases where the landlord can. In addition to monitoring, much of the land comes from family members where one might imagine there exist a greater set of interlinked transaction type enforcement mechanisms for landlords to prevent tenants from reneging on their promise to maintain plot fertility. A good deal of work has been carried out by economists examining the relationship between fixed investment and land rights (Feder and Feeney; Migot-Adholla et al; Bassett and Crummey; Besley). Studies based on the most detailed surveys of land rights in Africa provide only mixed evidence of any relationship between measures of the security of tenure and investment decisions. We can contribute to this literature by testing the hypothesis that the management of a plot's fertility depends on the cultivator's multifaceted property rights over the plot.

7 References

Ahn,PM (1993): Tropical Soils and Fertilizer Use. Harlow: Longman Scientific and Technical, .

Amanor,Kojo Sebastian (1994): The New Frontier: Farmers' Response to Land Degradation, A West African Study. Zed Books, London.

Aryeetey,Ernest (1993): Financial Integration and Development in Sub-Saharan Africa: A Study of Informal Finance in Ghana. Manuscript; ISSER/Legon.

Asadu,C; Diels,J; Vanlauwe,B (1997): A Comparison of the Contributions of Clay, Silt, and Organic Matter to the Effective CEC of Soils of Subsaharan Africa. Soil Science of American Journal 162(11:785-794), .

Barrett,Scott (1991): Optimal soil conservation and the reform of agricultural pricing policies. Journal of Development Economics 36(1, April), 167-187.

Bassett,Thomas; Crummey,Donald (Eds.) (1993): Land in African Agrarian Systems. University of Wisconsin Press, Madison.

Besley,Timothy (1995): Property Rights and Investment Incentives: Theory and Evidence from Ghana. Jpe 103(5, October), 903-937.

Brady,NC (1990.): The Nature and Properties of Soils. 10th ed. MacMillan, New York.

Clay,Daniel; Reardon,Thomas; Kangasniemi,Jaakko (1998): Sustainable Intensification in the Highland Tropics: Rwandan Farmers' Investments in Land Conservation and Soil Fertility. Economic Development and Cultural Change 46(2, January), 351-377.

Donovan,G and Casey,F (1998): Soil Fertility Management in Sub-Saharan Africa. World Bank Technical Paper No. 408, Washington, D.C. The World Bank.

Duxbury,J; Smith,M; Doran,J; Jordan,C; Szott,L; Vance,E (1989): Dynamics of Soil Organic Matter in Tropical Ecosystems. In: Soil Organic Matter as a Source and a Sink of Plant Nutrients. (Eds: Coleman,D; Oades,J; Uhara,G) University of Hawaii Press, Honolulu, . (N)

Feder,Gershon; Feeny,D (1991): Theory of Land Tenure and Property Rights. World Bank Economic Review 5(1), 135-153.

Goldstein,Markus; Udry,Christopher (1999): Agricultural Innovation and Resource Management in Ghana. Final Report to the International Food Policy Research Institute.

Gyasi,EA; Agyepong,GT; Ardayfio-Schandorf,E; Enu-Kwesi,L; Nabila,JS; Owusu-Bennoah,E (1994): Environmental Endangerment in the Forest-Savanna Zone of Southern Ghana. United Nations University.

Hawthorne,WD; Abu-Juam,M (1995): Forest Protection in Ghana With Particular Reference to Vegetation and Plant Species. IUCN/ODA/Forest Department Republic of Ghana, Cambridge, UK.

Hill,Polly (1963): Migrant Cocoa-Farmers of Southern Ghana., Cambridge; Cambridge University Press.

Klingelhofer,A (1972): Akwapin Handbook. In: Agriculture. (Ed: Brokensha,D) Ghana Publishing Corporation, Accra

Lewis,Tracy; Schmalensee,Richard (1977): Nonconvexity and Optimal Exhaustion of Renewable Resources. International Economic Review 18(3, October), 535-552.

Migot-Adholla,Shem; Hazell,Peter; Blarel,Benoit; Place,Frank (1991): Indigenous Land Rights Systems in Sub-Saharan Africa: A Constraint on Productivity? World Bank Economic Review 5(1), 155-175.

Udry,Christopher; Aryeetey,Ernest (1995): The Characteristics of Informal Financial Markets in Africa. Manuscript: University of Ghana.

Woomer,P; Martin,A; Albrecht,A; Resck,D; Scharpenseel,H (Eds.) (1994): The Importance and Management of Soil Organic Matter in the Tropics. John Wiley with the Tropical Soil Biology and Fertility Programme and Sayce Publishing, Chichester.

Table 1: Seasonal Agricultural Activities in Ghana

Weather	Month	Agricultural Activities
Dry Season	November	Cutting and cleaning
	December	Yam and maize harvesting
	January	Cassava harvesting
	February	Burning and brushing
	March	Cultivation of crops (maize, cassava) Weeding
Rainy Season	April	
	May	
	June	
	July	Maize harvesting
Minor Rains	August	Yam harvest, weeding
	September	Second maize planting
	October	

Source: Adapted from Kingelhofer (1972)

Table 2
Soil Testing Results

% organic matter	mean	median	standard dev.	number
1997	3.31	3.13	1.34	738
1998	3.05	2.92	1.14	1148
1997-1998 change	-0.30	-0.22	1.41	626
pH				
1997	6.4	6.4	0.76	738
1998	6.1	6.1	0.78	1148
1997-1998 change	-0.3	-0.3	0.73	626

Table 3a
Organic Matter and Village

	% OM, 1997		# obs, 1997	% OM, 1998		# obs, 1998	change in OM		# obs
village	mean	st.dev.		mean	st dev.		mean	st dev.	
Daman	3.51	1.04	169	3.41	1.14	219	-0.16	1.12	140
Pokrom	2.42	1.24	173	2.23	0.88	256	-0.15	1.30	140
Oboadaka	3.41	1.38	203	2.99	0.97	363	-0.49	1.64	169
Konkonuru	3.82	1.24	193	3.55	1.13	310	-0.35	1.44	177

Table 3b
pH and Village

	pH, 1997		# obs, 1997	pH, 1998		# obs, 1998	change in pH		# obs
village	mean	st.dev.		mean	st dev.		mean	st dev.	
Daman	7.2	0.39	169	7.0	0.47	219	-0.28	0.50	140
Pokrom	6.0	0.64	173	5.9	0.64	256	-0.24	0.77	140
Oboadaka	6.2	0.70	203	5.9	0.72	363	-0.37	0.73	169
Konkonuru	6.3	0.73	193	6.0	0.76	310	-0.29	0.85	177

Table 4a
Organic Matter and Toposequence

	% OM, 1997		# obs, 1997	% OM, 1998		# obs, 1998	change in OM		# obs
topo.	mean	st.dev.		mean	st dev.		mean	st dev.	
flat	3.25	1.28	355	2.98	1.09	477	-0.28	1.36	309
slope	3.37	1.37	211	3.13	1.08	314	-0.35	1.58	189
steep slope	4.23	1.39	54	3.63	1.26	117	-0.56	1.25	50

Table 4b
pH and Toposequence

	pH, 1997		# obs, 1997	pH, 1998		# obs, 1998	change in pH		# obs
topo.	mean	st.dev.		mean	st dev.		mean	st dev.	
flat	6.5	0.74	355	6.2	0.76	477	-0.31	0.65	309
slope	6.3	0.76	211	6.0	0.81	314	-0.32	0.80	189
steep slope	6.1	0.84	54	6.0	0.86	117	-0.21	0.86	50

Table 5a
Organic Matter and Soil Type

	% OM, 1997		# obs, 1997	% OM, 1998		# obs, 1998	change in OM		# obs
	mean	st.dev.		mean	st dev.		mean	st dev.	
sand	3.40	1.37	361	3.08	1.13	539	-0.38	1.47	313
loam	3.47	1.22	110	3.32	1.14	172	-0.07	1.31	97
clay	3.25	1.38	151	3.00	1.11	196	-0.39	1.40	138

Table 5b
pH and Soil Type

	pH, 1997		# obs, 1997	pH, 1998		# obs, 1998	change in pH		# obs
	mean	st.dev.		mean	st dev.		mean	st dev.	
sand	6.3	0.75	361	6.1	0.77	539	-0.3	0.75	313
loam	6.8	0.65	110	6.5	0.78	172	-0.2	0.66	97
clay	6.2	1.40	151	5.9	0.76	196	-0.4	0.69	138

Table 6
Soil Type and Village

	Daman	Pokrom	Oboadaka	Konkonuru
sand	41%	52	62	77
loam	41	14	10	19
clay	19	34	28	5

Table 7a

Crop Planted and Organic Matter

	% organic matter, 1997			% organic matter, 1998		
crop	mean	st dev	# of obs	mean	st dev	# of obs
pineapple	2.90	1.34	213	2.49	1.03	197
maize/cassava /cocoyam	3.45	1.32	351	3.19	1.14	464
veg/other mix	3.81	1.30	71	3.36	1.26	42
tree	3.40	1.02	27	3.52	1.02	37
fallow	2.91	1.40	4	3.01	1.14	35

Table 7b

Crop Planted and pH

	pH, 1997			pH, 1998		
crop	mean	st dev	# of obs	mean	st dev	# of obs
pineapple	6.1	0.71	213	5.8	0.71	197
maize/cassava /cocoyam	6.5	0.74	351	6.3	0.78	464
veg/other mix	6.6	0.69	71	6.2	0.85	42
tree	6.9	0.54	27	6.8	0.57	37
fallow	6.0	0.90	4	6.0	0.83	35

Table 8: Number of Plots Planted in Optimal pH range

	pineapple			maize			cassava		
Village	below	opt.	above	below	opt.	above	below	opt.	above
1	0	2	48	2	71	105	0	199	1
2	1	65	133	22	27	4	4	112	0
3	1	72	88	22	42	15	6	209	2
4	0	0	0	38	55	15	15	217	0

optimal pH levels are: pineapple 4.5-5.5 (Bartholomew and Kadzimin), maize: 6-7 (Ahn), cassava: 5-8 (Ahn)

Table 9 Changes in OM and pH on plots planted to the same crop 1997-1998					
	change in organic matter		change in pH		
	mean	st err	mean	st dev	# of obs
pineapple	-0.32	0.14	-0.27	0.07	108
maize etc.	-0.24	0.10	-0.30	0.05	154
other mix	-0.42	0.33	-0.40	0.14	7
tree	-0.18	0.24	-0.33	0.09	18
All crops	-0.25	0.07	-0.28	0.04	220

Table 10: Cropping Patterns by Gender (number of plots per crop)

Crop	Women	Men
Pineapple	32	289
Maize/Cassava/Cocoyam	378	523
Other mix	6	31
Trees	4	29

Table 11: Plot Characteristics and Change in Organic Matter
LAD Regressions

Variable	Coefficient	t	Coefficient	t
soil type = loam	0.47	2.90	0.43	2.08
soil type = clay	0.18	1.27	0.19	1.06
toposeq = slope	-0.06	-0.46	-0.01	-0.08
toposequ = steep slope	-0.47	-2.21	-0.45	-1.68
years since fallowed			0.03	0.99
constant	-0.25	-2.70	-0.37	-2.49
	N=543, F(4,538)=3.36, p=0.01		N=517, F(5,511)=1.74, p=0.12	

Table 12: Plot Characteristics and the Level of Organic Matter
LAD Regressions

Variable	Coefficient	t	Coefficient	t
Village 2	-1.30	-7.12	-1.21	-7.85
Village 3	-0.40	-3.08	-0.31	-2.83
Village 4	0.21	1.64	0.26	2.38
Soil type = loam	0.14	1.18	0.21	2.05
Soil type = clay	0.15	1.24	0.15	1.47
Toposeq = slope	0.10	1.01	0.12	1.41
Toposeq = steep slope	0.67	4.76	0.68	5.76
Years since fallowed	-0.086	-2.16	-0.065	-1.92
(years since fallowed)^2	0.004	2.25	0.003	2.25
Wealth	-0.091	-1.17	-0.120	-1.83
Wealth * years since fallowed	0.023	1.11	0.024	1.34
Test in year 2 of survey			-0.21	-2.75
Constant	3.40	19.91	3.42	3.19
	N = 1146; F(11, 1134)=12.74, p=0.00		N=1146; F(12,1133)=17.15, p=0.00	

Table 13: Determinants of Per-Hectare Profits
(Thousands of Cedis)
(LAD regressions)

	Pineapple Plots		Maize/Cassava Plots	
	Coefficient	t	Coefficient	t
Village 2	-1653.65	-0.82	30.96	0.21
Village 3	-2643.37	-1.32	-346.12	-3.40
Village 4	-7354.65	-2.07	-271.10	-2.78
Soil type = loam	-3081.11	-1.75	-123.94	-1.41
Soil type = clay	-2029.67	-1.67	49.91	0.57
Toposeq = slope	-1348.30	-1.17	28.30	0.41
Toposeq = steep slope	-2274.01	-0.85	0.15	0.00
Initial level of pH	-2088.73	-2.52	-16.03	-0.32
years since fallowed	682.86	2.25	91.63	7.55
constant	19786.95	3.20	250.72	0.68
	N=117; F(9,107)=8.35, p=0.00		N=312; F(9,302)=11.42, p=0.00	

Table 14: Probit Estimates of Fallow Choice in 1997/98

	Change in P(fallow)	t
Village 2	0.03	0.97
Village 3	0.02	0.68
Village 4	-0.01	-0.31
Soil type = loam	0.00	0.09
Soil type = clay	-0.02	-1.21
Toposeq = slope	0.92	11.80
Toposeq = mid slope	0.70	12.69
Toposeq = steep slope	0.98	9.09
OM after 1996/97 season	0.01	0.91
sample: all plots cultivated in 1996/97	N=635; χ^2(9)=3420, p=0.00	

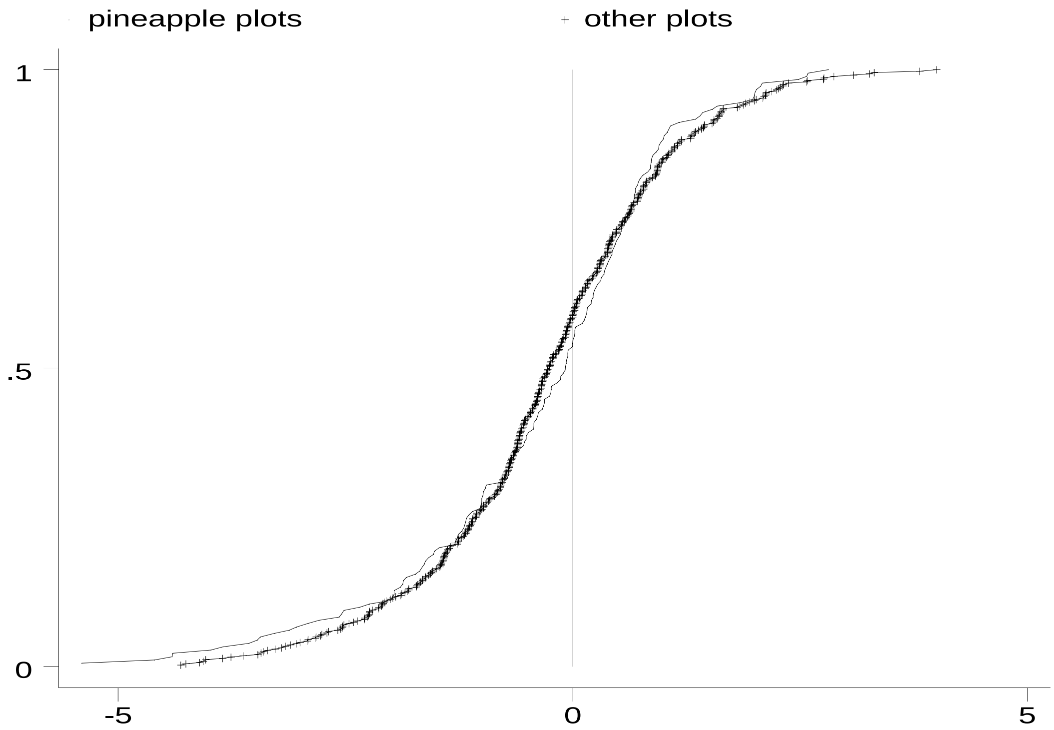

Figure 1: Distribution of Changes in OM on Cultivated Plots

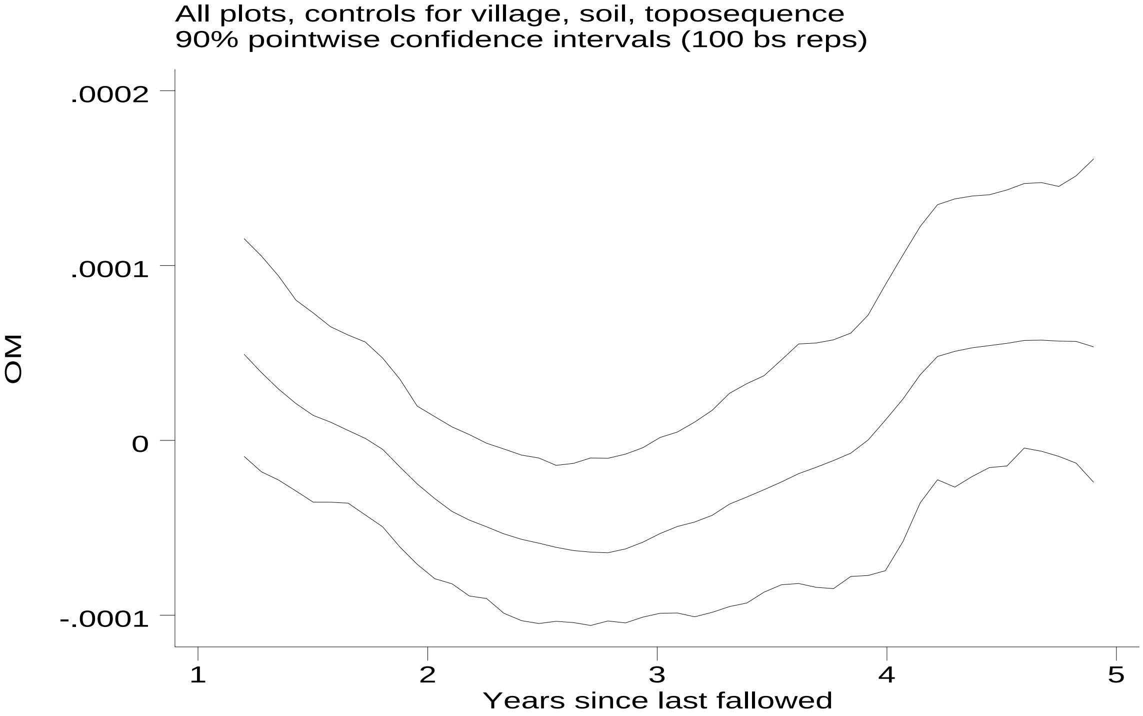

Figure 2: Time Path of Soil OM

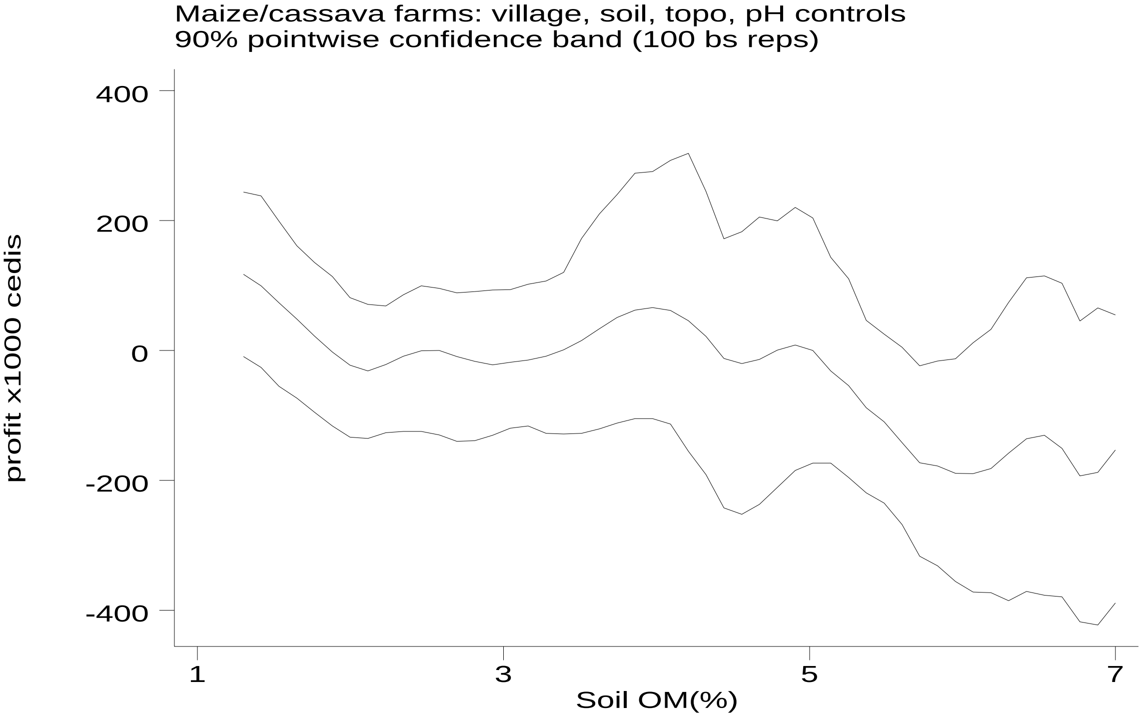

Figure 3: Soil OM and Profits on Maize/Cassava Farms

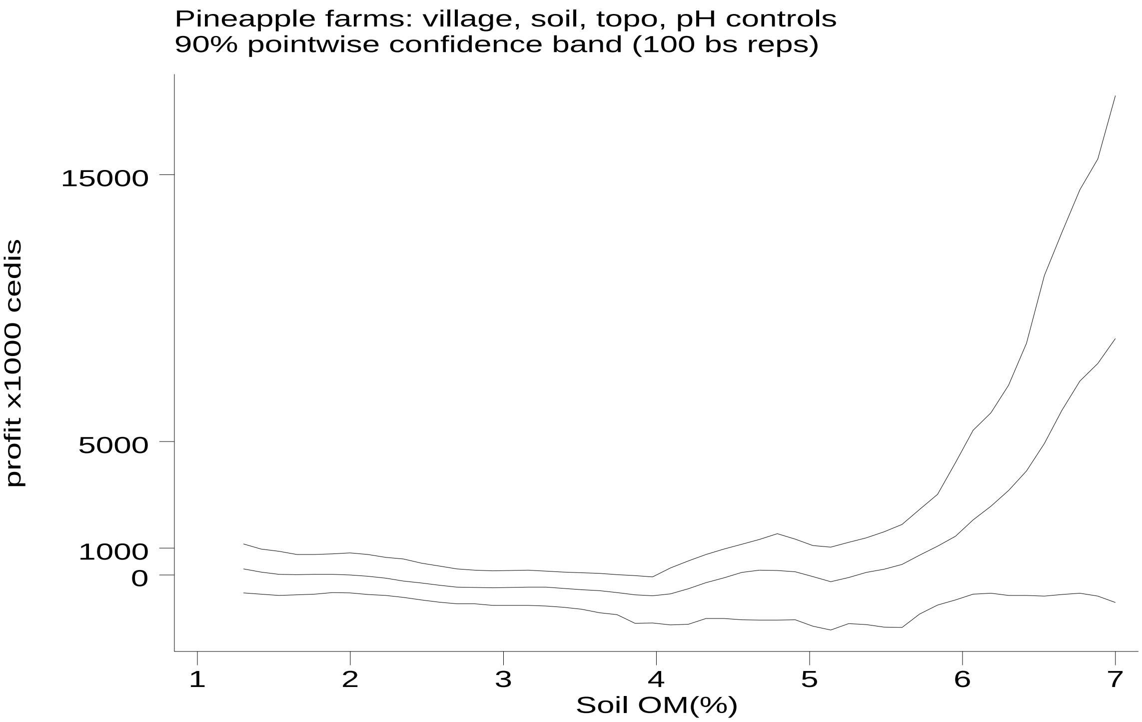

Figure 4: Soil OM and Profits on Pineapple Farms