An optimal phased replanting approach for cocoa trees with application to Ghana

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Abstract

This study solves for the optimum replacement rate (ORR) and initial replacement year (IRY) of cocoa trees (*Theobroma cacao*) in Ghana to maximize net present value and achieve steady state by employing a phased replanting approach. The annual ORR is 5%–7% across the three production systems studied: Low Input, Landrace Cocoa, High Input, No Shade Amazon Cocoa, and High Input, Medium Shade Cocoa. The optimal IRY ranges from year 5 to year 9 as a function of cocoa prices, fertilizer prices, labor prices, and percentage yield loss due to disease outbreaks. Deterministic results project economic gains that exceed currently practiced replacement approaches by 5.57%–14.67% across production systems with reduced, annual income volatility. The method applied in this study can be used to increase cocoa yields and stabilize income over time, and facilitate substantial quality of life improvements for many subsistence cocoa farmers in Ghana and around the world.

1. Introduction

Agriculture has historically played an important role in the Ghanaian economy. It accounted for 35.4% of gross national product (GNP) in 2007 (Bank of Ghana, 2008) and employed 56% of the total population (Central Intelligence Agency (CIA), 2011). Ghana was the world's largest cocoa (*Theobroma cacao*) producer in the early 1960s. From 2000 through 2007, annual Ghanian cocoa output averaged 614,500 tons (Food and Agriculture Organization of the United Nations (FAO), 2011) which contributed a mean 4.9% of total gross domestic product (GDP) (Bank of Ghana, 2008; Breisinger et al., 2007). Ghana experienced a large cocoa production yield decrease, partially due to aging tree stocks, from 580,500 tons in 1964 to a low of 293,355 tons in 1990 (FAO, 2011). Aging tree stocks are such a serious problem that, according to Bloomberg (2012), the Ghanaian government is subsidizing new tree replanting to increase national production to about 1.2 million tons per year by 2015. Ghana's average annual cocoa yield over the last 30 years (330 kg/ha) is among the lowest in the world and compares unfavorably to leading producers such as Cote d'Ivoire (580 kg/ha) and Indonesia (770 kg/ha). The World Bank (2011) suggests that one of the largest drivers of declining farm productivity is aging tree stocks. Low productivity results in low income for cocoa farming households in Ghana. According to a recent survey of 3,000 cocoa farmer households across Ghana, the average annual household income is 716 Ghanaian Cedi or roughly 375 USD (World Bank, 2011).

Previous studies (Asare and David, 2010; Gro-Cocoa, 2008; Hardy, 1960; Montgomery, 1981) show that retaining cocoa trees beyond their economically productive life is considered to be one of the largest contributors to diminishing cocoa yields. Vos and Krauss (as cited in Gro-Cocoa, 2008) report that most cocoa trees in many parts of West Africa are abandoned by cocoa producers after the trees have become old enough to have zero yield. Furthermore, the trees are subsequently not replanted or replaced. Unlike most conventional annual crops, cocoa producers have to weigh the benefits and costs of replacing

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Data Appendix Available Online

A data appendix to replicate main results is available in the online version of this article.

assets whose productivity is plateauing or diminishing over time. Given the fact that cocoa trees can yield fruit for up to 50 years but peak at a much earlier age, culling and replanting are considered necessary to maintain maximum orchard profitability over time. However, most impoverished cocoa producers find it difficult to forgo immediate income to enhance long-run revenue potential.

In general, stochastic and deterministic replacement models have been employed to determine a complete replacement of fruit trees such as for plum, peach, palm oil, apple, pear, coconut, and rubber trees (Arope, 1971; Etherington, 1977; Ismail and Mamat, 2002; Manos and Papanagiotou, 1983; Tisdell and De Silva, 2008; Ward and Faris, 1968). In cocoa production, several replanting methods have also been applied. For example, Murray (as cited in Lass, 2001b) found that complete replanting (the removal all cocoa and shade trees) produces a higher total yield than a partial replanting method (the removal all poor yielding trees over several years). However, there appears to be a void in the literature on the optimal phased replanting of cocoa.

This study develops a decision tool to empirically compute the annual optimum replacement rate (ORR) and initial replacement year (IRY) of cocoa trees under current production practices in West Africa. The proposed method employs a phased replanting approach to maximize the present value of profit that provides a consistent income stream for impoverished cocoa producers over time. The study examines the costs and returns of three common cocoa production systems in Ghana. The results compare the present value of current Ghanaian production practices (with no phased replanting of trees) with a phased replanting approach. This comparison shows that an annual replacement percentage can be achieved that can potentially provide low-income cocoa producers a higher and less volatile income stream.

Decreased yield variability in low-income countries may benefit both producers and consumers because it typically reduces price instability within markets. By utilizing an optimal replacement approach, semisubsistence cocoa producers in low-income countries would have the potential to increase yield and reduce income variability. Producers in low-income countries often value yield stability as much as yield potential because of the hardships in withstanding a poor production year. Yield stability (variance reduction) benefits agricultural producers because it reduces the volatility of annual income streams. This risk reduction could lead producers to increase investments in new technologies that could, in turn, increase overall productivity.

Timmer (1998) finds that consumers and middlemen benefit from stable agricultural prices because they do not face the risk of sudden and sometimes sharp reductions in real income. This benefit accrues disproportionately to the poor since they spend a larger portion of their budget on agricultural goods. Thus, the benefits to consumers and producers from price stabilization have a significant equity dimension that can play an important role in poverty alleviation. Moreover, the benefits to individual

farmers might also accrue to the market where stabilization of market output could lead to increased price stability thus tamping down market price oscillations over time. This study develops a phased replacement model for cocoa that can be used as a low-cost tool to potentially increase and stabilize cocoa producer incomes in impoverished regions of the world. This study will present various replanting methods and use secondary data collected from the Western region of Ghana to illustrate how phased replanting compares with the status quo in terms of profitability for cocoa producers. These results imply recommendations for the optimal replanting method.

2. Literature review

2.1. Life cycle of cocoa production

In general, an orchard production life cycle occurs in four stages: (1) an early period of no yield, normally occurring in year 1 through year 3, (2) a period of increasing yield at an increasing rate, (3) a period of increasing yield at a decreasing rate, and (4) a period of decreasing yields (Ward and Faris, 1968). The last stage is associated with trees past their yield prime that results in a period of decreasing producer income. A cocoa tree can live for more than 100 years and bear fruit for up to 50 years. However, yields after 25 years of growth are greatly diminished. The annual yield loss, however, can be gradual over time making it difficult for impoverished producers to decide when and what percentage of trees to replace to maximize the present value of their income stream over time.

2.2. Replanting methods for cocoa production

Figure 1 displays the yield life cycle of cocoa production in Ghana for three commonly used production practices: Low Input, Landrace Cocoa (LILC), High Input, No Shade Amazon Cocoa (HINSC), and High Input, Medium Shade Cocoa (HIMSC) over a 25-year period (Gockowski et al., 2009). Montgomery (1981) concludes that maximum cocoa yields are obtained between the ages of 15 and 25 years after planting with a possible, profitable life span of up to 50 years. Nevertheless, yield begins to slowly decline when the tree reaches 15–25 years of age, and then declines more rapidly until the tree no longer bears fruit. While it is true that some cocoa trees can be profitable up to 50 years, Fig. 1 is constructed to be consistent with the data and models in our study. Assuming each pod contains 0.039 kg of dried beans (Abenyega and Gockowski, 2001), Asare and David (2010) suggest that if a cocoa tree produces less than 10 pods per year (or 0.39 kg per year per tree), a producer should consider replanting. Lass (2001b) suggests that replanting methods under consideration should be partial replanting of poor yielding trees, total replanting (clear-felling), and phased replanting.

Partial replanting replaces all poor yielding trees over several years (Lass, 2001b). The advantages of partial replanting
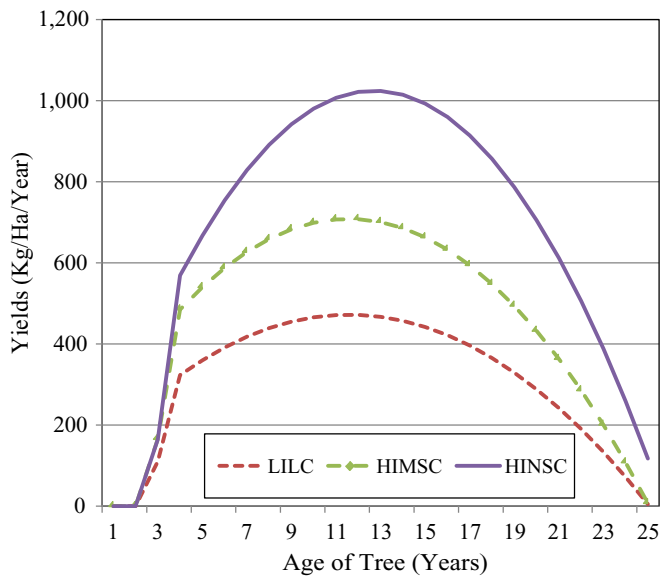
Fig. 1. Cocoa yield curves over one production cycle (25 years) in Ghana for three predominant production systems: LILC, HINSC, and HIMSC.
Source: Gockowski et al. (2009) and Afari-Sefa et al. (2010).

are that cocoa producers still receive the revenue from existing productive cocoa trees, while replanting is in process, and no new land area is required. The disadvantages involve the potential spread of cocoa swollen shoot virus (CSSV), a disease transmitted by capsids that causes yield loss and tree death, other diseases from the existing trees to newly planted trees, and the large amount of labor required by the replanting activities (Asare and David, 2010). Another large disadvantage of this method is that it takes roughly a five-year period to identify unprofitable trees, prune weak trees, plant temporary shade, and clear field drains. Then, the unprofitable trees that have been identified are cut down, and young cocoa trees are planted, fertilized, and pruned (Lass, 2001b). As concluded by Shephard (as cited in Lass, 2001b), it is expensive to replace every dead tree or fill every blank space throughout the farm. It delays the attainment of profitable yields at least 15 years and provides insufficient extra yield to offset the losses from injuries incurred to the surviving trees in the replanting process.

Complete replanting involves the removal all cocoa and shade trees (shade trees provide protection from direct sun and wind so enhances growth efficiency in early stages of development (Urquhart, 1955)). Asare and David (2010) argue that it is the best replanting method on unproductive farms where all trees are past the fruit bearing stage. An advantage of complete replanting is that it potentially disrupts the life cycles of diseases spreading to the new cocoa trees, especially in areas where CSSV is prevalent. A disadvantage is the requirement of large amounts of labor, capital, and inputs at one point in time which makes it infeasible for most small-scale cocoa producers. Additionally, these producers would have a zero revenue stream in the first three years of the replanting period (Asare and David,

2010). Given that most cocoa producers in West Africa are semisubsistence farmers, years without revenue could mean going from food secure to food insecure. Therefore, without alternative income or savings from prior years to support their livelihoods for the first three years of the production cycle, this method is likely infeasible. Alternatively, cocoa producers can generate income in an early period of no cocoa yield through planting other annual cash crops.

Phased replanting is a rotation method in which a certain percentage of cocoa trees is replanted annually until the entire farm has been completely replanted (Lass, 2001b). This method spreads the labor demand over time and stabilizes annual cash flows to the producer. Lass (2001b) states that this method is widely adopted on large plantations and farms. Further, he argues that there is no intrinsic reason why all cocoa producers, including small-scale farmers, cannot adopt this method. Of course, farmers have to overcome the negative cash flow in the early years of orchard establishment, which is often supplemented by crops such as plantains and coco yams. Phased replanting—which frequently generates the best results in terms of revenue and revenue smoothing—is often times difficult to effectively implement as the producer must decide both when and how much of an orchard to replace. All the replanting methods have associated advantages and disadvantages. However, given the massive amount of capital needed for a complete replant and the five year period to identify unprofitable trees in the partial replanting method that is myopic for an individual's farm, this study focuses on the phased replanting method.

2.3. Replacement models

Replacement models have widely been applied in many economic problems including orchard management. According to Perrin (1972), the basic principle of asset replacement is "to compare gains from keeping the current asset for another time interval with the opportunity gains that could be realized from a replacement asset during the same period" (p. 60). Similarly, Faris (1960) concludes that "the optimum time to replace an asset is when the marginal net revenue from the present enterprise is equal to the highest amortized present value of anticipated net revenue from the following enterprise" (p. 766). Given that cocoa yield decreases at an increasing rate over time (Fig. 1), it is clear that some form of replacement is needed to both stabilize and optimize cocoa producers' annual returns over time.

There are two basic types of replacement models commonly used for managing perennial crops: deterministic and stochastic. Deterministic models assume that all prices, costs, and yields are known with certainty over time. Stochastic models recognize that future events cannot be predicted with certainty. Deterministic models typically optimize net present value (NPV), while stochastic models maximize expected NPV. Clearly, reality is stochastic but the present analysis utilizes deterministic assumptions as a first approximation to a truly optimal solution.

In recognition of this fact, alternative scenarios are analyzed to explore the sensitivity of the deterministic solutions to changes in assumptions about output prices, input costs, and production methods.

For orchard management, Faris (1960) solves for the optimal replacement of peach trees under deterministic assumptions. The decision to replace trees at the end of the year or let them bear fruit for another year is determined by comparing which option leads to a higher expected net revenue. Several empirical studies have adopted the Faris method in palm oil producing areas. Arope (1971), for instance, uses combinations of yields and prices of oil palm and kernel to determine revenues and finds that the optimal replacement with different price levels and interest rates range from 31 years to more than 35 years. However, Arope (1971) suggests that the replanting should be implemented after age 30 to avoid higher harvesting costs and marginal yield due to problems engendered by increasing palm oil height.

Ismail and Mamat (2002) employ several data sets and assumptions for palm oil trees. Tree life is constrained to no more than 32 years due to height constraints; cost variables include land clearing, lining, holing, seedling planting, fertilizer, wage, and price of fresh fruit bunches (FFBs) that is based on crude palm oil (CPO) prices. The optimum replanting age depands on the FFB price, costs, technology, and discount rate. Ismail and Mamat (2002) find that when the FFB price is $64.10 (2011 USD) per ton, the optimal replanting age ranges from 25 to 26 years. However, when the FFB price increases to $70.51 (2011 USD) per ton, the optimal replacement age declines to a range of 24–25 years.

Ward and Faris (1968) solve a stochastic model for plum tree replacement rates. The authors use a Markov chain process with a matrix of transition probabilities from one stage to the next to solve for the optimal replacement strategy. Ward and Faris (1968) use dynamic programming to determine the optimal replacement based on the age, yield, net revenue, and the probability distribution of random events and assume that the trees have no salvage value. In contrast, Ward and Faris (1968) also solve a deterministic version of the model to compare the deterministic results with the stochastic model results. The solutions to the stochastic and deterministic models are identical although this equivalence is not to be expected in all applications. Ward and Faris (1968) conclude that the deterministic model is the more appropriate model to use because it is much simpler and requires less data.[1]

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[1] In essence, unknown parameters in our model—yield, cocoa prices, and costs—are replaced with their sample means. Assuming that these estimates are the means, maximizing the deterministic problem is equivalent to maximizing the expected value so long as prices at the national level are uncorrelated with yields on a particular farm. Such an assumption seems plausible so that our solution is a close approximation to maximizing the expected value of the more realistic stochastic problem.

3. Data and model specifications

Twenty-five years of annual data from Western Ghana on cocoa yield and input use levels were obtained from Gockowski et al. (2009). Total labor and input costs are calculated by the number of laborers (including operator) employed per day (six hours) and the quantity of inputs used per hectare for various production practices, all valued at 2011 prices. Revenue is calculated by multiplying yield (kg/ha) by the price of cocoa (USD/kg) as May 2, 2011 (International Cocoa Organization (ICCO), 2011). Additionally, inflation, which is based on the percentage of annual average inflation in December 2010, is estimated at 10.26% (Bank of Ghana, 2011a). The discount rate, which is based on Treasury bill rates for a six-month period, is 10.67%, the most recent available at the time of the analysis (Bank of Ghana, 2011b). Because the selection of the inflation rate is from one point in time, a sensitivity analysis is undertaken in our empirical analysis to examine the impact of this assumption.

Afari-Sefa et al. (2010) provided production budget data gathered from various secondary sources, which was augmented with primary data on input prices, output prices, and labor estimates from purposive and expert interviews conducted in several communities in the cocoa belt in March 2009. Production (yield) data, specifically the effects of shade and age on the yield of cocoa, were obtained from The Ghanaian Cocoa Research Institute (CRIG) as reported in various issues of the institute's annual report. The authors also used data from the Sustainable Tree Crop Program (STCP) who provided a secondary data set from its baseline survey of over 4,500 cocoa producers from across West Africa in 2001 and 2002. Farmers from both the Ashanti and Western regions of Ghana were included. Labor estimates were obtained from field data for 40 cocoa farmers in the Western Region STCP. Farms were measured by Afari-Sefa et al. (2010) using GPS handsets that reduced measurement error in the estimates of person-days per hectare for the various cultural tasks. Average labor requirements for the various activities per hectare and per ton of cocoa were estimated in six hour person-days for the various tasks involved in cocoa production. Data on tree felling and cutting into logs and insecticide application were lump-sum labor activities evaluated on a per hectare basis.

Because cocoa trees do not start bearing fruit until the age of three, in the status quo scenario where there is complete planting/replanting of the orchard at years 1 and 26, producers are assumed to grow cocoyam (*Colocasia esculenta*) and plantains (*Musa paradisiaca*) to supplement their income for the first three years. Gockowski et al. (2009) and Afari-Sefa et al. (2010) provided labor and inputs required as well as revenue for three years of cocoayam and plantain production in Ghana.

The ORR and IRY for maximizing NPV are calculated for three cocoa production systems commonly used in Ghana and throughout West Africa (which provides 61% of global cocoa supply (FAO, 2011)). The LILC production system uses unimproved local landrace cocoa varieties, pesticides, and fungicides

over the life cycle, but no inorganic fertilizer. Costs and returns are estimated for 1 ha of unimproved cocoa planted at 3 × 3 m spacing (1,100 plants/ha). No nursery costs are incurred as the farm is directly seeded with unimproved LILC cocoa varieties. Typical of most farmers it is assumed that there is no use of agrochemicals other than those provided by the Government of Ghana's mass spraying program. The amounts of pesticides, fungicides, and inorganic fertilizer used, on average, for LILC is 0.11 liters of Confidor per year, 31.68 sachets (50 g) of Ridomil per year, and 0 kg per year, respectively, provided by the government. Like Victor et al. (2010), we assume that shade levels for LILC system are 70 shade trees per hectare. The LILC production system is popular with impovershed producers who cannot obtain financing for inputs.

HINSC uses Amazon hybrid seed stock, high levels of inputs (inorganic fertilizer and pesticides), but no shade trees. Costs and returns are estimated for 1 ha of mixed Amazon hybrids planted at 3 × 3 m spacing (1,100 plants/ha) with no permanent shade. Afari-Sefa et al. (2010) assume that cocoa pods are obtained in November from COCOBOD seed gardens operated by the Seed Production Unit and cultivated by the farmer in a nursery for five months. Of the 1,400 seedlings started, 1,100 are planted after rooting out the off types. An 80% seedling survival rate requires an additional nursery effort of 280 seedlings for replacement in the second year. In addition to the chemicals provided by the Government of Ghana's mass praying program, the farmer who implements HINSC applies 0.44 liters of Confidor per year, 31.68 sachets of Ridomil per year, and 6.83 bags of 50 kg Asaasa Wura fertilizer (NPK 0-22-18+9CaO+7S+6MgO(s) active ingredient) per year, respectively. The HINSC production system is popular with larger plantation style producers who can obtain financing for inputs such as fertilizer and fungicide.

Conversely, HIMSC uses mixed Amazon hybrid seed stock, high input (inorganic fertilizer, pesticides, and fungicides), and a roughly 70 shade trees per hectare (Victor et al., 2010) and is popular among small-scale producers who can obtain loans for inputs. Afari-Sefa et al. (2010) estimate costs and returns for 1 ha of mixed Amazon hybrids planted at 3 × 3 m spacing (1,100 plants per hectare) with permanent shade provided by indigenous tree species. Cocoa and timber trees are sown under the temporary shade canopy provided by plantains planted at a density of 1,600 per hectare. Agrochemicals use includes the application of 371 kg/ha of compound fertilizer, 1.8 kg/ha of copper oxide plus metalaxyl to control black pod disease, and 480 mL/ha of imidacloprid to control capsids.

3.1. Baseline scenario

In determining the optimal returns associated with cocoa replacement, a baseline scenario is computed for each of the three production systems using a cost, yield, and input price structure as derived from Gockowski et al. (2009). Under the baseline scenario, an optimal solution is calculated using the assumptions for prices, yield loss, etc., as listed for the baseline scenario in Table 1. The cocoa price is set at the ICCO cocoa price of $3,305.79 (2011 USD)/metric ton of beans observed on May 2, 2011 (ICCO, 2011). Ghana remains the only major cocoa producing country in the world without a fully liberalized marketing system. The Ghana Cocoa Board (COCOBOD) is the sole exporter of Ghanaian cocoa, guaranteeing farmers a minimum price at 70% of the net free on board (FOB) price. For the 2012 growing season, farmers received 76.04% of the FOB price (Delmas, 2011).[2] This study assumes that the annual FOB price will be fixed at 76.04% in the future, given that the FOB price is a function of both politics and a host of other attributes which costs are difficult to forecast out (quality control, phytosanitary costs, farmers, housing schemes, etc.).[3] Thus, for this study, the cocoa price will be set at $2,513.72 per metric ton of beans.

Second, the baseline labor price is fixed at 3.5 Ghanaian Cedi (GHc)/day per laborer or $2.37 (2010 USD) as estimated by Gockowski et al. (2009). Third, baseline fertilizer, insecticide, and fungicides prices are also constant at GHc 14.7/50 kg or $9.98 (2010 USD), GHc 16.8/liter or $11.40 (2010 USD), and GHc 1.8/sachet or $1.2 (2010 USD), respectively (Gockowski et al., 2009). Fourth, baseline inflation and discount rates are 10.26% and 10.67% per year, respectively (Bank of Ghana, 2011b) as discussed above. By setting inflation at 10.26% per year, the prices of labor and the other inputs rise at this rate. Fifth, the baseline exchange rate is held constant at GHc 1.47/USD, the average for 2010 (IMF, 2011b). Although revenue flow from the production of cocoa does not begin until the third year, producers are assumed to obtain revenue from cocoyam and plantain production the first three years.[4] Plantain and cocoyam are planted one year prior to the cocoa seeding and then intercropped for the first two years of the cocoa production cycle.

From the baseline scenario for each of the three production systems, five alternative scenarios are solved to derive the impact on ORR and IRY. The five projected changes are: (1) 3% cocoa price increase annually, (2) 5% fertilizer price increase annually, (3) 5% labor price increase annually, (4) 20% annual

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[2] It should be the % FOB is not static but rather dynamic between years. In 2010, the FOB percentage was 72.16 of the international price. The remaining FOB percentage was allocated toward: a price stabilization fund (1.5%), buyers margin (8.42%), haulers cost (3.4%), storage and shipping (1.16%), quality control (1.66%), crop finance (1.06%), scale inspection and phytosanitary (0.01%), COCOBOD (9.34%), farmers' housing scheme (0.04%), replanting/rehabilitation (0.64%), and farmers' social security (0.61%) (Kolavalli et al., 2012).

[3] Another difficulty in forecasting FOB% is that it can also be a function of Ivorian cocoa prices. The smuggling of cocoa from Ghana to Cote d'Ivorie can be significant. Vigneri et al. (2004) found that 20% of Ghanaian cocoa farmers knew Ivorian cocoa prices and that 24% of Ghanaian cocoa farmers knew a producer who smuggled into Cote d'Ivoire. In situations like this, the COCOBOD has been known to revise FOB% mid year to lessen smuggling.

[4] Gockowski et al. (2009) and Afari-Sefa et al. (2010) estimate that profits of cocoyam and plantain production in Ghana are −$58.51, $425.56, and $133.94 USD (2010) per hectare for years 1, 2, and 3, respectively.

Table 1
Baseline and variations in assumptions over two production cycles (50 year) for LILC, HINSC, and HIMSC production systems

	Baseline scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Cocoa price (USD/MT)[*]	2,513.72	2,513.72	2,513.72	2,513.72	2,513.72	2,513.72
Projected cocoa price increase (per year)	0%	3%	0%	0%	0%	0%
Labor price (GHc)	3.5	3.5	3.5	3.5	3.5	3.5
Projected labor price increase (per year)	0%	0%	0%	5%	0%	0%
Fertilizer price (GHc)	14.7	14.7	14.7	14.7	14.7	14.7
Projected fertilizer price increase (per year)	0%	0%	5%	0%	0%	0%
Insecticide price (GHc)	16.80	16.80	16.80	16.80	16.80	16.80
Fungicide price (GHc)	1.8	1.8	1.8	1.8	1.8	1.8
Percentage yield loss from black pod	0%	0%	0%	0%	20%	40%
Percentage per hectare infected by black pod	0%	0%	0%	0%	10%	10%
Exchange rate (USD/GHc)	1.47	1.47	1.47	1.47	1.47	1.47

[*]*Source:* Cocoa price is that received by Ghanaian producers and is 76.04% of ICCO-stated price (2011). Labor, fertilizer insecticide, and fungicide prices computed from data in Gockowski et al. (2009) and Afari-Sefa et al. (2010); exchange rate from IMF (2011b); other figures are hypothesized growth rates for the scenarios.
Note: Shaded numbers represent deviations from the baseline scenario. The projected annual increases in cocoa, labor, and fertilizer prices are in addition to inflation. All prices grow at the inflation rate in all scenarios unless they grow at an even faster rate as indicated for scenarios 1, 2, and 3.

yield loss due to a black pod outbreak on 10% of a farm's total area, and (5) 40% annual yield loss due to black pod on 10% of a farm's total area. The model spreads the 10% affected area across age cohorts evenly. Black pod (*Phytophthora* pod rot) is mainly caused by the fungi *Phytophthora palmivora, P.megakarya,* and *P.Capsidi* and related species (Brasier and Griffin, as cited in Willson, 1999) and quickly spreads when humidity is high (Willson, 1999). Black pod is considered important in this study because it is a common fungi in West Africa and previous studies have shown that it can lead to large yield losses. Total global loss due to black pod is estimated at between 10% and 30% of total global cocoa production (Padwick and Medeiros as cited in Lass, 2001a). Similarly, Ward et al. (as cited in Lass, 2001a) find that the infected pods rate is more likely to range from 30% to 60.9%. It is assumed that black pod only affects 10% of the farm because once identified, its spread can be contained through proper production practices. The assumptions regarding yield loss and infection rates for the various scenarios are given in Table 1.

After the baseline solution is derived, the five additional scenarios are solved to examine the impacts from changing the various baseline assumptions. Scenario 1 examines the impacts of increased cocoa prices spurred by increased worldwide cocoa demand and/or political instability in cocoa producing regions. Increased incomes and chocolate consumption are highly correlated worldwide. The rise of middle classes in China and India (who are consuming more chocolate with demand growing at 3% and 7%, respectively, in the last five years) have increased global demand for cocoa (Simmons, 2010). There is also an increased global demand for a higher cocoa percentage (dark chocolate) in chocolate products that would not increase the volume of chocolate sold in general, but would increase the cocoa volume needed to produce higher percentage cocoa products. ICCO (2007) states that the dark chocolate market is estimated to account for 5%–10% of the total global market. Recently, political unrest in Cote d'Ivoire, the largest cocoa producer, has led to elevated cocoa prices. These three factors have caused cocoa prices to jump to their highest levels ever in 2011 to over $3,393 (The Guardian, 2011). Additionally, the cocoa price also increases by a constant 0.66% per year above the general inflation rate (the average real price increase for 25 years of historical cocoa price data 1986–2010) and about 12% in the last 10 years (International Monetary Fund (IMF), 2011a). Thus, scenario 1 assumes a 3% increase in price, while the input costs grow only at the rate of inflation.

Scenario 2 examines the impact of fertilizer price increases based on the possibility that the fertilizer subsidy provided by the Ghanaian government could be reduced or that the global price of fertilizer would continue to rise due to demand and/or higher petroleum prices. In this scenario, the fertilizer price is assumed to increase 5% annually, holding all other variables constant except for inflation effects.

Scenario 3 focuses on impacts of agricultural wage increases. The Bank of Ghana (2011a) reports an increase of the minimum daily wage rate from GHc 3.11 in January 2010 to GHc 3.73 in February 2011. While wages increased 19%, real GDP only increased by 6.51% over the same time span (World Bank, 2012). In scenario 3, it is assumed that labor price increases by 5% per year, holding other variables constant except for inflation effects.[5]

Scenario 4 assumes that a black pod outbreak occurs and the percentage yield loss is 20% on 10% of the farmed area, holding all other variables constant. Since black pod is a fungus and spreads slowly, it is assumed that only a portion of the farm is infected because appropriate actions would be taken to contain further contamination. Finally, scenario 5 assumes a similar black pod outbreak but the percentage yield loss is increased to 40% with the percentage of the farm infected held

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[5] This assumption along with the increased fertilizer price assumes a producer can maintain both levels of input use even with higher costs. In West Africa, such assumptions maybe unrealistic and access to credit would be necessary. This study, however, does not consider access to or cost of capital and assumes that cocoa farmers are able to provide labor and inputs as required for each production system.

to 10%. Yield loss estimation is based on findings by Ward et al. (as cited in Lass, 2001a). Scenarios 1–5 are compared to the optimal baseline solution and all baseline scenarios are compared to the status quo (replacement does not take place until the tree bears no more fruit which we assume happens when the tree is 25 years old).

4. Methodology

To solve for the optimal return, the study computes the net future value (NFV) in each year as a function of net nominal (inflation adjusted) revenues for a given ORR and IRY. Then the NPV is computed as the sum of the annual, discounted NFV. This study considers the importance of both the inflation rate (because it is often high in low-income countries) since it increases the price level over time and strongly affects the future value of money, and the importance of the discount rate since it determines present value of money over the future earnings.

A two-dimensional matrix is constructed in Excel with varying annual replacement rates (the ORR) along the columns and an initial year for beginning replacement along the rows (the IRY). Each element in this matrix is the NPV for a given replacement rate and the associated IRY. The ORR ranges from 4% to 10% and the IRY ranges from year 5 to year 20.[6] The combination of percentage of replacement rates and IRY that gives the highest NPV is the optimal solution.[7]

The NPV and NFV for the 50 year horizon (to reflect long-term cocoa production and to reach a steady state) models are defined as follows:

NFV is defined as

$$NFV_t = Yld_t{}^* P_t(1+r)^t - C_t(1+r)^t +$$

$$\sum_{t=1,2,3,26,27,28}^{T} (Yld_{it}{}^* P_{it}(1+r)^t - C_{it}(1+r)^t) - C_{pt}(1+r)^t, \tag{1}$$

where

NFV_t = Net future value in period t.
Yld_t = Yield (kg/ha) of cocoa in period t for a given hectare, and depends upon the age distribution of trees on that hectare.
$P_{t*}(1+r)^t$ = Cocoa price in period t compounded with inflation rate r.
$C_{t*}(1+r)^t$ = Cost of cocoa production in period t compounded with inflation rate r.

$C_{Pt*}(1+r)^t$ = Cost of new cocoa replanting in period t compounded with inflation rate r.
$\sum_{t=1,2,3,26,27,28}^{T}(Yld_{it}{}^* P_{it}(1+r)^t - C_{it}(1+r)^t)$ = the net return of planting crop i (cocoayams or plantains) in periods 1, 2, 3, 26, 27, and 28 (years associated with complete replanting and thus no cocoa yield) compounded with inflation rate r. Periods 26, 27, and 28 are equal to zero if phased replanting takes place.

NPV is computed as

$$NPV = \sum_{t=1}^{T} NFV_t \frac{1}{(1+r_d)^t}, \tag{2}$$

where r_d is the discount rate.

To determine annual average return, NPV is divided by 50 to give the annual average present value of profit. Thus, this average return includes both the steady-state years as well as the initial years before the steady state is achieved. Here, "steady state" implies that the percentage of trees replanted in any one year does not vary from year-to-year and that the yield from the hectare remains constant. This study also assumes no salvage value of cocoa trees consistent with Ward and Faris (1968) and Tisdell and De Silva (2008).

It should be noted that the intention of this study is not to present a whole farm planning model. However, that being said, the maximization of net profits from cocoa has to be embedded in an economic framework of a utility/profit maximizing farm household that faces a budget constraint. Thus, this study casts the optimization problem as one where a farm household is maximizing the utility of the NPV of returns from the cocoa enterprise over 50 years. Somewhat similarly to Chavas and Holt (1990), the study assumes that net revenue from the cocoa enterprise (that may include alternative crops like cocoyam and plantain production during the early years of orchard establishment) is the sole source of income. In the Chavas and Holt approach, the budget constraint for consumption is set by the net revenue generated from the enterprise. In such a case—assuming that utility is an increasing function of NPV—then optimizing NPV is the utility maximizing activity.

Such an approach is the implicit assumption of Faustmann (Ward and Farris, 1968) and others who optimize NPV from intertemporal enterprises.[8] Obviously, the approach abstracts from the year-to-year income needs of farmers, credit and labor availability, and initial land endowment. The model compensates for these simplifications by allowing for alternative cash crops during early years of crop establishment, noting the need for credit programs to smooth out household income flows and pricing labor inputs even though labor may be internally (family) provided. This method also assumes constant returns to scale so that size of land endowment is not relevant. Clearly imposing period-by-period income, credit, and labor constraints

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[6] Replacing cocoa trees by less than 4% or over 10% indicates that the completion of replacement of an entire farm for one production cycle would take 33.3 to 100 years, or nine years or less, respectively. Setting the IRY at less than five years of age or over 20 years of age is not necessary since the cocoa trees bear fruit starting at age three and decreasing yields begin after year 20.

[7] For all scenarios solved, all optimal solutions were in the interior of the matrix, i.e., no corner solutions. This justifies having 4% ≤ ORR ≤ 10% and 5 ≤ IRY ≤ 20 in the search procedure for the ORR and optimal IRY.

[8] As cited and discussed in Scorgie and Kennedy (1996)

Table 2
Summary of NPV, optimal replacement rates (ORRs), IRY, steady state, and percentage change in NPV over two production cycles (50 year) for the LILC production system

	NPV[*]	ORR (%)	Initial replacement (year)	Steady state (year)	Percentage change in profit
Status quo[**]	389.68	–	–	–	–
Baseline scenario	445.47	6	9	25	14.31[†]
Scenario 1[a]	1,428.97	6	7	23	220.78[‡]
Scenario 2[b]	445.47	6	9	24	0.00[‡]
Scenario 3[c]	333.63	7	8	22	−24.88[‡]
Scenario 4[d]	430.07	6	9	25	−3.48[‡]
Scenario 5[e]	414.58	6	9	25	−6.96[‡]

[*]Denotes the highest NPV in (2010 USD/ha/year).
[**]Includes revenue from cocoayam and plantain production for years 1–3 as well as the 26–28.
[†]The value is compared with status quo.
[‡]The value is compared with the baseline scenario.
[a]Assumes that the cocoa price will increase annually by 3%.
[b]Assumes that the fertilizer price will increase annually by 5%.
[c]Assumes that the labor price will increase annually by 5%.
[d]Assumes a black pod outbreak on 10% of the farm resulting in a 20% loss on the infected hectares.
[e]Assumes a black pod outbreak on 10% of the farm resulting in a 40% loss on the infected hectares.

Table 3
Summary of NPV, ORR, IRY, steady state, and percentage change in profit over two production cycles (50 year) for the HINSC production system

	NPV[*]	ORR (%)	Initial replacement (year)	Steady state (year)	Percentage change in profit
Status quo[**]	962.63	–	–	–	–
Baseline scenario	1,016.25	5	7	26	5.57[†]
Scenario 1[a]	3,093.07	5	5	24	204.36[‡]
Scenario 2[b]	978.18	5	7	26	−3.75[‡]
Scenario 3[c]	730.98	6	8	24	−28.07[‡]
Scenario 4[d]	983.94	5	7	26	−3.18[‡]
Scenario 5[e]	951.62	5	7	26	−6.36[‡]

[*]Denotes the highest NPV in (2010 USD/ha/year).
[**]Includes revenue from cocoayam and plantain production for years 1–3 as well as the 26–28.
[†]The value is compared with status quo.
[‡]The value is compared with the baseline scenario.
[a]Assumes that the cocoa price will increase annually by 3%.
[b]Assumes that the fertilizer price will increase annually by 5%.
[c]Assumes that the labor price will increase annually by 5%.
[d]Assumes a black pod outbreak on 10% of the farm resulting in a 20% loss on the infected hectares.
[e]Assumes a black pod outbreak on 10% of the farm resulting in a 40% loss on the infected hectares.

Table 4
Summary of NPV, ORRs, IRY, steady state, and percentage change in profit over two production cycles (50 year) for the HIMSC production system

	NPV[*]	ORR (%)	Initial replacement) (year)	Steady state (year)	Percentage change in profit
Status quo[**]	569.35	–	–	–	–
Baseline scenario	652.88	6	9	25	14.67[†]
Scenario 1[a]	2,207.06	6	7	23	238.05[‡]
Scenario 2[b]	620.91	6	8	24	−4.90[‡]
Scenario 3[c]	448.93	7	7	22	−31.24[‡]
Scenario 4[d]	629.64	6	9	25	−3.56[‡]
Scenario 5[e]	606.40	6	9	25	−7.12[‡]

[*]Denotes the highest NPV in (2010 USD/ha/year).
[**]Includes revenue from cocoayam and plantain production for years 1–3 as well as the 26–28.
[†]The value is compared with status quo.
[‡]The value is compared with the baseline scenario.
[a]Assumes that the cocoa price will increase annually by 3%.
[b]Assumes that the fertilizer price will increase annually by 5%.
[c]Assumes that the labor price will increase annually by 5%.
[d]Assumes a black pod outbreak on 10% of the farm resulting in a 20% loss on the infected hectares.
[e]Assumes a black pod outbreak on 10% of the farm resulting in a 40% loss on the infected hectares.

would increase specificity but detract from the generality and policy prescriptions of this model.

5. Results

5.1. Comparing NPV, ORR, and IRY across scenarios

This section provides the optimal baseline scenario results for NPV, ORR, IRY, and percentage change in profit from the status quo (which is defined as harvesting fruit until the tree bears no more at age 25 years and then replanting the entire farm) as well as the five scenario iterations from the baseline scenario for each of the three cocoa production systems: LILC, HINSC, and HIMSC over a 50 year period.

Tables 2–4 show the NPV, ORR, IRY, and year in which steady state is reached, and percentage change in NPV for the LILC, HINSC, and HIMSC production systems relative to the "Status Quo" solutions that are also displayed. The optimal solutions for the three production systems and scenarios require replacing 5%–7% of trees in orchards annually, with replacement commencing anywhere from year 5 to year 9 after planting (Tables 2–4). In the baseline solution for each system, substantial NPV gains (14.31%, 14.67%, and 5.57%) are associated with using the ORR of 6% with IRY at year 9 for the LILC and HIMSC and ORR of 5% with IRY at year 7 for HINSC production systems compared to maintaining the status quo. For cocoa producers living on less than $2 per day (78.5% of Ghanaians),

this increased income could be used to improve their quality of life.[9]

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[9] When the models were estimated assuming the producer received the actual international market price, not the price paid by the Ghanaian COCOBOD NPV for the status quo increased by 54%, 58%, and 50% for LLIC, HIMSC, and HINSC, respectively. That being said, these numbers are most likely inflated due to the fact that the COCOBOD retains a portion of the FOB price to

The results also suggest that when the price of cocoa increases by 3% per annum holding all other variables constant except the inflation rate (scenario 1), the IRY declines by two years to capture benefits of the higher cocoa prices in the long run and reaches steady state earlier to stabilize annual returns (Tables 2–4). In other words, greater revenue is achieved by expediting the IRY. This finding is in line with the study by Ismail and Mamat (2002). The solutions indicate that cocoa producers can increase profit over baseline profits by 220.78%, 204.36%, and 238.05% for LILC, HINSC, and HIMSC production systems, respectively, by shortening the IRY if the price increase is captured by the producer and not the middlemen. The general implication is that IRY is sensitive to moderate prices swings but replacement rate is not.

In scenario 2 where fertilizer price increases by 5% per annum above the inflation rate (from 0% annually) holding all other variables constant, the NPVs for HINSC and HIMSC decline by 3.75% and 4.90% from the baseline scenario, respectively (Tables 3 and 4) since fertilizer costs increase from 10.44% to 18.8% and from 12.5% to 22.1% of total cost for HINSC and HIMSC, respectively. The profit for the LILC production system is equivalent to that of the baseline scenario because no inorganic fertilizer (thus no price increase) is applied as a nutrient supplement for this system. Given the small proportion of costs accounted for by fertilizer, it is not surprising that the profits are not as sensitive to fertilizer price changes as to cocoa price changes.

Additionally, the fertilizer price increase results in new optimal ORR and IRY for HIMSC, where the IRY moves from year 9 to year 8 as the fertilizer cost increases. The IRY is accelerated because cocoa producers try to minimize the impact of further fertilizer price increases and want to avoid additional fertilizer costs for existing cocoa trees. However, the IRY for HINSC is the same as in baseline scenario even with the increased price of fertilizer. Since fertilizer is not relevant to the LILC system, the IRY remains unchanged at year 9.

In scenario 3, labor price increases by 5% per annum above the inflation rate (from 0% anually), holding all other variables constant. Profits decline approximately 24%–31% from the baseline results across the three production systems (Tables 2–4). Labor is one of the largest cost components in cocoa farming which accounts for 65.19% (LILC) to 81.88% (HINSC) of total costs. Therefore, small changes in the labor wage have substantial impacts on profitability. For the LILC scenario, the wage increase also results in ORR increasing by one year from the baseline scenario and a one-year decline of the optimal IRY. Whereas for HINSC and HIMSC, the ORR increases to 6% and 7%, respectively. The IRY for HINSC is delayed year 1 to year 8 but one year earlier (from year 9 to year 8) for HIMSC as the labor cost increases to 89.5% and 87%

reinvest in the cocoa economy in the forms of educational scholarships, input and supply subsidies, and research in an attempt to increase yields and decrease costs. Interestingly, the ORR and IRY did not change under this alternative scenario.
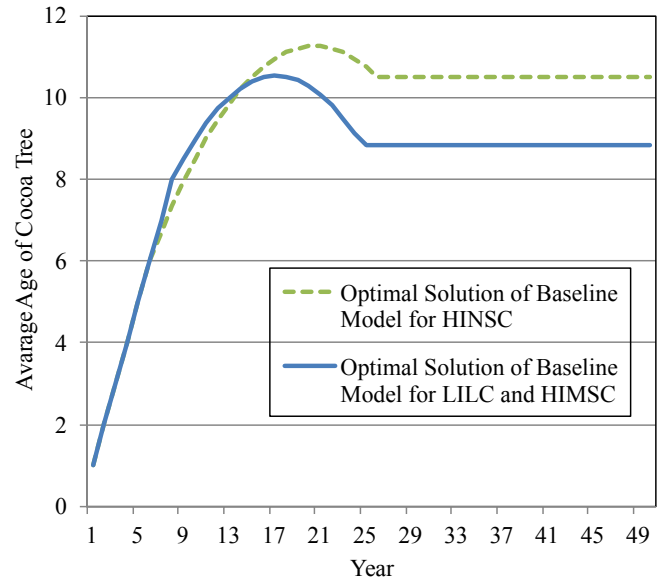

Fig. 2. Average age of cocoa trees in optimal baseline models for LILC, HIMSC, and HINSC production systems over 50 years.

of total cost, respectively. Thus, speeding up the replanting rate (ORR) of cocoa trees helps cocoa producers to minimize the impact of further labor cost increases. The effect on IRY is mixed.

In scenario 4 (where a 20% annual yield loss due to a black pod outbreak affects 10% of the total cocoa land farmed), the ORR and IRY are unchanged from the baseline scenarios for LILC, HINSC, and HIMSC, respectively. Similarly, when annual yield loss increases to 40% from a black pod outbreak with the same 10% of land being affected (scenario 5), the optimal ORR and IRY remain unchanged from those of the baseline scenarios. The solutions remain unchanged from the baseline because the yield loss impacts are small relative to the other variables that drive the model (e.g., labor and cocoa price). Total annual yield loss due to black pod incidence is 2%–4% and profit losses are 3.18%–3.56% in scenario 4 and from 6.36% to 7.12% in scenario 5 across all production systems.

5.2. Steady state and yield of optimal replacement over two production cycles

Figure 2 shows the average tree age and the year steady state of cocoa tree rotation is achieved for each production system under the baseline assumptions. Given the 6% ORR and IRY in year 9 for the LILC and HIMSC production systems, all first generation cocoa trees will have been replaced with new seedlings by the end of the 24th year. As a result, steady state is achieved at the beginning of year 25 and the average age of a cocoa tree in steady state is 8.84 years. This occurs during a period of increasing yield at a decreasing rate (Fig. 2). For the HINSC system, the ORR is 5% and IRY is in year 7. The steady state is achieved at the beginning of year 26 and the

Table 5
Comparison of total yields between optimal replacement models and the status quo over two production cycles (50 years)

Yield*			
Production system	Optimal replacement model	Status quo	Percentage change in yield
LILC	16,987	15,435	10.06%
HINSC	35,472	33,929	4.55%
HIMSC	25,480	23,152	10.06%

*Denotes the total yield over 50 years in kg/ha.

average age of a cocoa tree in steady state is 10.5 years. The LILC and HIMSC production systems have the same average ages of cocoa trees but the HINSC average age is higher due to the difference in peak yield year across production systems.

Table 5 compares the total cocoa yield over 50 years (two production cycles for the status quo) between the optimal replacement model baseline scenario and status quo under the three production systems. These solutions show that aggregate yield can be increased by 10.06% for the LILC and HIMSC and by 4.55% for HINSC production system (Table 5).

Figure 3 compares the NPV per year over 50 years among the optimal replacement models and status quo (0% annual replacement rate until year 26) under the LILC, HINSC, and HIMSC production systems. It indicates that the HINSC production system provides higher profits than LILC and HIMSC production systems. However, LILC and HIMSC have higher aggregate of percentage increase in yield (Table 5) over their status quo solutions than HINSC has over its status quo solution. In general, the optimal replacement solution increases yield for each production system over their status quo solutions but by different percentages. The profit maximizing strategy for a cocoa producer is HINSC but capital (credit) constraints might force producers to adopt the less capital-intensive methods of LILC and HIMSC.

6. Conclusions

This study has empirically estimated the annual ORR and IRY of cocoa trees that maximize the NPV of cocoa production. Given that there are multiple production practices, three of the most prevalent productions systems in Ghana and West Africa were chosen as applications for modeling: (1) LILC, (2) HINSC, and (3) HIMSC. Empirical data from Ghana on yield, cocoa price, production costs, inflation, and discount rates for three cocoa production systems were used in constructing the models. To demonstrate the sensitivity of solutions to changes in major model assumptions, the study calculated ORR and IRY based on hypothesized changes in projected cocoa prices, fertilizer prices, labor prices, and percentage yield loss due to disease outbreaks.

The study finds that the ORR for all scenarios for the three production systems ranges from 5% to 7%, whereas the optimal IRY varies from years 5–9. When compared with the status quo of no replacement until year 26 when all trees are replaced (complete replanting), substantial economic gains are estimated at 14.31%, 5.57%, and 14.67% higher for LILC, HINSC, and HIMSC, respectively, when using the ORR indicated in the baseline scenario (phased replanting).

The five scenarios display a range of effects on NPV, ORR, and IRY. Cocoa and labor price volatility make cocoa production very risky because small percentage movements in cocoa and labor prices alter profits demonstrably. As cocoa price increases by 3% per annum above inflation, the annual profit increases by at least 204% above the baseline scenario for each production system. Labor price also has a substantial, opposite effect on profit. As labor price increases by 5% per annum above inflation, annual profit declines by 24%–31% across production systems.

While optimal phased replacement improves profit across all production systems, farmers may be constrained from choosing the system—HINSC—that gives the greatest profit. Small-scale cocoa producers in West Africa often lack access to credit. Credit is needed to pay for the inputs associated with HINSC or even HIMSC, and thus producers may be forced to choose low-input systems such as LILC. This study, however, does not consider access to or cost of capital and assumes that cocoa farmers are able to provide labor and inputs as required for each production system. But this is clearly a fanciful assumption. If a farmer begins a new farm, then the farmer potentially faces at least three years of no revenues and must pay orchard establishment costs experienced during the first three years. The farmer could try to generate revenues by planting alternative crops in these early years as we assume here. But since the gains to annual income are attractive on a percentage basis, efforts to increase farmer access to reasonable credit are justified. This might require direct government intervention.

The primary value of this study is that substantial improvements in yield and income can be achieved using the optimal replacement method, regardless of production system used. As reported by the World Resources Institute (2011), 78.5% of the Ghanaians live on less than $2 per day (USD). The majority of the poor in Ghana are small-scale, semisubsistence farmers. If producers in low-income countries adopted the optimal replacement method for the HIMSC production practice, their estimated income would increase 14.67% per hectare per year. This increased income would provide opportunities to improve quality of life through increasing caloric intake, improving human capital by sending their children to school, and reinvesting in the farm. Of course, if all cocoa farmers followed optimal replacement method, there would be some downward pressure on cocoa prices due to increased supply.

This study can be used as a tool to increase the cocoa yields and stabilize producer income over time, and thereby aid people who live under the poverty line in cocoa producing areas. The study results provide a tangible alternative to producers
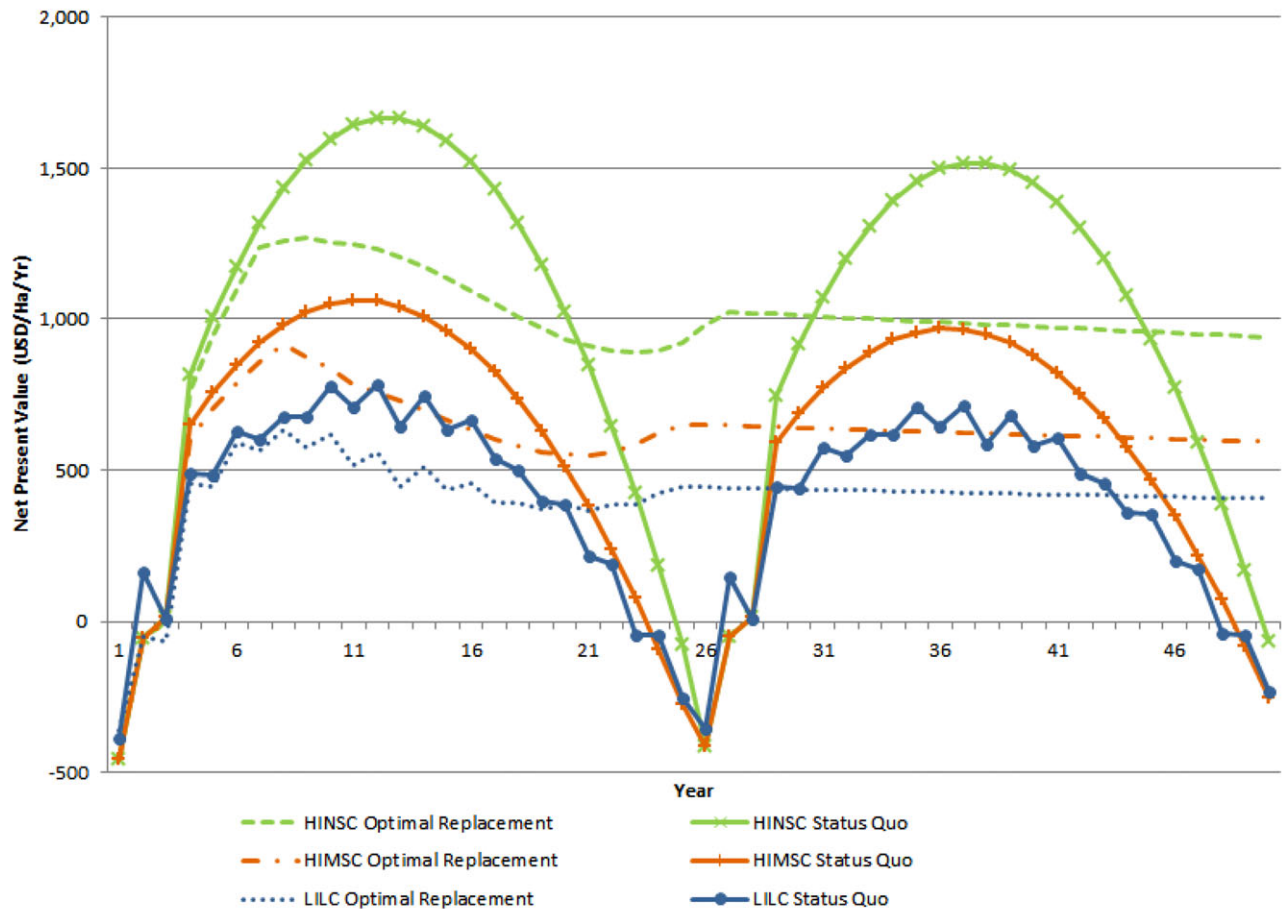
Fig. 3. NPV (USD/ha/year) over two production cycles (50 years) for optimal replacement models and status quo for the LILC, HIMSC, and HINSC regimes.

who typically are hesitant to cull productive assets in that it illustrates the benefits of reaching steady state and thus steady revenue generation. One important feature is that the solution allows producers to reach a hypothetical steady-state revenue that would help to smooth annual income. Often time, producers in low-income countries value revenue stability as much as revenue potential. The Excel based model is employed to provide extension personnel in low-income countries with a simple yet powerful tool to illustrate to producers the benefits of continual, phased tree replacement. Many times in low-income countries, producers sit idly by as their yield decreases and their subsequent income decrease due to the increasing age of cocoa trees. This method could change that by employing and encouraging timely, phased replanting.

Acknowledgments

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