EFFECT OF FARMERS' LIVING INCOME ON COCOA PRODUCTIVITY IN GHANA.

THESIS SUBMITTED IN PARTIAL FULLFILMENT OF THE REQUIRMENTS FOR
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BY

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God richly bless you all. Amen

ABSTRACT

Cocoa is an important commodity of Ghana. The Goal of the government of Ghana is to produce around 1000,000 tons every year. This target was achieved once in the 2010-2011 season and has not been achieved anymore. Studies have shown that the yield per hectare for farmers has been decreasing for the past decade. Whilst the ideal kg per hectare that farmers could produce if they are able to focus all their resources on their farms will be around 1800 kg/hectare. Currently farmers are not able to meet the yield potential of 1800 kg/hectare or come close to it. Based on studies Some of the major factors attributing to low productivity are inadequate application of fertilizers on farms, low level of farm maintenance which include, weeding and clearing of debris, spraying of the farm against diseases. The aim of this thesis was to establish a relationship using system dynamics approach between yield and factors contributing to the yield of cocoa farmers. Through literature what was found is that, living income of farmers is major factor contributing to the yield. With low incomes, farmers do not weed, spray, or apply fertilizers on their farms. Farmers also find it difficult to cut down their old trees. With this, we were able to explore the system and find policies to alleviate these problem behaviours to help increase the yield of farmers. There were policies that was explored during this research to try and suggest possible solution to the problem at hand. One of the major recommendations was to increase the price of cocoa. Also helping farmers remove old cocoa tree will also contribute to higher yield. Some of the limitations of this research were availability of data for certain variables. So, assumptions based on experienced as a farmer and living among farmers must be made.

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CHAPTER ONE: INTRODUCTION

1.1 Background

Ghana is the second largest producer of cocoa in the world. The cocoa subsector accounts for about 12 percent of total agricultural value added, 7 percent GDP, and 20–25 percent of export earnings (World Bank, 2018). Cocoa generates employment and income for around one third of all Ghanaians (Dormon et al., 2004). About 800,000 households depend on cocoa production as a source of income and employment (Smith & Sarpong, 2018).

Cocoa production in Ghana was in a decline over from 1980's through to the 90's due to declining soil fertility, incidence of diseases and pests and low investment in the sector among other factors. But the volume of cocoa produced in the country has been increasing in an unprecedented rate since 2001. Many actors in this sector attributed this production boom to an increase in fertilizer use and other government intervention at the beginning of 2001 (Vigneri, 2007). One of the major contributions to this boom is the government provision of fertilizers to cocoa farmers at zero cost to the farmers. The idea of the government implementing this policy was to shift the burden of cost of production from the farmers to the government so that farmers will be able to apply the necessary inputs to the farm to achieve a maximum level of production. This is very beneficial to both parties because government needs higher production levels to able to sell more at the world market whilst farmers also need higher production levels to get higher income from their production.

Since the implementing this policy in 2001, the overall production of cocoa has been on a rise whilst the yield per hectare has been rising steadily too (Vigneri, 2007). However, in 2010-2011 season, Ghana achieved its highest production ever by producing over 1,000,000 tons of cocoa

(COCOBOD, 2020). But after the that season the country has not been able to achieve that height again. Also, the yield per hectare has also been declining since the peak in 2012 and has not risen again(Aneani & Ofori-Frimpong, 2013). In a report written by World Bank, it was argued that the average cocoa yield gap in Ghana is one of the biggest in the world, estimated at more than 100 percent, implying that the cultivated areas could produce twice as much cocoa as they do currently (World Bank, 2018). This shows that even though the government is providing all these incentives to reduce the cost of producing cocoa and help improve production through fertilization and application of pesticides, the yield per hectare and overall production has not been improving since reaching its peak.

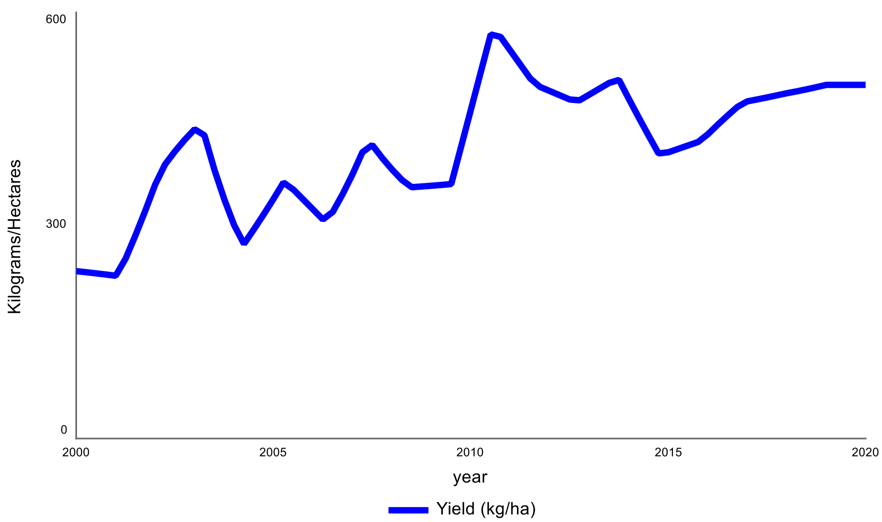

Figure 1: Average Ghanaian Farmers yield per ha

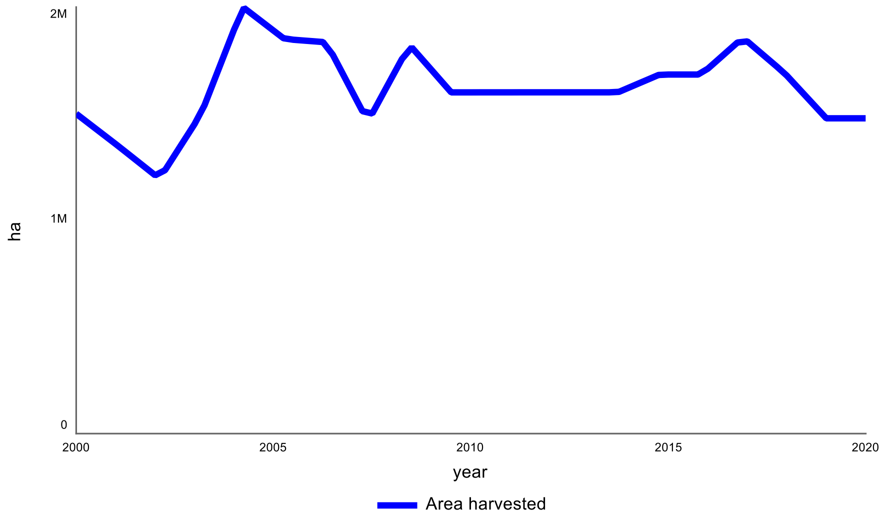

Figure 2: Cocoa Land area harvested per year.

1.2 Problem Statement

The Government of Ghana gives out free fertilizers to farmers to apply on their farm to achieve a maximum output (AGRA, 2018). This policy was the start of the boom in production of cocoa in the early 2000's(Vigneri, 2007). Government of Ghana has a goal of producing more than 1000000 tonnes of cocoa every year (COCOBOD, 2020) but this was only reached in 2011-2012 season. The yield per hectare of most Ghanaian farms is between 300 and 400 kg per hectare (Aneani & Ofori-Frimpong, 2013; IMANI, 2019; Vigneri, 2007). Whilst the ideal kg per hectare that farmers could produce if they are able to focus all their resources on their farms will be around 1800 kg/hectare(Aneani & Ofori-Frimpong, 2013). Currently farmers are not able to meet the yield potential of 1800 kg/hectare or come close to it. Based on studies Some of the major factors attributing to low productivity are inadequate application of fertilizers on farms, low level of farm maintenance which include, weeding and clearing of debris, spraying of the farm against diseases and pest (Aneani & Ofori-Frimpong, 2013). A study also found that less interaction between extension service personnel and farmers also crucial to productivity (Wessel & Quist-Wessel, 2015). Farmers Living income is one of the reasons for the reduction in productivity (Fountain & Hütz-Adams, 2020; Smith & Sarpong, 2018). Because farmers living income so far below the living income benchmark, farmers to look for alternative source of income in order to maintain their household, especially their immediate needs. Currently, most cocoa farmers in the main cocoa production countries in West Africa does not earn a living income. 9.4% of cocoa farmers live above the living income Benchmark. Almost of the famers (90.6%) are living below the living income benchmark. This means that most Cocoa farmers in Ghana cannot afford a decent living with the income that they get from selling their produce (Fountain & Hütz-Adams, 2020). It also applies to choosing between family and applying fertilizers, farmers will rather choose to feed their families than apply fertilizers on their farm. Because of this situation most farmers in the rural areas result to selling part if not all their fertilizers given by the government. These fertilizers are sold to merchants in the market to get money to cover their household expenses. This kind of behavior influences the overall production of cocoa because less fertilizers are applied to the farms compared to what is needed for the farmers to achieve a maximum yield. This affects future yield thereby leading to low income. With low income from production there is less reinvestment of cash into the farm thus continuous low productivity. It is believed that this kind of behavior is one of the factors that is hindering the effectiveness of the government intervening policy to help farmers achieve a maximum productivity. This study seeks to address the living income of cocoa farmers and its effect on production.

1.3 Research Objectives

The main objective of this research is to examine the living income of farmers and its interaction with the cocoa production system of Ghana. This research seeks to look at how the livelihood of farmers impedes the intervening policies of the government of Ghana in the cocoa sector. Specifically, this research seeks to:

1. Identify the underlying structure that explains the relationship between farmers living income and if effect on cocoa production.
2. Explore the behaviour that rises from this structure.
3. Test policies to alleviate the problematic behaviour.

2.0 METHODS

2.1 Research Strategy

The method employed in this study is quantitative system dynamics modeling and simulation-based analysis. This allows us to represent, explicitly, coherently, and consistently, relevant hypotheses and, eventually, theories by way of simulation models. In this way it is easy to visualize and analyze the dynamic behaviour between the livelihood of farmers and the impact it has on farmers cocoa productivity.

2.2 Data Collection

To build, test and validate a system dynamics model, there are two types of information needed. First, the structural components that produced the complex nature of the problem at hand. Secondly, time series data for known modes of behaviour.

Mental data that is extracted from the experiences and observation from people within the system, numerical data and written data are some of the types of data sources that are often used in the system dynamics studies (Jay W. Forrester, 1992). But in this research, only two types of the sources of data were used. Secondary data and mental models were used in this research. Primary data was not collected for this research. The secondary data was collected through published articles and literature and published government data on the internet. Mental models was built based on experienced and observations as a person who has lived and communicated with cocoa farmers for more than a decade.

2.3 Model Analysis

To support the model testing during this research process, techniques and guidelines such as the formal model analysis and validation procedures were used (Sterman, 2004). To validate and test building blocks of the model in order to find areas that have to be improved, partial model testing was used (Jack B. Homer, 2012). The reason for validating and analyzing the model was to build confidence in the ability of the model to address the research questions, give deeper interpretation of the behaviour of the model and highlight the leverage points of the mode (Nichols, 2019).

In building confidence in the structure of the model, indirect structure-oriented tests, direct structure tests and behaviour test were used. Model structure test were prioritized before behavioral test (Sterman, 2004). For behaviour testing, the direction, shape, and magnitude of the model behaviour is used. Also with structure confirmation test, variables which directly influence a stock were validated by comparing the flow equations with those documented in literature (Barlas, 1996). Regarding the model and policy structures, both the testing and analysis were applied.

3.0 LITERATURE REVIEW

3.1 Household available Cash

Household available cash represents the available cash holdings of farmers in the country. This is determined by how much farmers can save the income that they get from farming. This is very important because saving helps farmers to invest in their farms and increase productivity (Batista & Vicente, 2019). Studies have shown that providing farmers access to financial services increase the resource allocation, productivity, welfare and contributes financial resilience among households (Dupas & Robinson, 2013; Han & Melecky, 2013). Africa is considered to have the lowest usage when it comes to the application of fertilizer coupled with low adaptation of improved agricultural technologies resulting in low productivity thereby leading to lower incomes (Batista & Vicente, 2019). The income of Cocoa farmers is not increasing exponentially compared to their expenses. This is due to low productivity and low producer price over the years (IMANI, 2019). It is very difficult for farmers to save money to reinvest in their farms because their expenditure is mostly higher than their income.

A study conducted by Smith & Sarpong, (2018) about the living income of farmers in rural cocoa growing areas in Ghana showed that on an average farmers spend about GHS 1,464 ($329) per month for a typical family of two adults and three children. The estimate was based on the actual cost of living in 2018. The Anker methodology was used to estimate the cost of living, which includes low cost nutritious diet, basic decent healthy housing and all other essential needs (Anker & Anker, 2017). The table below shows that 52% of the cost of living in 2018 were for food, 13% for housing, 30% for other essential needs, and 5% for sustainability.

Table 1: Breakdown of Living Income benchmark for a family of 2 adults and 3 children in rural cocoa growing regions of Ghana.

Item	GHS per month	USD per month[2]
Food costs per month	757	170
Housing costs per month	198	44
Non-food non-housing costs per month	439	99
Additional 5% for sustainability and emergencies	70	16
Total costs per month for basic but decent living standard for family of 2 adults and 3 children	**1,464**	**329**

(Smith & Sarpong, 2018)

The living income concepts is based on the idea that families should have enough income to cover their basic needs (i.e. poverty alleviation), afford a standard of living that is decent and should be able to undertake in any cultural and social life (Smith & Sarpong, 2018). This definition of living income has been accepted by the living income community of practice:

> *"A Living Income is the net annual income required for a family in a particular place to afford a decent standard of living for all members of that family. Elements of a decent standard of living include food, water, housing, education, healthcare, transport, clothing, and other essential needs including provision for unexpected events."*

The total amount of income that a family earned within a given year is considered as the net annual family income. This include cash and non-cash income (for example food that is produced by members of the family). The figure below represents the four factors that shows a decent living as globally defined.

Figure 3: Component of basic but decent life for a family (Smith & Sarpong, 2018)

3.2 Cocoa farmers living income.

About 80% of the cocoa farmer in Ghana are small scale farmers with an average of about 3 to 4 hectares of land. Cocoa farmers have an average yield of about 0.42 tonnes per hectare (ICI, 2017). In Ghana cocoa farmers are producing below what the potential yield. An experimented yield potential conducted by (Aneani & Ofori-Frimpong, 2013) in Ghana showed that maximum cocoa productivity with a combination of fertilizer and variety is about 1891 kg/ha. But currently the maximum yield per hectare in Ghana is around 400 kg/ha. This means that the cocoa yield Gap in gap in Ghana is around 1491 kg/ha. (World Bank, 2018) also reported that the yield gap in Ghana is so great that the current area of production can produce twice as much as currently being produced. This shows that the most farmers are producing at a very low level.

Low yields reduce the amount of income generated from the farm thereby preventing the farmers from having the ability to accrue savings. The seasonality nature of cocoa farming means that incomes generated from production are not consistent year-round. Families that depend on cocoa farming are highly vulnerable and are deep in poverty during off-seasons. A typical cocoa farmer has a family of six to eight members to support with the income from the sale of the cocoa (World

Cocoa Foundation, 2020). To be able to survive, farmers must find alternative means to get money in order to cover their household expenses and farming inputs for the next season, yet there is limited access to credit in the rural communities (ICI, 2017). Currently only few farmers in major cocoa growing areas in Ghana are living above the living income benchmark. Figure 3 shows the

3.3 Cocoa Producer Price

One of the elements that affects the income of cocoa farmers in Ghana is the producer price of cocoa. The price that producers receive for their cocoa is determined by a committee called the Produce Price Review committee (PPRC). This committee fixes the price of cocoa every year at the beginning of the cocoa harvesting season. This means that farmers cannot negotiate prices of cocoa. This can be advantageous for farmers during a bear market when world market prices are falling because farmers' prices will not change even though the prices are falling. On the other hand, it can be a disadvantage when during a bullish market when the prices are rising (Bymolt et al., 2018). According to the data from International Cocoa organization (ICCO), the fixed prices for Ghanaian farmers are lower than what most producers from liberalized countries receive. This result in farmers receiving less income for their produce overtime, contributing to lower living income of farmers in Ghana.

3.4 Cocoa Yield

Increasing Cocoa yield is very crucial in economic growth and development. Increase in yield can be achieved by using improved agricultural technologies and management systems. Yield can be define as production per unit area (Aneani & Ofori-Frimpong, 2013). In Ghana, the realized cocoa yield is much lower than the potential yield (World Bank, 2018). Yield potential of a crop is the yield achieved when the crop is grown under a conducive environment with adequate moisture and nutrients with no pest and diseases (Lobell et al., 2009). The boom of production that occurred in the early 2000's can also be attributed to increase in farmland rather than the yield per ha. So as farmlands are converted for different purpose rather than cocoa production it reduces the overall production level of cocoa (Aneani & Ofori-Frimpong, 2013; Vigneri, 2007). Low cocoa yield can be attributed to factors like low input use, inadequate maintenance, pest and disease control, age of the farm and little or no fertilizer use. These are common factors causing low yield in cocoa producing countries (Wessel & Quist-Wessel, 2015).

3.5 Effect of Spraying on cocoa yield

In Ghana, pest and diseases cause a major economic loss in cocoa. This is very common in Ghana since most of the farms are small and more often isolated. This makes controlling of pest and diseases very difficult (Wessel & Quist-Wessel, 2015). In Ghana, virulent strains have had a major impact on the yields which lead to large removal of cocoa trees in the past. Frequency of spraying against diseases like black pod diseases and capsids have a positive influence on cocoa yield. Black pod disease can destroy half of the farm in a wet and humid weather (Idachaba & Olayide, 1976). Capsids feed on the succulent foliage of cocoa trees and can cause death in an extreme case. Cocoa Research Institute of Ghana (CRIG) recommends farmers to spray 4 times per annum with insecticides to ensure capsid control and effective disease control (Aneani & Ofori-Frimpong, 2013).

3.6 Effect of Fertilizer application on cocoa yield

Cultivating cocoa on a piece of land for a long period of time causes the nutrient of the soil to decline overtime. In Ghana so many farm lands have inadequate nutrient because of continuous planting of crops on the same piece of land for a long period of time (Appiah et al., 2000). Fertilizer application has a positive effect on yield. But according to Nunoo et al., (2014) when studying fertilizer application among farmers on of the cocoa districts in Ghana they found out that most farmers do not apply fertilizer at all or use inadequate amount on their farms. Out of 200 respondents only 51 farmers applied fertilizers whilst the rest did not.

CHAPTER 4. MODEL DESCRIPTION

4.0 Dynamic Hypothesis

Dynamic hypothesis is a conceptual model that typically consist of stock and flow diagram (SFD) or casual loop diagram (CLD) or both. This seeks to explain the critical feedback loops that is responsible for driving the behaviour of the system. The endogenous structure of the model should be able to generate the reference mode of behaviour of the system when the model is simulated. Thus the changes in the dynamic behaviour of the system is caused by the endogenous structure (Sterman, 2004). The overall cocoa production system in Ghana can be represented on a causal loop diagram and stock-flow diagram can generate the dynamic behaviour of the cocoa production system. The production system is therefore hypothesized on a causal loop diagram and stock-flow diagram to generate the cocoa production system in the reference mode.

4.1 MODEL OVERVIEW

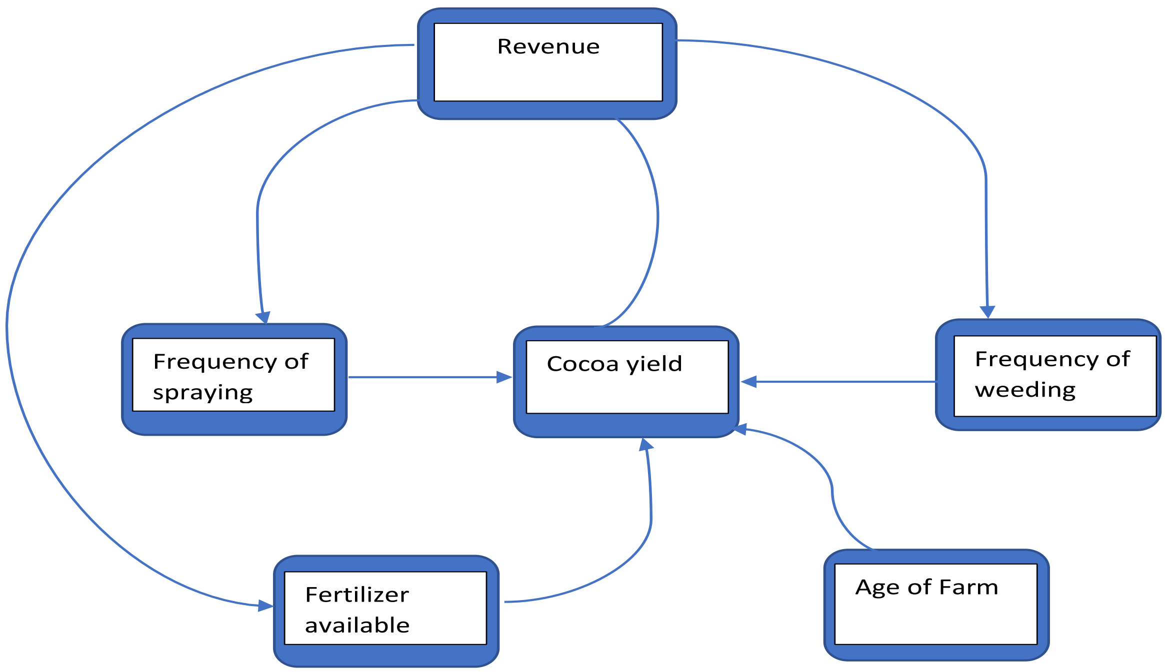

Figure 4: Model Overview

This chapter details the model description. The model that was used in this study is described extensively in this chapter. The model presented here represents the quantified, operational and testable synthesis of already available articles. The model consists of a structure that represents the farmers household available cash which is influence by the farmers total expenditure and income. The model also consists of a structure which deals with the cocoa productivity levels of the farms. From figure 4, the model shows the relationship between factors that affect cocoa yield. The relationship between cocoa yield and household available cash is also shown. Also, how household available cash affects all the factors that affects the yield of the farm. Detailed description of the model is given for the rest of this chapter. Also, this chapter will show the academic literature that formed the basis of the model.

4.2 MODEL STRUCTURE

4.2.1 Cocoa Yield

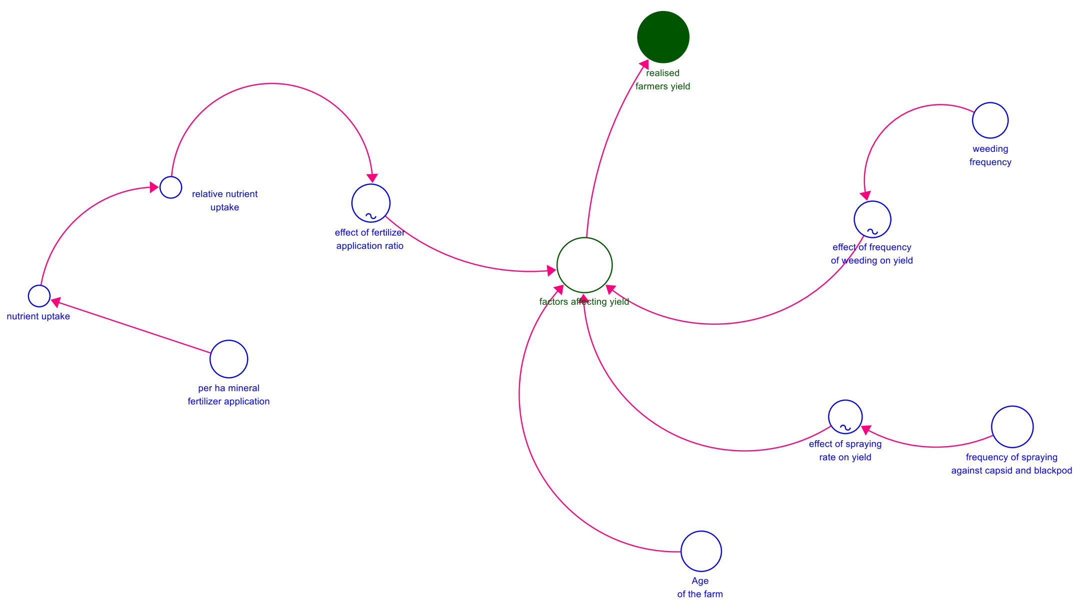

Figure 5: Cocoa yield structure

From the model cocoa yield in Ghana is affected by four major factors. These factors are the fertilizer available for application, age of farm, frequency of weeding and frequency of spraying. Fertilizer application is very important to increase the yield of cocoa farm.

Farmers are expected to apply certain amount of fertilizer every year on the farm. The lesser the application of fertilizer on the farm the lesser the realized yield and vice versa. Fertilizer application has a positive impact on the realized cocoa yield. Frequency of weeding also has a positive impact on cocoa yield.

Farmers are expected to weed their farms 4 times in a year. If farmers meet this threshold, it helps to increase the productivity of the farm but if they weed less than what is expected yield of the farm is going to decrease.Frequency of spraying cocoa farms also has a positive effect on the realized yield. The more farmers spray their farms the higher their expected yield because it leads less pods being destroyed by diseases and pest. Age of the farm is also a major factor that affect the overall yield of the farm. The higher the age of the farm (i.e., more old trees than productive and young trees), the lower the yield of the farm (Aneani & Ofori-Frimpong, 2013; Laven & Boomsma, 2012; Wessel & Quist-Wessel, 2015).

4.2.2 *Age of Farms*

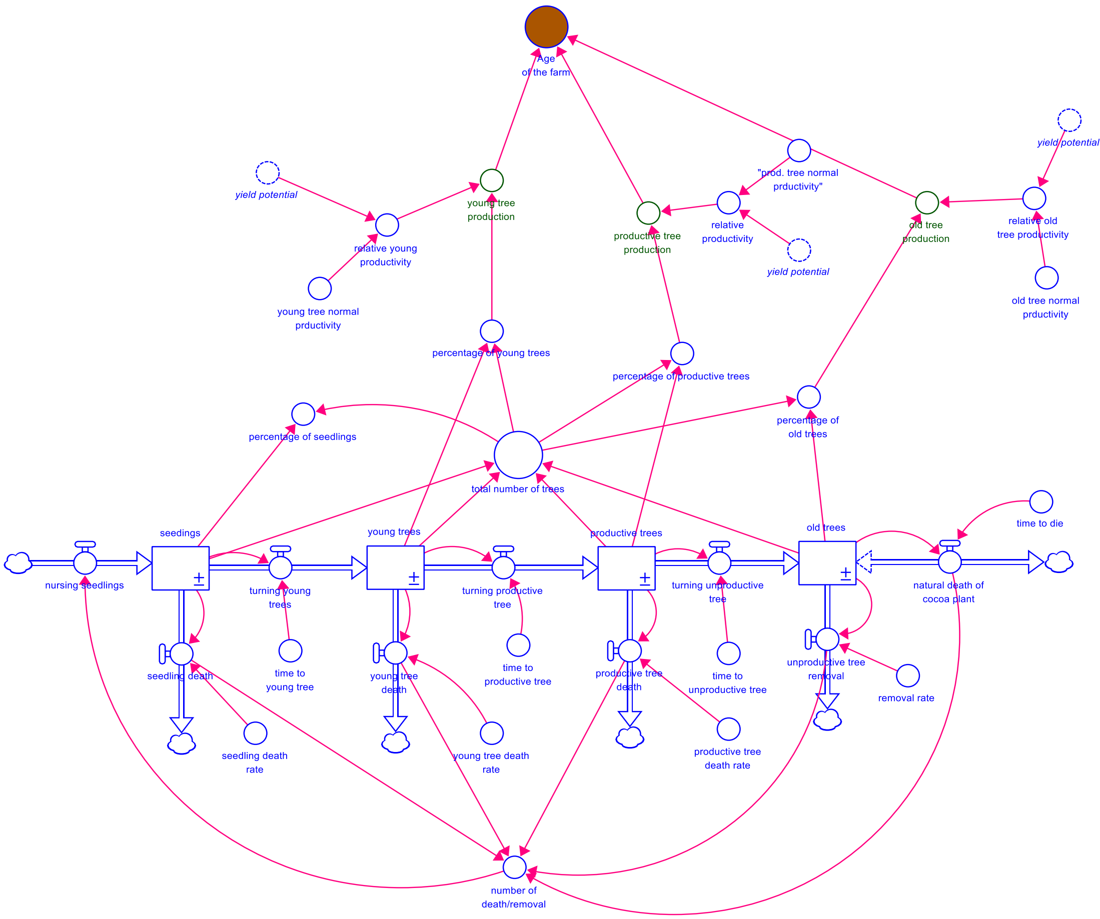

Figure 6: Age of cocoa farm

This structure was built based on the aging chain structure from (Sterman, 2004). Productivity of a cocoa tree is based on the age of the tree. It takes about 10 years before cocoa tree reaches its maximum productivity stage. It takes about 50 years for cocoa trees to last before it dies or cannot produce anymore. Age of cocoa farms contribute significantly to the productivity of cocoa farms. The higher the age of the farm the low the yield per hectare. So, it is ideal for farmers to have cocoa farms that is in an appropriate age range. The ideal situation is to have majority of the trees on the cocoa farm in the stock of productive trees and young trees. This is because the cocoa trees in the productive and young tree stocks gives the maximum productivity. Cocoa trees that are old gives less yield and so does cocoa seedlings. The overall productivity of the farm depends on the percentage of the various age group the trees that are present on the farm. Each age group has its old productivity levels. Productive tree has the highest productive levels followed by young tree and then old tree are less productive.

4.2.3 Fertilizer Application

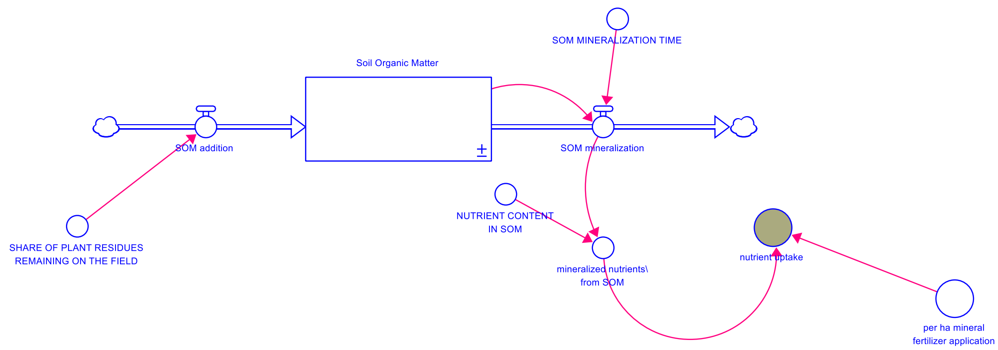

Figure 7: Fertilizer Application

The stock of organic matter is influenced by the share of plant residues that is coming from cocoa tree throughout the years. For plants to get access to the nutrients from the soil organic matter it must go through a mineralization process in which it takes about 30 years. Soil from the organic matter is not enough to produce maximum yield so additional fertilizer is needed to complement the nutrients already in the soil. If fertilizer application increases, higher amount of nutrients are available to plants which leads to higher yields. This structure is taken from the PHD thesis of Andreas Gerber (Gerber, 2016).

4.2.4 *Weeding and Maintenance*

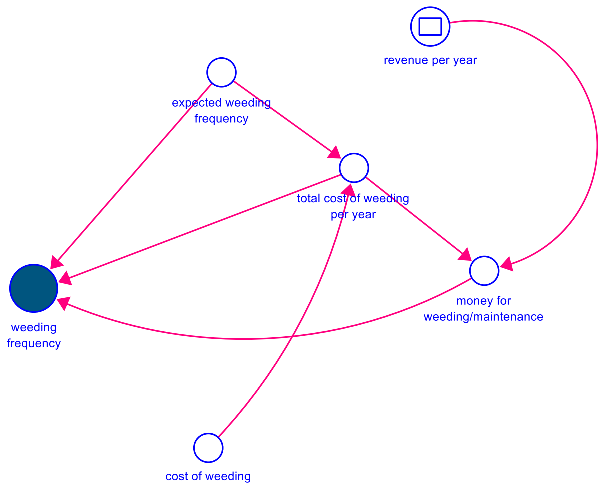

Figure 8: Weeding and Maintenance.

The number times that farmers weed and maintain their farms in a year has a positive impact on the productivity of the farm. There is an expected number of times that farmers are supposed to weed their farm in a year. Crop Research Institute of Ghana (CRIG) has the threshold to be 4 times a year (Aneani & Ofori-Frimpong, 2013). For farmers to be able to weed their farms, they need money to hire labor.

If farmers revenue is low, they will not be able to hire enough labors to weed the farms thus not meeting the threshold of the number of times they are supposed to weed and maintain the farms. As farmers revenue goes down the frequency of weeding also goes down which then leads to yield decreasing. If farmers have enough revenue, they can increase their frequency of weeding the farm thus leading higher yields.

4.2.5 Spraying of Pest and Diseases

Spraying against pest and diseases has a positive relationship with yield. There is an expected number of times that farmers are supposed to spray their farm in a year. Crop Research Institute of Ghana (CRIG) has the threshold to be 4 times a year. For farmers to be able to spray their farms, they need money to hire people and buy fuel for their spraying machine.

If farmers revenue is low, they will not be able to meet the number of times they are expected to spray their farms. As farmers revenue goes down, the frequency of spraying their farms also goes down thus, decrease in cocoa yield.

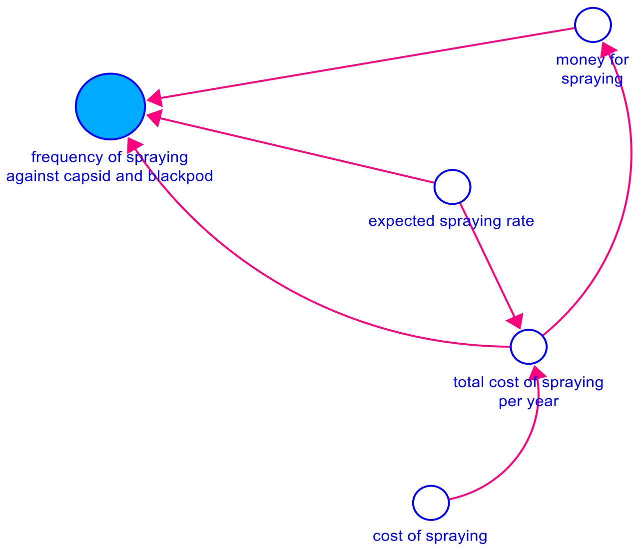

Figure 9: Spraying against pest and diseases.

4.2.6 *Production Cost*

There are several costs that is involved to make up total production cost of farmers. Every year, farmers must spend certain amount of money to produce cocoa fruits. There are important farming activities that farmers must undergo to, and these activities cost money. Farmers need money to apply fertilizers, plucking pods, breaking of pods, drying of seeds, pruning of cocoa trees, hiring of labour and transporting of farm produce in and out of the farms. These activities make up for the total farming expenditure. As total production cost increases greater than the revenue from selling cocoa, the farming profits decreases.

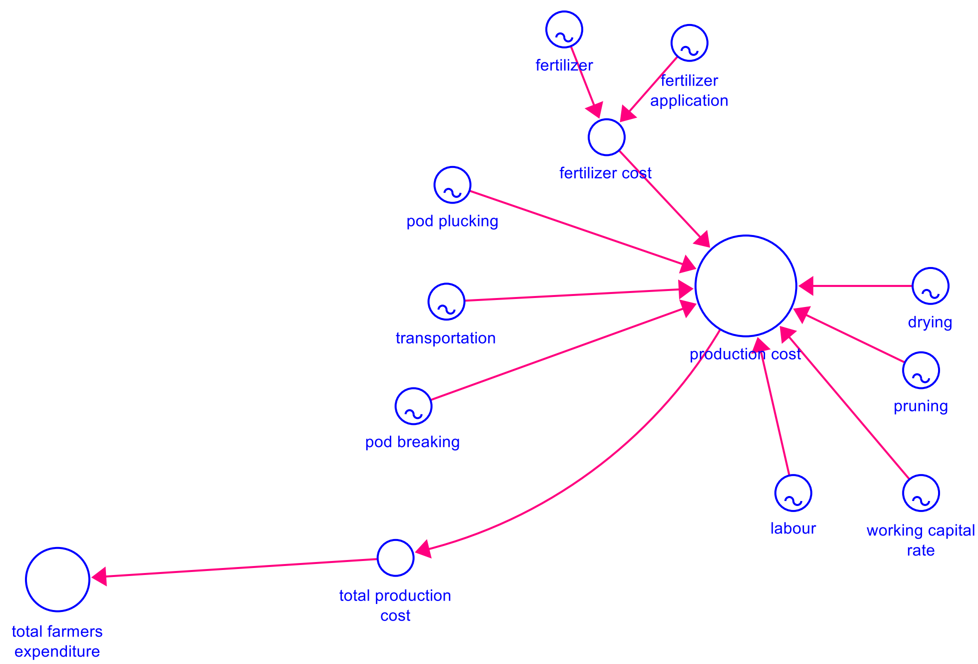

Figure 10: The cost of production

4.2.7 ***Household Available Cash***

The household available cash is the cash available to farmers after they take subtract their living expenses from the profit from farming. The living expenditure is made up of various basic expenses that farmers must deal with it every year. They are the housing cost, which is the rent they pay for the house that they live in, food expenditure is the total cost of food for farmers and their families for the year. There are expenses that does not fall in the housing and food expenditure but can be the money for transportation, church offerings etc. These costs are classified as the non-food non-housing cost. There are cost that are not planned for, and these costs are classified as the emergency cost. All these costs are basic cost of living for farmers that they cannot do away with. The lower the revenue from the selling cocoa, the lower the profits from farming and vice versa.

Cocoa farming is the major source of income for majority of farmers in Ghana. Profits from cocoa is the revenue from cocoa minus the total production cost of cocoa that year. Farmers use the available money to take care of their basic needs. Farmers basic needs is classified in this model as the living expenditure. At the end of the year, the available cash will determine how they are going to use the freely given fertilizer by the government. Are they going to sell to get money to take of their families or they are going to apply these fertilizers on their farm? One of the main questions this model seeks to answer is what the effect of farmers livelihood on the overall productivity on their farm? It is believed that if farmers have enough cash to take care of their basic needs, they will be able to focus on putting or their efforts into their farms.

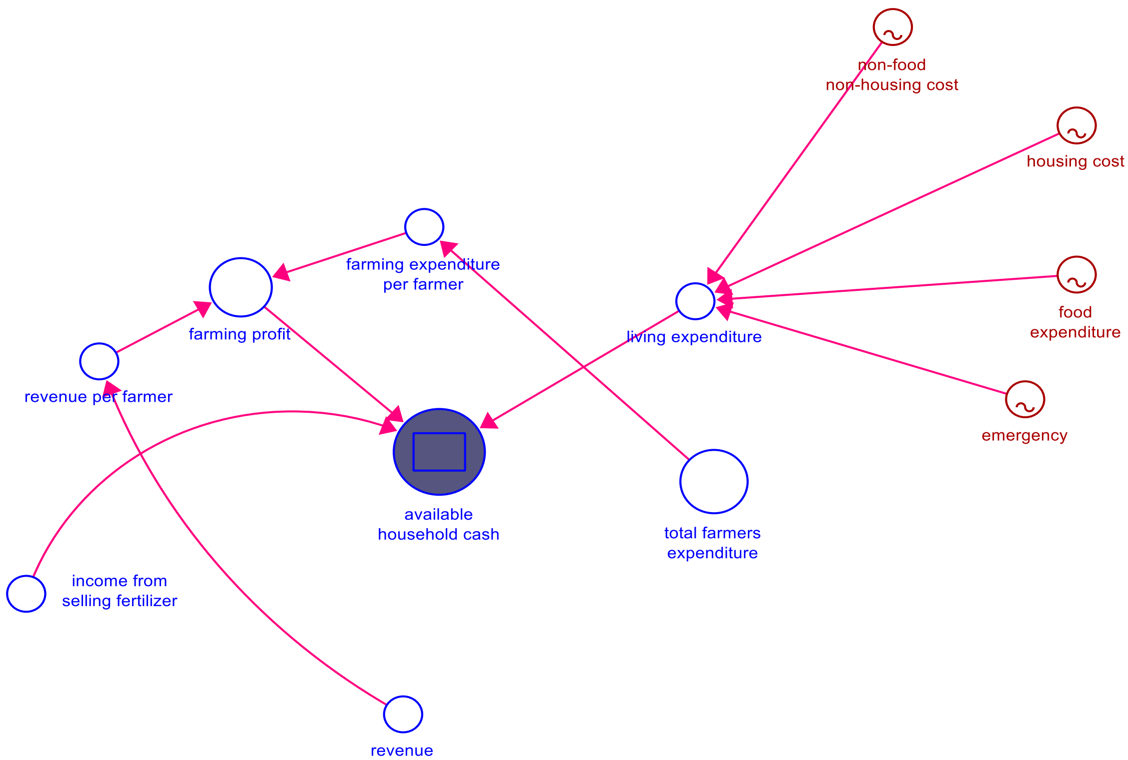

Figure 11: The Household available cash

5.0 MODEL CALIBRATION

This section presents the quantitative findings from literature, relating to the concept of the model. Table 2 shows the exogenous variable their value, unit, and their sources. These findings in the table were used to calibrate the model together with estimations that was produced due to lack of data.

Table 2: parameter values from data sources and by estimation

Exogenous input	**Value**	**Unit**	**Data source**
Farming Expenditure			
Production cost	1250	Cedis/ha/year	This an estimation from (Smith & Sarpong, 2018) about the living income of cocoa farmers in Ghana.
Spraying cost	67.3	Cedis/ha	This an estimation from (Smith & Sarpong, 2018) about the living income of cocoa farmers in Ghana.
Weeding and maintenance cost	73.9	Cedis/ha	This an estimation from (Smith & Sarpong, 2018) about the living income of cocoa farmers in Ghana.
Living Expenditure			
Non-food,non-housing cost	439	Cedis/year/farmer	This an estimation from (Smith & Sarpong, 2018) about the living income of cocoa farmers in Ghana.

Housing cost	198	Cedis/year/farmer	This an estimation from (Smith & Sarpong, 2018) about the living income of cocoa farmers in Ghana.
Food expenditure	757	Cedis/year/farmer	This an estimation from (Smith & Sarpong, 2018) about the living income of cocoa farmers in Ghana.
emergency	70	Cedis/year/farmer	This an estimation from (Smith & Sarpong, 2018) about the living income of cocoa farmers in Ghana.
Land			
Area harvested	1480000	ha	Data collected from (Knoema, 2020)
Average land per farmer	4	ha	Average land per hectare was estimated from (Aneani & Ofori-Frimpong, 2013; Wessel & Quist-Wessel, 2015)
INITIAL VALUES			
INIT Seedlings	50	tree	This is based on the assumptions derived from online literature.
INIT young trees	50	tree	
INIT productive trees	150	tree	
INIT old trees	200	tree	

Soil organic matter	14.8	Ton/ha	
Available household cash	1000	Cedis/farmer/ year	Initial value assumed from personal observations and communication with farmers.
FRACTIONS			
Expected weeding frequency	4	Dmnl	This was based on the information from Crop Research Institute of Ghana (CRIG)
Expected spraying rate	4	Dmnl	This was based on the information from Crop Research Institute of Ghana (CRIG)
Seedling death rate	0.5	Dmnl/year	This was based on (Animah, 2017) about the growth cycles of cocoa plants
Young tree death rate	0.05	Dmnl/year	This was based on (Animah, 2017) about the growth cycles of cocoa plants
Productive tree death rate	0.001	Dmnl/year	This was based on (Animah, 2017) about the growth cycles of cocoa plants
Removal rate	0.03	Dmnl/year	This was based on (Animah, 2017) about the growth cycles of cocoa plants

DELAYS			
Time to young tree	5	year	Data collected from (Animah, 2017) about the production cycle of cocoa plants
Time to productive tree	5	year	Data collected from (Animah, 2017) about the production cycle of cocoa plants
Time to unproductive tree	30	year	Data collected from (Animah, 2017) about the production cycle of cocoa plants
Time to die	60	year	Data collected from (Animah, 2017) about the production cycle of cocoa plants
Soil Mineralization time	30	year	It takes about 30 years for the process of mineralization to complete to release nutrients to plants.
Available cash delay time	1	year	Since cocoa harvesting occurs seasonally. It takes approximately a year for farmers to get revenue from their farm.

<table>
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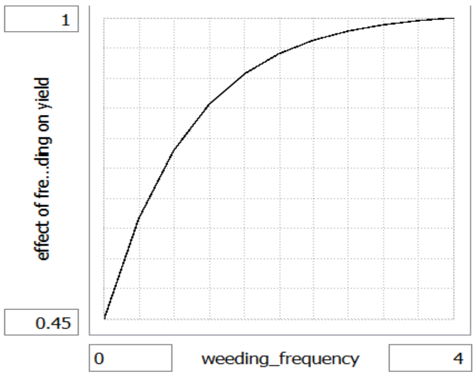
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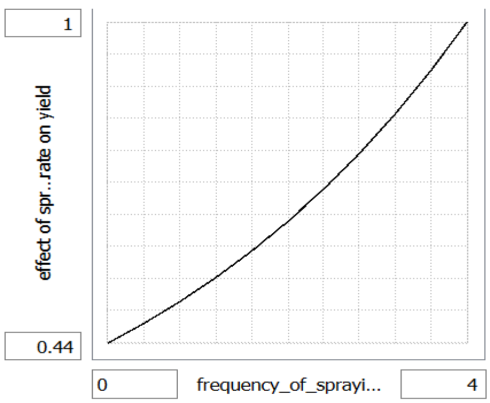
<tr><td>Effect of spraying on yield

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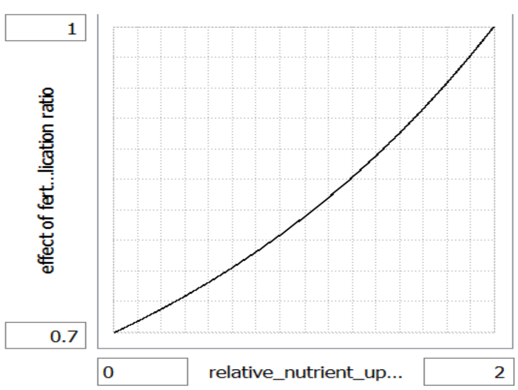
<tr><td>Effect of fertilizer application on yield

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</table>

5.1 Feedback Loop:

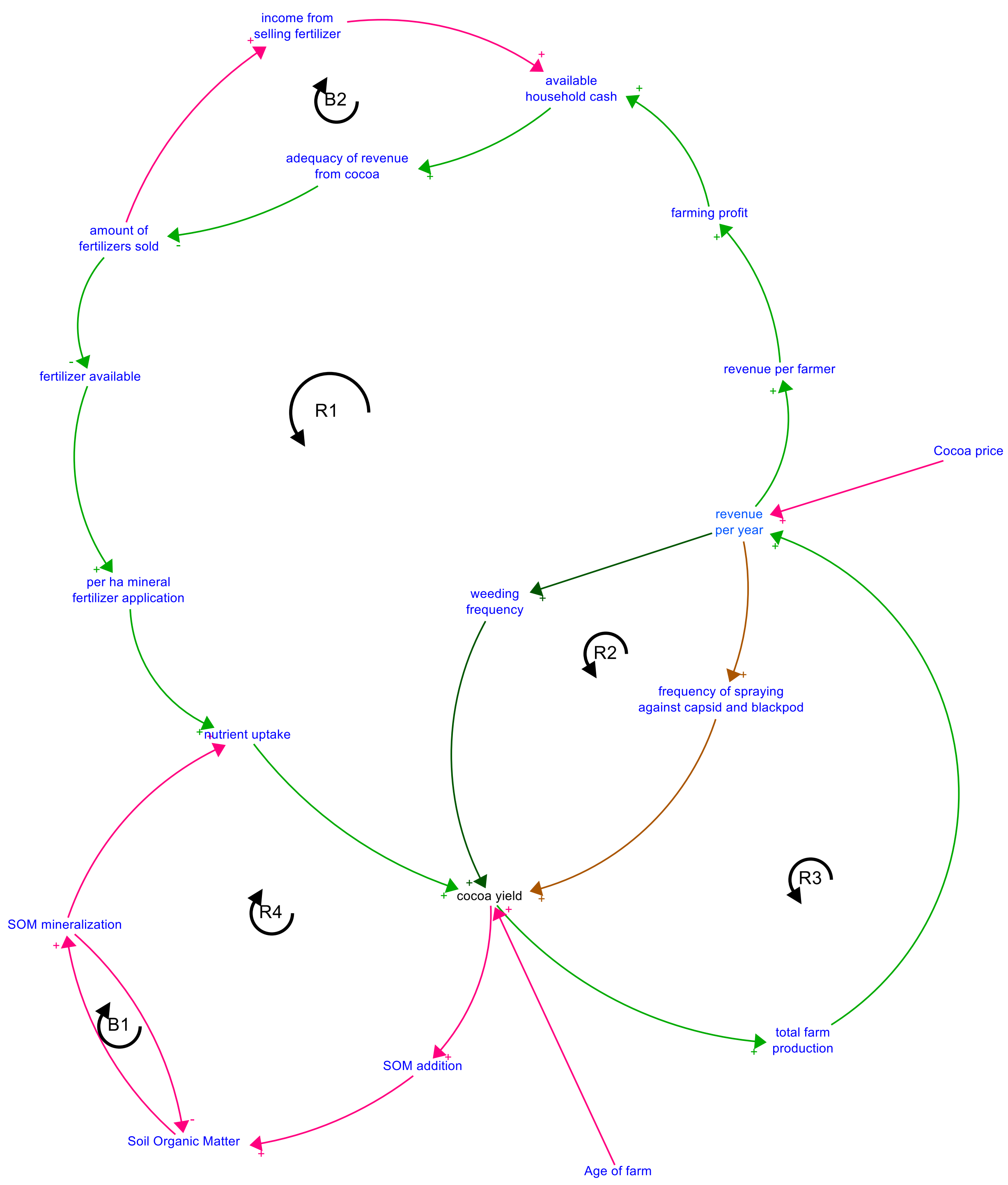

Figure 12: Feedback loop

As farmers yield per ha increases, the total production of farmers increases which increases the revenue of farmers. As the revenue of farmers increases more than their expenditure, their profit from farming increases. With farmers having enough cash needed for their basic needs, the tendency of selling the free fertilizer given to them by the government reduces therefore making more fertilizers available for the farmers to apply on the land. When farmers can apply adequate fertilizers on their land every year, farm yields per hectare increases thereby leading to more production and revenue every year (R1). This loop is a reinforcing loop that keeps farmers in a poverty trap because the short-term gains of cash from selling the fertilizer leads to decrease in the yield therefore lower income in the future. One of the major factors that affect the yield of cocoa is the weeding and maintenance of the farm. When the revenue from cocoa increases, farmers can increase the frequency in which they are able to weed and maintain their farm. As farmers increase the number of times that they weed and maintain their farms in a year, the higher their cocoa yield per hectare (R2).

The third factor that affects the farmers realized yield per hectare is their ability to spray their farmers adequately every year. As their revenue increases, farmers can spray their farms adequately which leads to higher productivity therefore higher revenue (R3). Another factor affecting farmers yield is the fertility of the soil which can be increased by increasing the amount of fertilizer that is applied on the land every year. The lesser the nutrient available to plants, the lesser the realized yield (R4). The process of mineralization determines available nutrients to the plants, the higher the mineralization time, the longer it takes for plants to get access to nutrients and utilized to increase productivity (B1).

Farmers in Ghana are in a poverty trap were they constantly in need for extra income because of the increase in the living expenditure in the country. One of things that farmers try to use to mitigate this situation is to find alternative ways of getting money to meet their basic needs. This loop tries to keep farmers above the poverty line where they try to sell their fertilizers to support their basic needs (B2).

6.0 MODEL VALIDATION

Validating a system dynamics model is such an important process. Model validation is a gradual process intended to build confidence in the simulation model(J. W. Forrester & Senge, 1980). It is important that the modeler shows that the model relate to existing knowledge about the system the modeler is investigating(J. B. Homer, 2012). There are three test that must conducted in order to validate a system dynamics model. These are direct structure tests, structure-oriented behaviour test, and Behaviour pattern test.

6.1 Direct Structure Test.

J. W. Forrester & Senge, (1980) proposed examples of direct structure tests. These are structure verification tests, direct extreme-conditions test and dimensional consistency test.

6.2 Structure Verification Test

To pass the structure verification test, the model structure must not be different from the knowledge about the system. Variables a the knnd stocks must be must have relationship similar to that of the system under investigation (J. W. Forrester & Senge, 1980). The components of the structure of the model based on the knowledge of existing literature which showed in detail under relevant sections of this thesis and under the model documentation section.

6.3 Parameter Verification Test

Parameter verification test is the process of evaluating the constant parameters in the model structure compared to knowledge that exist in the real system. In the case of this model, literature about the system have been reviewed and values that falls between the range were chosen for the constant parameters in the model structure.

6.4 Direct Extreme Condition Test

This is the process where all the equations of the model are assessed to make sure that they are robust under extreme conditions. To undertake this test, each equation must be inspected to ensure that its response is adequate to the extreme inputs. MIN or MAX functions was employed so that equations do not take unreasonable values. The upper and lower boundaries of table functions were taken to make sure that values remain reasonable under extreme conditions.

6.5 Dimensional Consistency Test

Units of measurement have been assigned to all variables in the simulation model. These units must be consistent to consider the equation to be valid. If the unit is not consistent with the equation given, Stella will show unit errors. Correcting the Unit errors must be done with correct equations and relationship with variables but not using fudge factors.

6.6 Structure-Oriented Behaviour Test

6.6.1 Behaviour Sensitivity Test

This is the test that determines parameters that the model is highly sensitive to. The sensitivity test is to help provide more valuable insights about the model and parameters that we need to further investigate. This also provides insights about the leverage points of the model and where there need for adjustment through policy. Sensitivity analysis was done on some of the key variables in the model to see how sensitive these variables are to the behaviour of the model.

Share of cash for spraying.

From figure 13, run 1 is the base run from the model. At run 2, When the share of cash for spraying is set to zero which means that there is no money allocated for spraying the cocoa, the realized farmers yield is at the lowest point whilst the available cash is lower than the base run. This means cash available to farmers will be lowered in the long run but will not be drastically affected. When the share of cash is set to 1 at run 11, there is a sharp increase in the realized farmers yield from 2000 and continues at a higher rate till 2020. This means that if farmers were to use maximum amount of money needed for spraying the cocoa farm, they will achieve a higher yield. On the other side, the cash available to farmers starts to decrease in the beginning until it goes negative. This means farmers allocating all the revenue to spraying in the long run will reduce their money drastically.

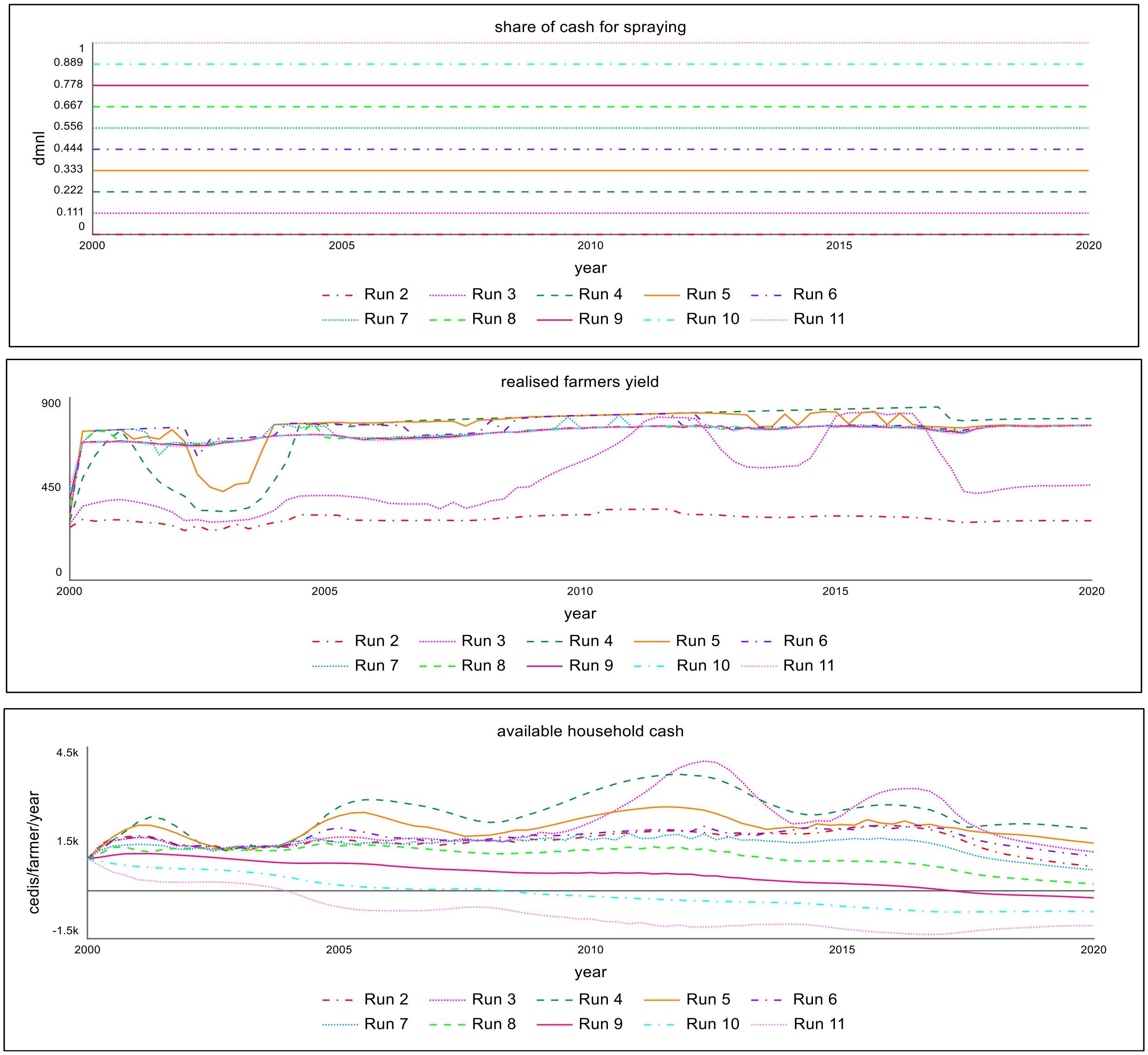

Figure 13: Sensitivity analysis for share of cash for spraying

Share of cash for weeding.

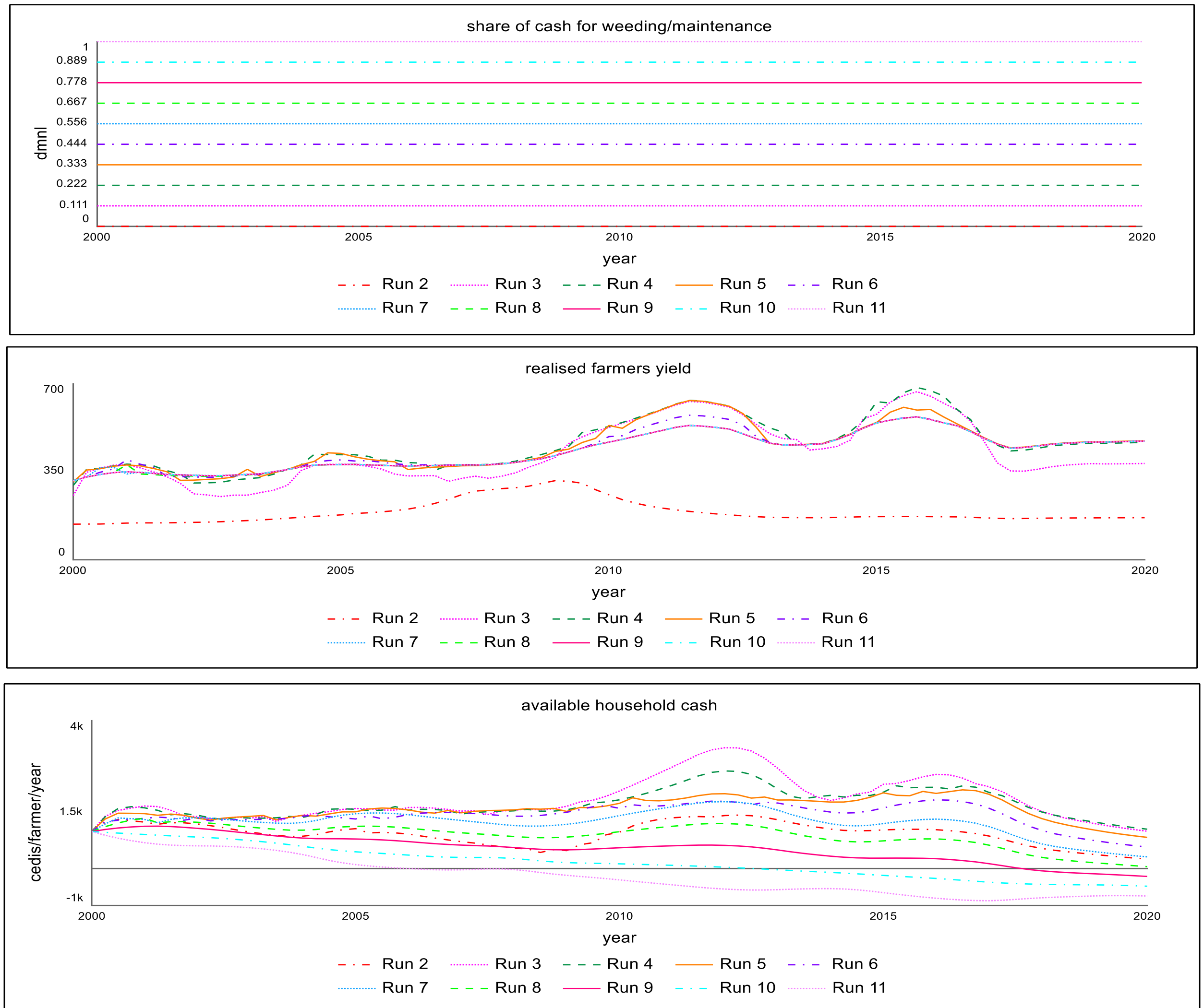

Figure 14: Sensitivity analysis for share cash for weeding

Looking at the effect of share of cash for weeding/maintenance of realized farmers yield and cash available. Run 2 is a scenario where the farmers do not maintain their farms at all and the share of cash for weeding/maintenance is 0. Realized farmers yield is at the lowest and almost flat line. This shows that weeding is very significant in increasing or maintaining the yield of farmers. Run 3 is the optimal run where farmers spending about 11% of them an optimal yield and the maximum amount of money. The available household cash is remaining the same from 2000 until it starts to decline after 2015. This shows that not maintaining the farms has a long-term effect of the cash of farmers. Run 7 to run 11 does not have a major change in the realized farmer's yield. If the share of cash for weeding is set at 100% or 50%, there is no major effect of on the realized farmer's yield. Setting the share of cash for weeding at 1(100%) the household available cash declines overtime and eventually goes negative.

Removal Rate

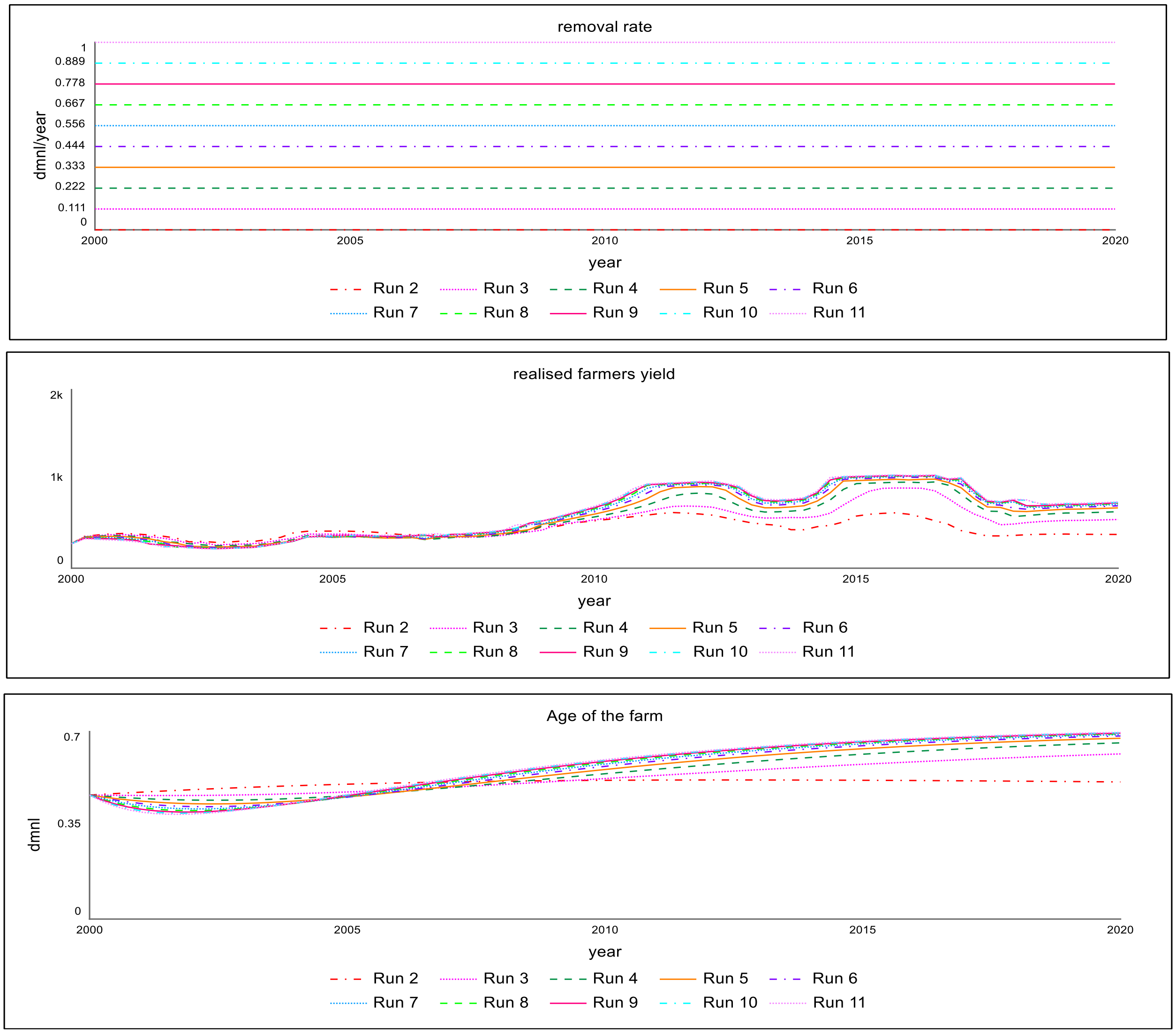

Figure 15: Sensitivity analysis for removal of old trees

From figure 15, with run 2 when the removal rate is set to zero which is no old cocoa trees are removed and remain on the farm, productivity slowly declines over the years. This eventually negatively affects the overall yield in the long run. With run 11 when the removal rate is set to 1, that is all old trees are removed and replaced by new ones, the productivity of the of the farm decreases initially but increases overtime. This shows a higher productivity in the long run when the old trees in the farm are removed and replaced with new ones. This also influences the realized farmers yield, initially the yield is lower but increases overtime above the base run.

7.0 MODEL BEHAVIOUR

7.1 Base Run

The model was run for the 20 years, from 2000 to 2020. The results of the baseline scenario can are presented. From the simulated model farmers yield has been increasing steadily since 2000 until it reached a peak and starts to fall. Initially, there was an increase in yield, this can be attributed to not selling their fertilizers (see figure 14) but applying fertilizers on their farmers. This caused a virtuous cycle leading to high nutrient uptake which caused higher yield which leads to increase in household cash. As the household cash increased, within the period there was less fertilizer sold. From figure 16 it can also be seen that within this period the effect of fertilizer on yield also increased. This behaviour is caused by loop R1 which demonstrates that as fertilizer application increases, farm yield also increases which leads to higher household available then farmers less likely to sell their fertilizers. It takes time for loop R4 to take effect, so its effect is seen later as more and more yield has been harvested plant residue added to the soil. It can also be seen that behaviour pattern of the simulated model does not quite match the reference mode. This can be attributed to factors that has affected the yield of cocoa farmers which has not been considers in this model. Some of these factors are the rise of illegal mining (Galamsey), Switching from cocoa farming to different arable farms, discarding of lands due to disputes among families.

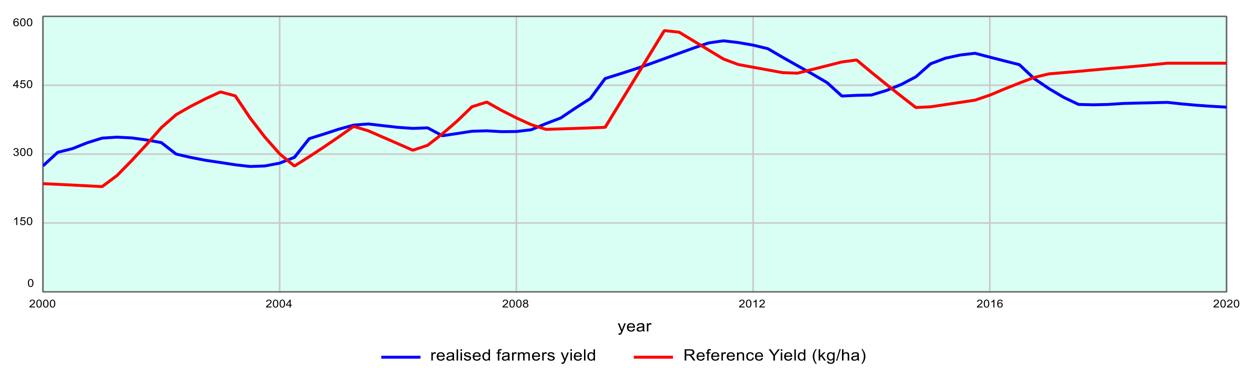

Figure 16: realised Yield and Reference yield

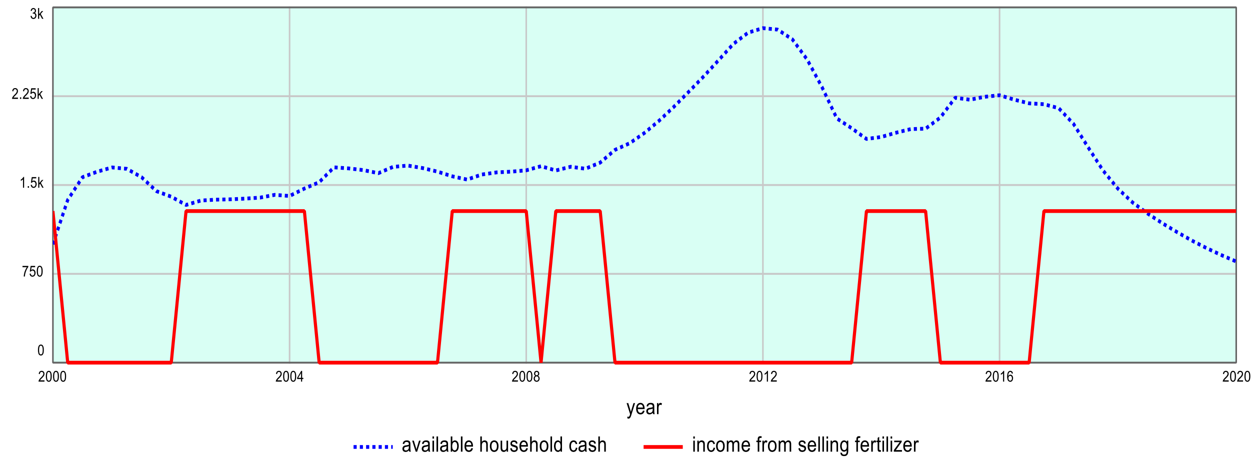

Figure 17: Farmers household cash and selling of fertilizers.

There is a balancing loop B2 that breaks the cycle for increased in yield because there was less cash for farmers next time around which resulted in farmers selling their fertilizers and concentrating less on weeding and spraying their farm. This can also be attributed to the prices of cocoa going down from 2002 to 2004 (figure 15). The decrease in cocoa prices activated loop B2 which caused farmers to sell their fertilizers therefore causing a vicious cycle by leading to decrease in fertilizer application, less farmers yield, less revenue thereby causing farmers to sell more of their fertilizers. This vicious cycle was broken when prices were increased in the world market. This can be seen after 2004 in figure 15. This caused loop R1, R2 and R3 to be activated again causing and increased in yield thus an increase in revenue.

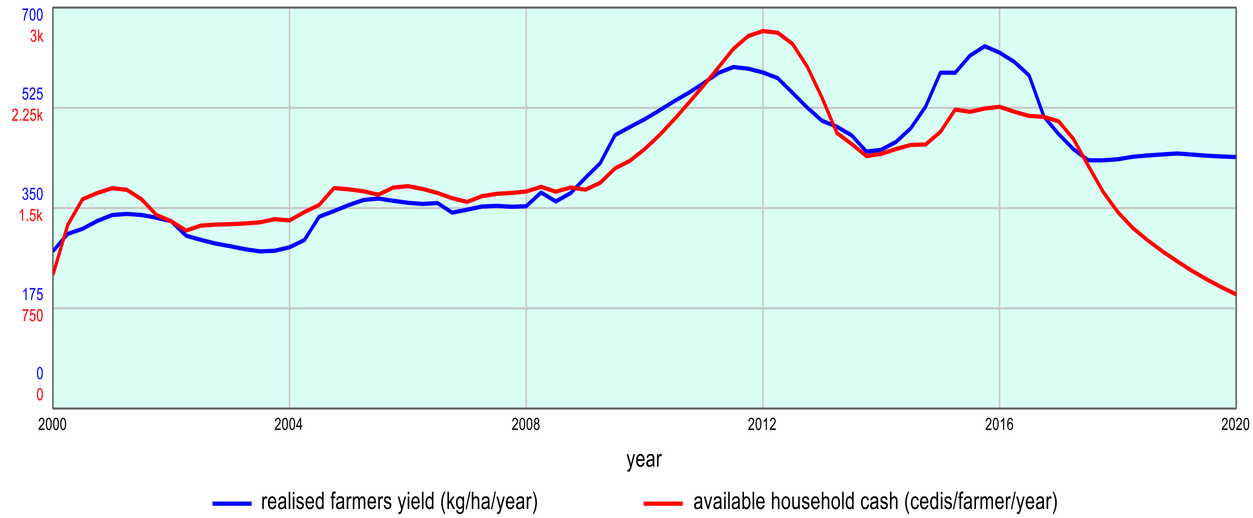

Figure 18: Farmer's cocoa yield and farmers cash

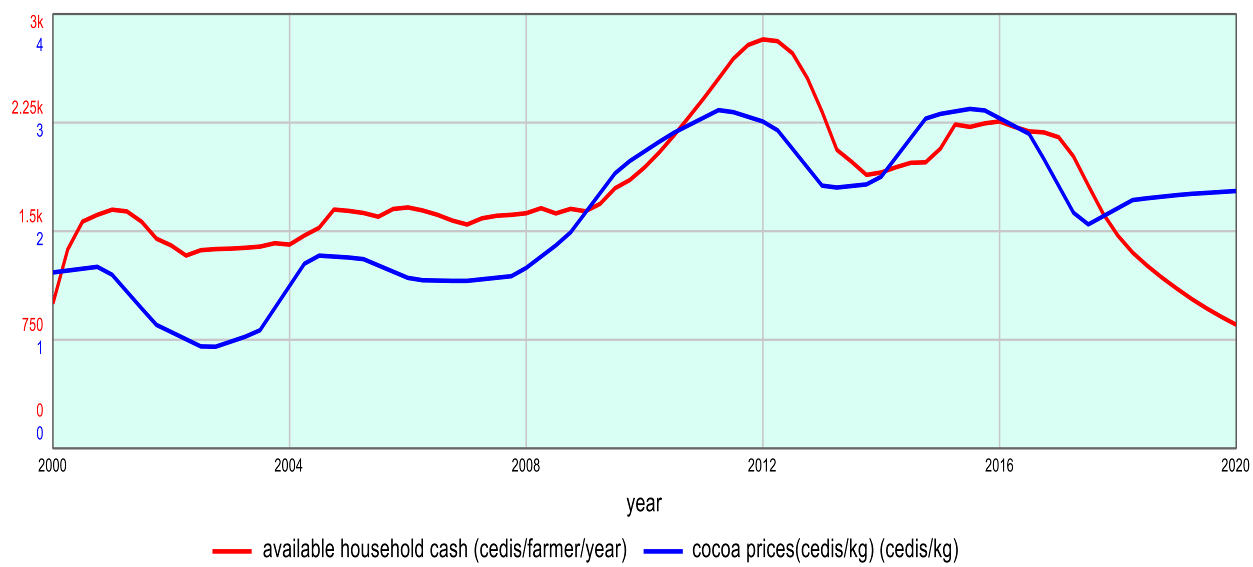

Figure 19: Cocoa prices and farmers' cash

Looking at effect of fertilizer application on farmers yield (figure 16), reinforcing loop R4 is the main driver of this part of the model. The increase in the yield can be seen to have attributed to the increased in the fertilizer application ratio. As fertilizer application increases, nutrient uptake increases thus increased in farm yield. As the farm yield increases more soil organic matter is added to the soil which takes time before it is released for the plant to take it. This process completes the loop R4. The loop R4 feeds into loop R1 pushing the intensity of the R1 to create a strong loop when activated. At the peak of the cocoa yield 2010 and 2015, this loop was strongest in the behaviour of the yield.

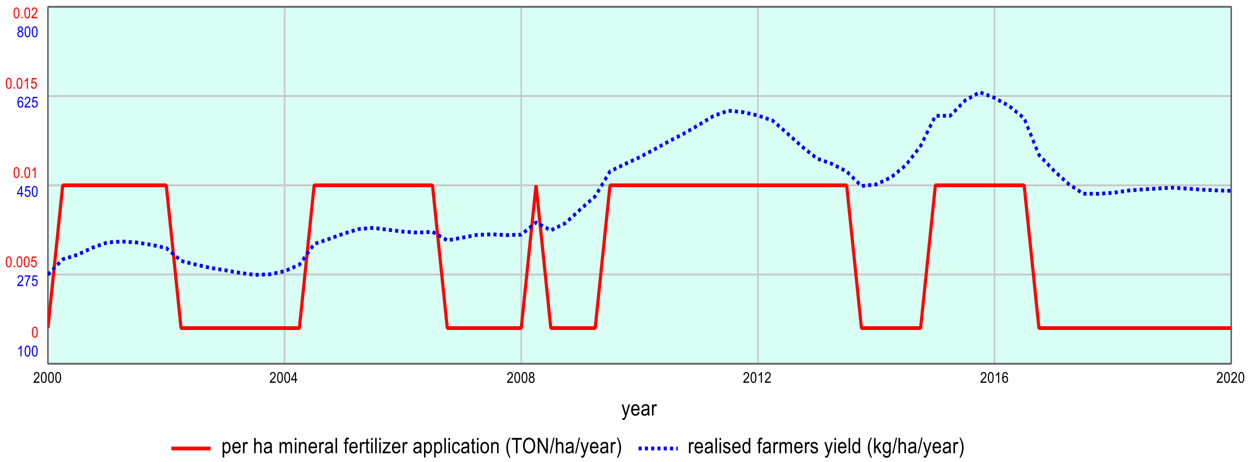

Figure 20: Relationship between fertilizer application and yield

Figure 18 looks at the relationship between the weeding and maintenance of the farm and yield where from 2010 to 2015 where there was a continuous increase in the yield of cocoa, there was not major decrease in the weeding and maintenance of cocoa farmers. Weeding and maintenance of the farm was stable at a higher rate. When the weeding decreased at 2015, then the yield dropped. This behaviour is caused by the R2 loop. This loop strengthens as the revenue generated by farmers increases. This can be seen in figure 15 where within the same period on increment the prices of cocoa was at the highest level.

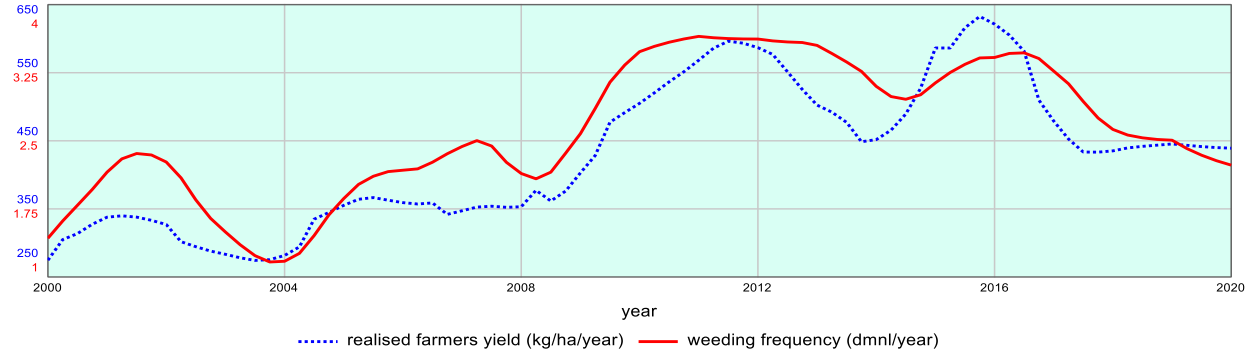

Figure 21: Relationship between weeding and farmers' yield

The price of cocoa has an influence on the application of fertilizer. As the price of cocoa decreases, overtime, the fertilizer application also decreases and vice versa. This is because, as the price cocoa decreased, weeding, and spraying of farms also decreased which led to lower yield. Lower yields lead to low income for farmers as their expenses increase. With lower incomes, farmers tend to sell most of their freely given fertilizers to support their basic needs therefore lower fertilizer application.

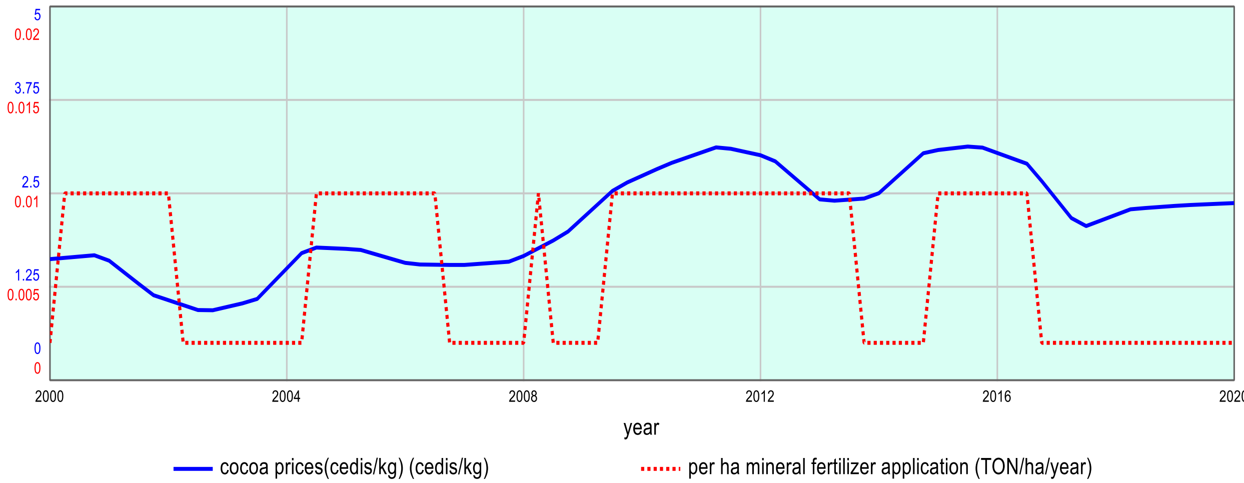

Figure 22: Cocoa price and Fertilizer application

7.2 EXTRAPOLATED COST OF WEEDING AND SPRAYING

Figure 20, the model was run into the future to see how the cost of weeding and spraying will affect the overall yield of cocoa. The cost of weeding and spraying was extrapolated since we do not know the cost in the future. When cost is extrapolated into the future, yield decreases significantly because cost increases. With higher cost, less money for farmers to reinvest in their farm, therefore lower yields in the future.

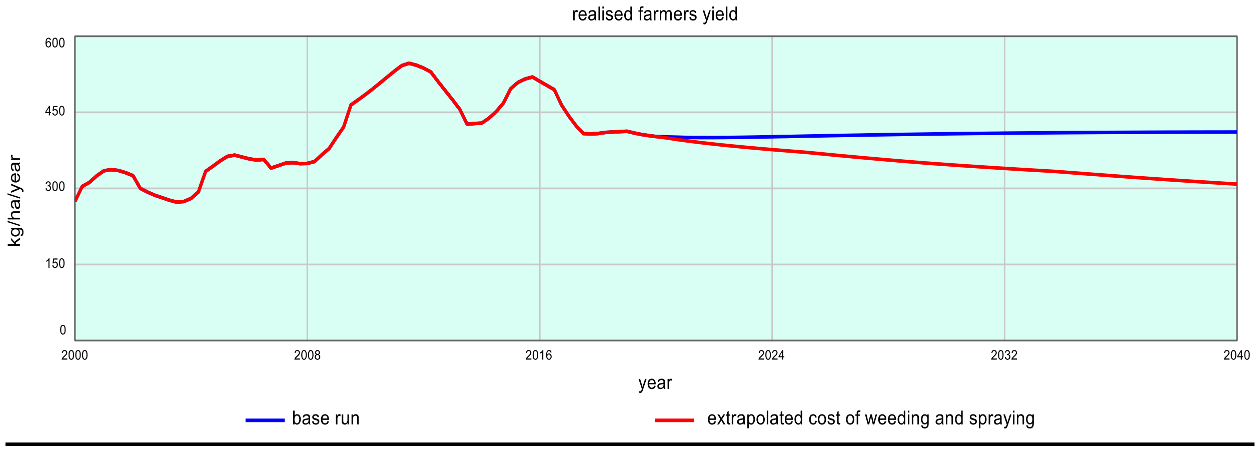

Figure 23: weeding and spraying cost extrapolated.

8.0 POLICY ANALYSIS

8.1 Increasing the price of Cocoa.

The government of Ghana controls the prices of cocoa for farmers. Every year the government set the price for farmers, so farmers have no negotiating power over how much they want to sell their cocoa. Figure 23 shows that it is possible to increase the yield of farmers by increasing the price of cocoa. Increasing the price of cocoa to 2.8 cedis and above shows a significant increase int the yield of cocoa in the future. When the price of cocoa is increased, it leads to an increase in yield of farmers. This is because when the price of cocoa increases, farmers get more money per hectare, this strengthens the loop R1, R2 and R3 turning a vicious cycle of the loop to a virtuous cycle. Thus, increase in weeding and maintenance of their farm and applying the necessary levels of fertilizer without selling the fertilizers.

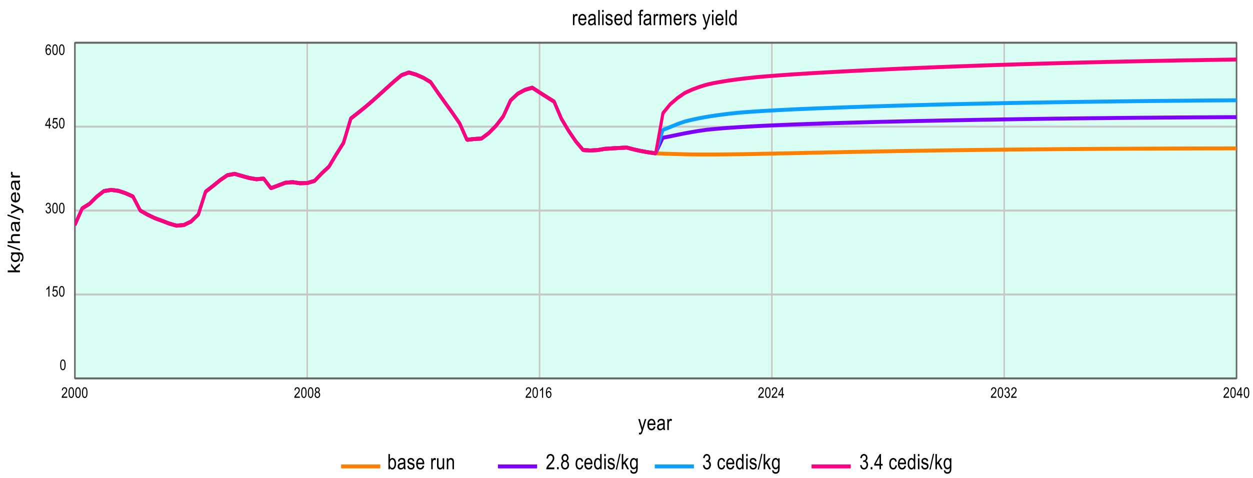

Figure 24: Yield after price increase

This led to increase in the yield of farmers thereby increasing their overall income that they get from cocoa the next time around. This activates the loop R1 and as farmers have more money available to them to take care of their basic needs, farmers will not sell their fertilizer thereby leading to more fertilizers being applied, thus more yield Setting the price of cocoa at 4 cedis per hectare may give a higher yield.

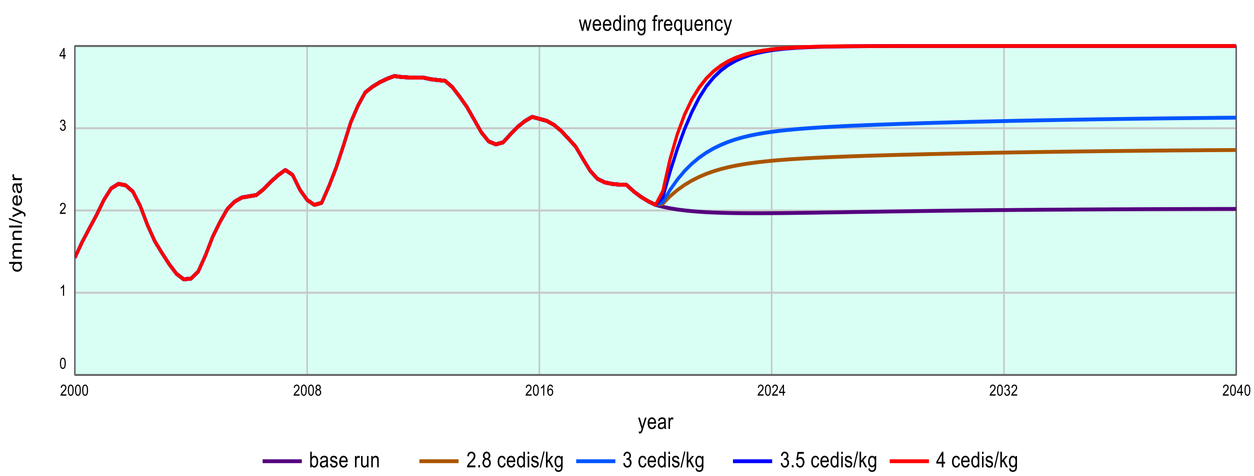

Figure 25: Weeding frequency with price policy

With revenue going up, loop R2 is strenghten and its viciouness is reversed so that farmers are able to maintain the frequency at which they are suppose ot weed their farms. With famers maintaining the level of weeding, it helps boost the level of yield in the farm. With yield of farmers increasing their revenue increase thereby increasing their household available income. This also leads to farmers having more money available for their farms. This shows that government focusing on increase in prices will decrease the cost of providing fertilizers for farmers. Providing fertilizers is high cost venture that the government undertake, so if fertilizers are provided for farmers in the hope that it will used on their farms to bring future return on the investmennts for government. So if farmers are not using these fertilizers it is the government that looses in the long run. For government to see higher returns on their investment they must work on the price of cocoa too so that it provides a good environment for farmers to able to apply these fertilizers on their farms. Farmers being able to apply these fertilizers on their farms allow the policy of providing free fertilizers work effectively.

8.1.1 Removing old cocoa trees.

Removing old cocoa tree has an impact on the yield of cocoa. If the government adopt a policy of removing and replanting new cocoa trees for farmers, the long-term results will be an increase in the cocoa yield. Initially as cocoa trees are being and removed and seedlings being replanted, yield of farmers will decrease for a few years and will start to increase after that. The new planted trees will bring up higher yield. Removing 5% of the old cocoa tree gives slightly higher yield than the current run. From figure 26, removal rate of about 30% gives a higher yield than a removal rate of about 10%. This shows that the higher the removal rate of old cocoa trees, the higher the yield in the future.

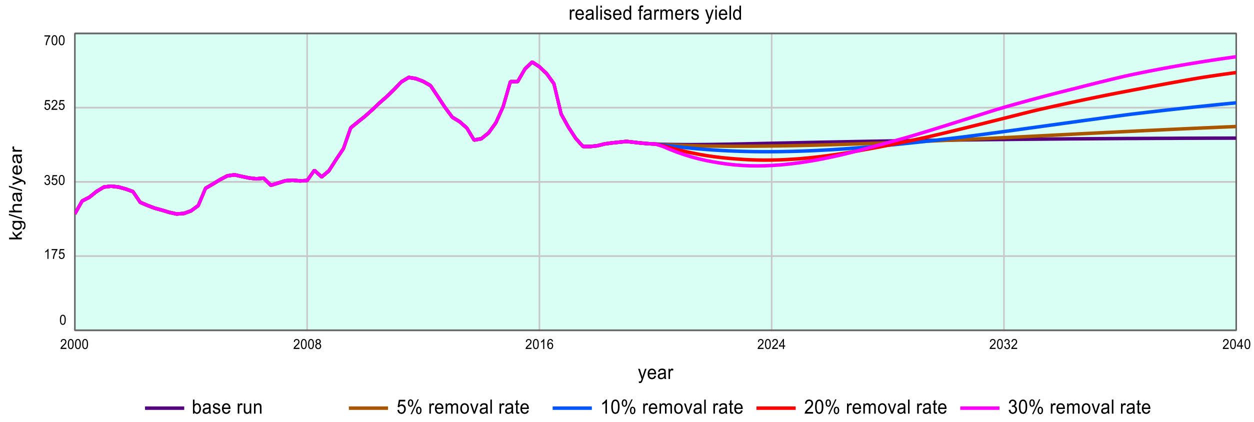

Figure 26: Yield with removal rate policy

8.2 FARM MANAGEMENT PRACTICES

8.2.1 Share of cash for spraying against pests and diseases.

Figure 27 look at the impact of the management of cash towards the spraying of cocoa farms affect the overall yield of the farmers. Increasing the share of cash for spraying by 12% shows an increase in the yield of cocoa. Pest and disease has been one of the greatest factors decreasing cocoa in Ghana and farmers in Ghana have not been known to adequately spray their farms (Aneani & Ofori-Frimpong, 2013). So, if farmers increase their share of money for spraying to 15% or above, it will greatly affect their yield because, as the share of cash for spraying increases, loop R3 strengthens causing farmers to meet the frequency at which they are supposed to spray their farms. This will set in motion the loop R1 in the next time around causing to be reversed from vicious cycle to a virtuous one. As these loops turn, yield continues to rise. Spraying of farms reduces the occurrence of pest and diseases and as all these R1 and R3 turns to a virtuous one due to increase in spraying of farms, there will be less diseases and pest infestations in farms which will lead to a continuous higher output.

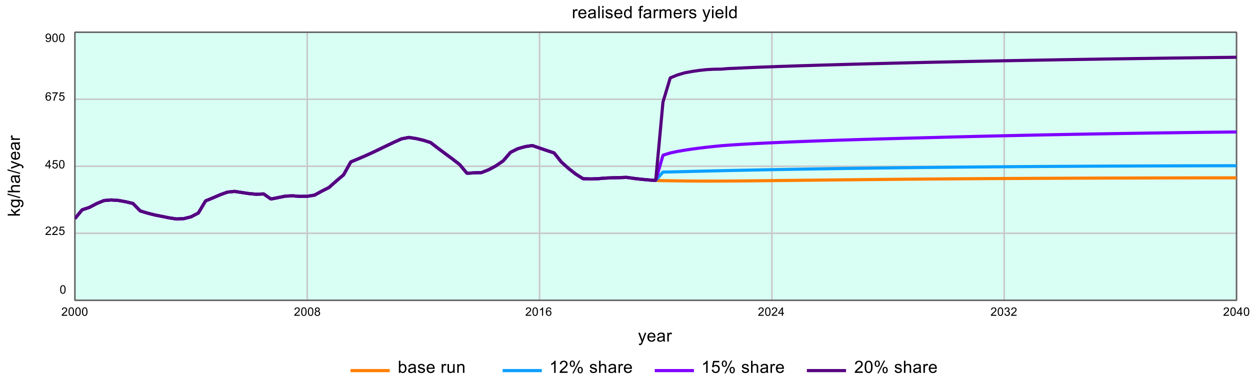

Figure 27: Share of cash for spraying

8.2.2 Share of cash for weeding and maintenance.

Figure 28 also looks at the share of cash allocated for weeding of cocoa farms. Weeding of farms leads to less competition of the cocoa crops with the weeds and this allows the cocoa plants to achieve a maximum output.

If farmers increase their share of money for spraying to 15% or above, it will have an impact on the yield because, as the share of cash for weeding increases, loop R2 strengthens causing farmers to meet the frequency at which they are supposed to weed their farms. This will set in motion the loop R1 in the next time around causing to be reversed from vicious cycle to a virtuous one. As these loops turn, yield continues to rise. Weeding of farms reduces the competition between weeds and cocoa crops and as all these loops R1 and R2 turns to a virtuous one due to increase in weeding of farms, there will be less competition among cocoa trees and weeds in farms which will lead to a continuous higher output.

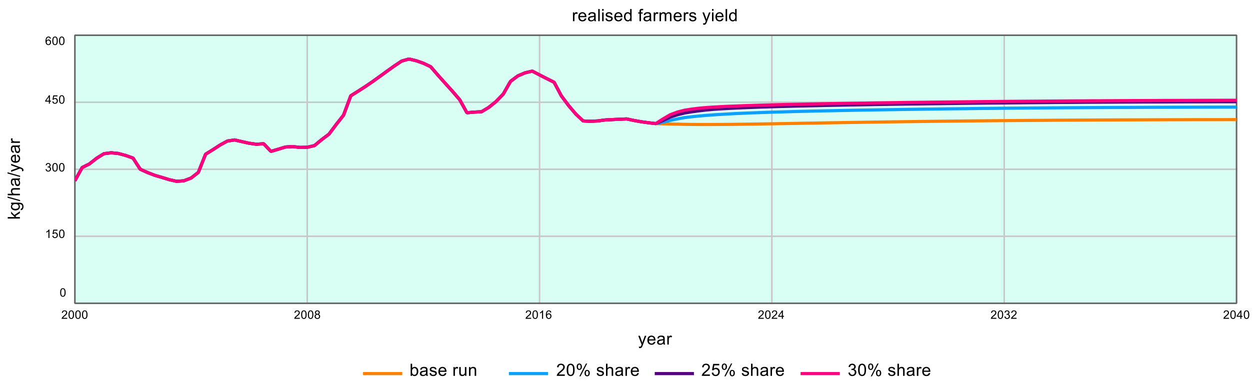

Figure 28:Share of cash for weeding and maintenance.

8.3 Combination of increase in Price and removal rate

Figure 29 and 30 look at the combining the two policies of increasing the price of cocoa and embarking on removing old cocoa trees from farms. Figure 29 look at the situation where government set the price at 2.8 cedis/kg and figure 30 also look at a situation where the price is set at 3 cedis/kg. At 2.8 cedis and 10% removal rate, the yield decreases but not lower than the base run. 10% removal rate does not really affect the yield at the beginning of the policy compared to that of 15% and 20% removal rate. Even though 20% removal rate initially reduces greatly the yield of farmers, the effect on yield on the long run is greater than that of the 10% removal rate or the 15% removal rate. Now at what price and removal rate gives the most yield for farmers? 2.8 cedis and 20% removal gives yield just above 600 yield/ ha and seems to stabilize at that region (figure 29). At the price of 3 cedis/kg and 20% removal rate, the yield does not initially drops as that of 2.8 cedis and 20% removal rate, this is because even though farmers are removing old trees at a higher rate, they have enough money to maintain their farmes at a higher level to give maximum productivity. So even thought the yield falls it does not take long for it to bounce back because the farms are well taken care of. So at the price of 3 cedis/kg and 20% removal rate gives farmers higher output compared to 2.8 cedis/kg and 20% removal rate. So in order for the government to implement the removal rate policy, the government must make sure that the price of cocoa is increased above 3 cedis/kg to ensure maximum output from farmers.

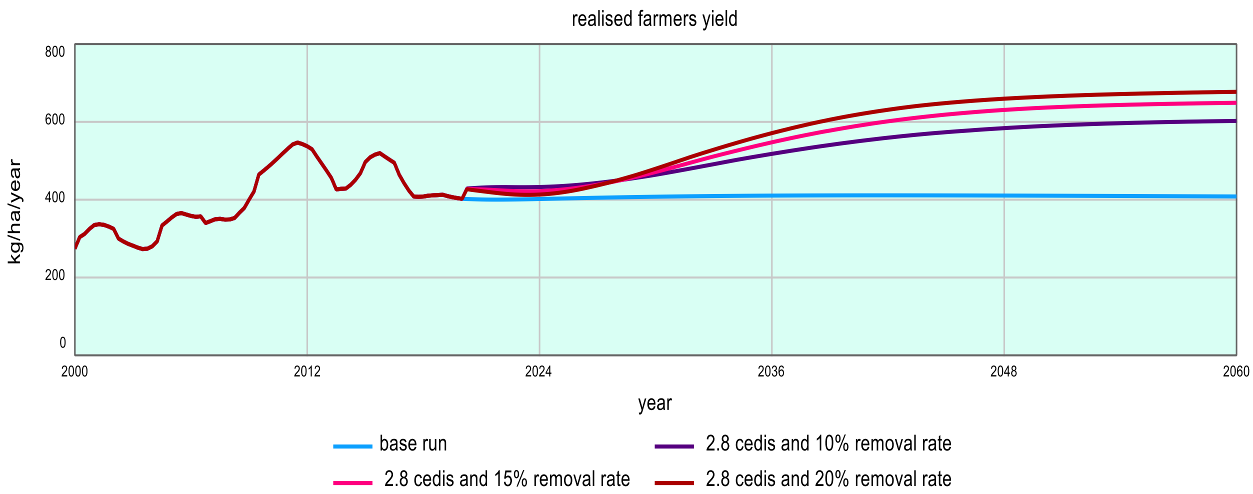

Figure 29: Increasing price (2.8 cedis/kg) and removal rate.

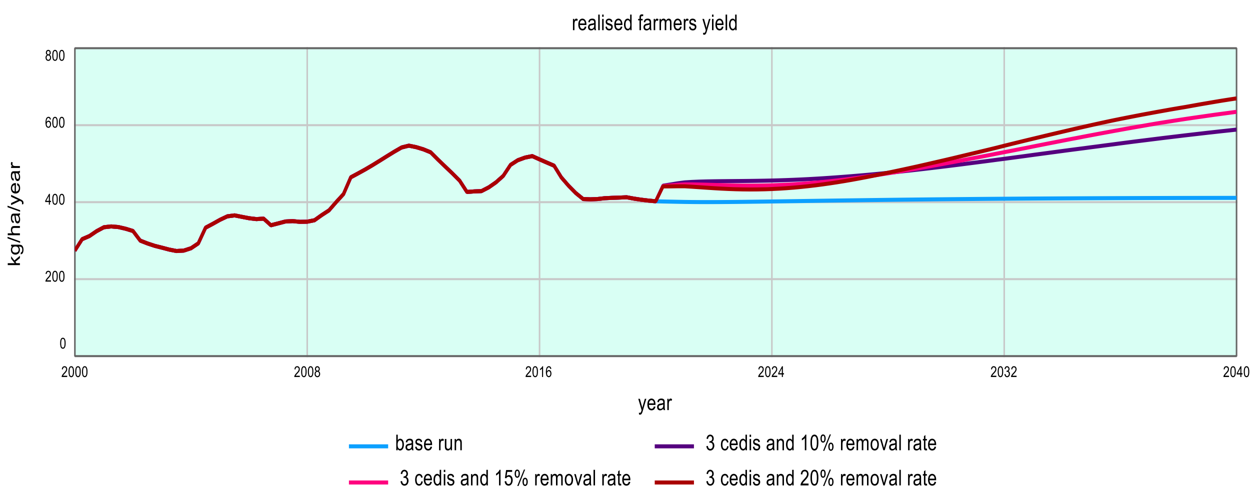

Figure 30: increasing price (3 cedis/kg) and removal rate.

9.0 POLICY SCENARIO ANALYSIS

9.1 Scenario 1: Cost of weeding (extrapolated and continuous) and removal rate

We can also look at how the cost of weeding and removal rate can affect the yield in the future. Figure 31 presents how future cost of weeding can affect the removal rate policy on yield. The cost of weeding is extrapolated into the future to see how it affects yields when run with policy of removing old cocoa trees from the farm. Base run extrapolated cost decreases the yield in the future. This means that with cost of production expected to increase in the future, farmers cannot sustain yield. When there is 10% removal rate and cost is extrapolated it is still not enough to increase the yield as it gives yields lower than the current run. So, the ideal removal rate is 20% and above because at this rate, even as the cost increases, farmers can achieve a higher yield in the future.

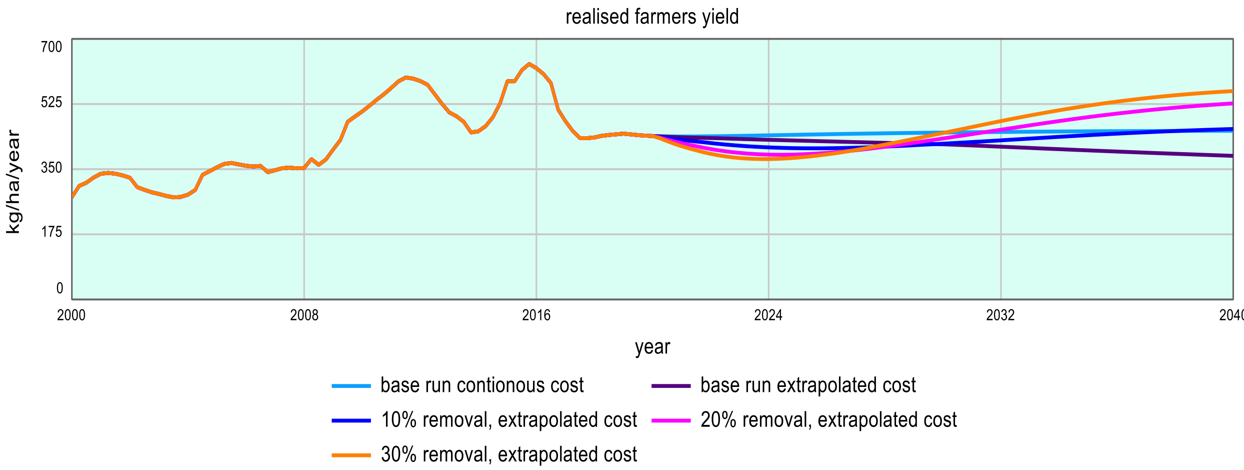

Figure 31:Cost of weeding (extrapolated and continuous) and removal rate

9.2 Scenario 2: Cost of spraying (extrapolated and continous) and removal rate

We can also look at how the cost of spraying and removal rate can affect the yield in the future. Figure 32 presents how future cost of spraying can affect the removal rate policy on yield. The cost of weeding is extrapolated into the future to see how it affects yields when run with policy of removing old cocoa trees from the farm. Base run extrapolated cost decreases the yield in the future. With 10% removal rate, there is no significant increase in the yield of farmers. This means that even if the government embark on a 10% removal rate, since the cost is still increasing, yield will still not increase significantly. Spraying cost is expected to increase in future so removal rate of 20% or more will be ideal for farmers to achieve higher yield.

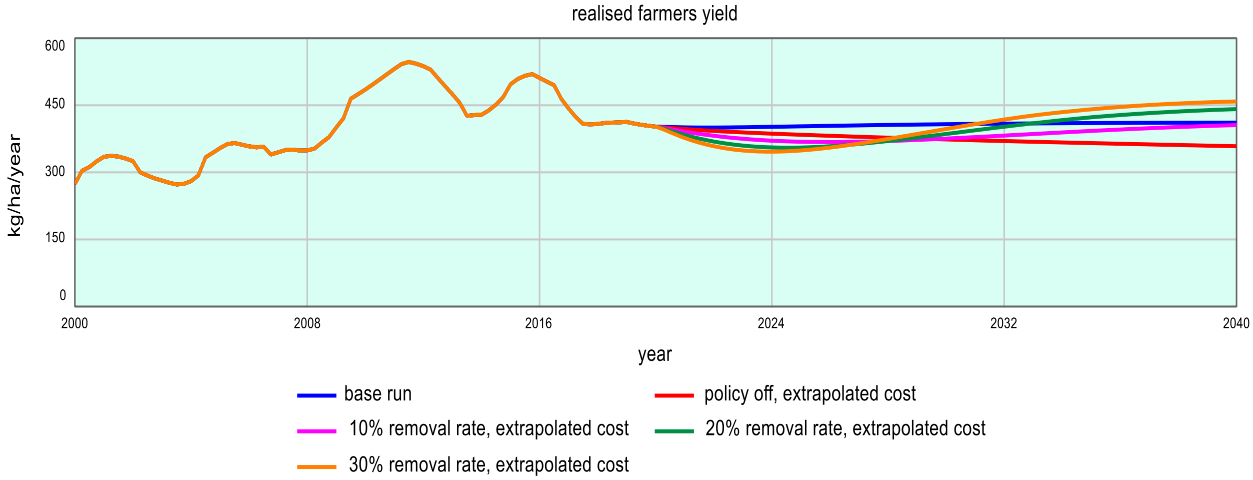

Figure 32: Cost of spraying (extrapolated and continuous) and removal rate

9.3 Scenario 3: Weeding and spraying cost extrapolated

We can also look at the both the weeding and spraying extrapolated into the future. From the figure 33d it can be seen that with the spraying and weeding cost expected to increase, 10%, 20%,30% will not be able to increase the yield of farmers. With the just the policy of removing the old trees from the farms will not increase the yield of farmers even if the government help remove about 50% of the old trees from farms. This shows that only focusing on the removal rate may help with the yield but will not be enough if the cost of weeding and spraying continuous increase.

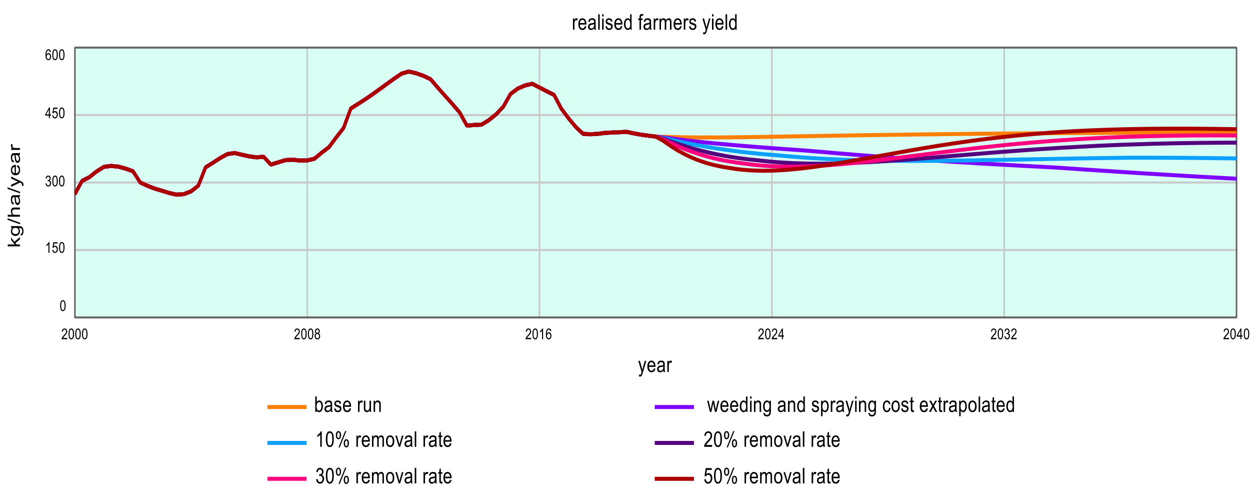

Figure 33:Removal rate policy with both weeding and spraying cost increased.

9.4 Scenario 4: Extrapolated weeding and spraying cost with price and removal rate policy

Since just removal rate is not enough when cost of spraying and weeding increases. The government can consider both removal rate and price increase. With price of cocoa increased to 3 cedis/kg, increasing the removal rate 10% will not highly increase the yield. Even increasing the removal rates 20% or 30% will still not increase the yield that much. From the figure 30, at the price of 3.5 cedis/kg and above with 40% increase in the removal rate of old cocoa tree will give a great increase in the yield of farmers.

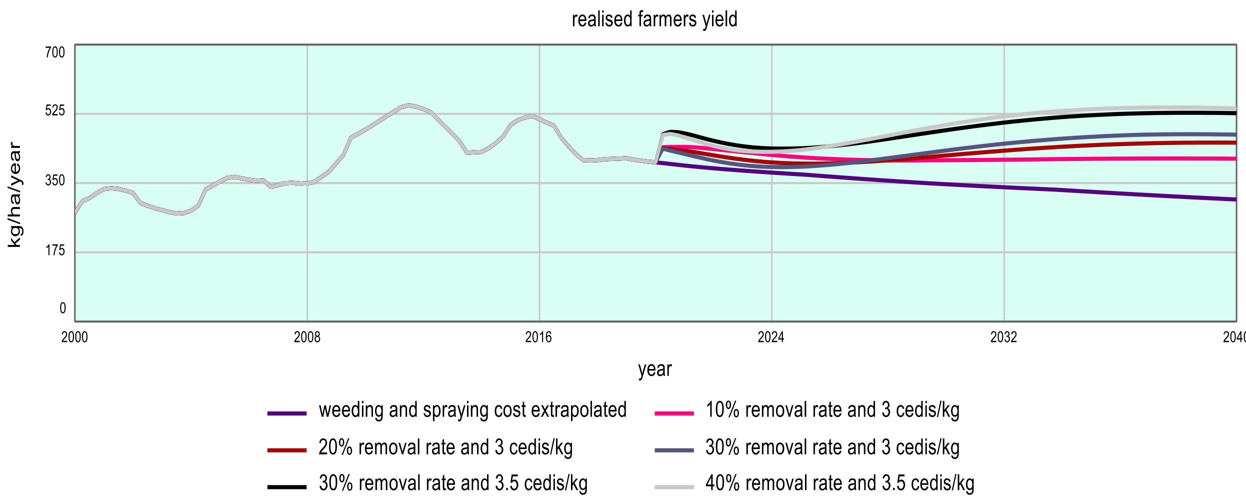

Figure 34: combination of removal rate and price policy with extrapolated cost

9.5 Scenario 5: Extrapolated living expenses and Household available cash.

It is important to consider how removal rate policy affect the farmers living situation. For the removal rate policy to work, farmers must be assured that they will not suffer during the time of the policy. This is because, as farmers remove cocoa trees, the yield goes down, so does their income. So, convince farmers to remove their cocoa trees, government must compensate them by increasing the price of cocoa, so that even if the yield goes down in the few years, their money will increase because of the price increase. In Figure 33, the two polices were combined where there will be an increase in price of cocoa and increase in the removal rate of old cocoa trees. 20% removal rate with price increased to 3 cedis/kg is still not enough to get farmers out of poverty. At least 30% removal rate and a price increase of about 3.5 cedis and above will increase the cash of farmers.

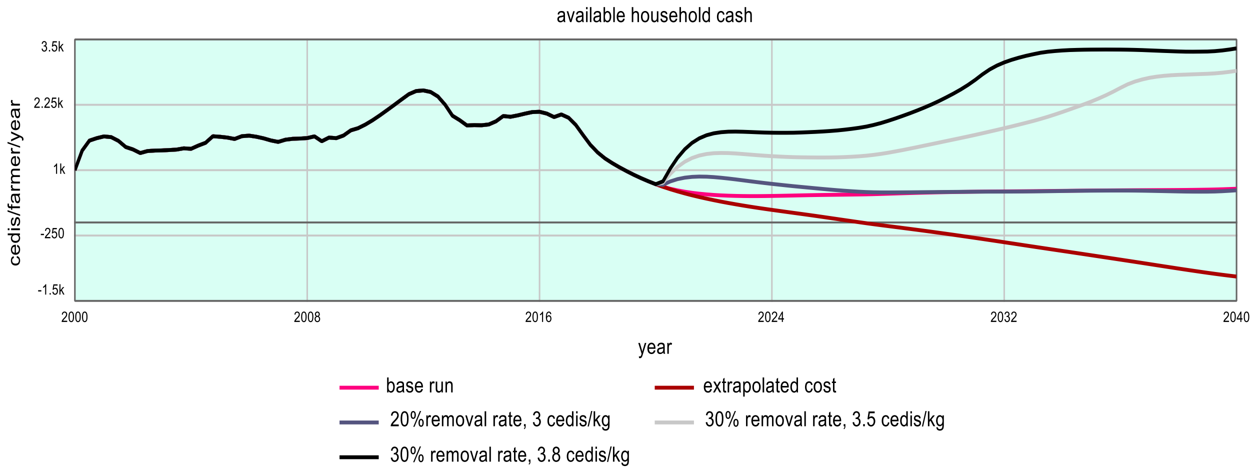

Figure 35: combining removal rate and price policy with extrapolated living expenditure cost.

It is important that even though farmers may want an increase the price of cocoa, it is also important that they consider the removal of old cocoa trees from the farm. This is because with an increase in price and lower yield per hectare, farmers are still going to be in poverty.

10.0 POLICY AFTERMATH

10.1 Aftermath of increase in price policy

The policy was run for a 20-year period and stopped. The figure 36 shows the results after 20 years. When the policy is stopped after 20 years, yield sharply drops to the original levels. This is because as price stops, revenue decreases, the virtuous loop cycle of R1, R2 and R3 reverses back to a vicious cycle where weeding, spraying and fertilizer application reduces.

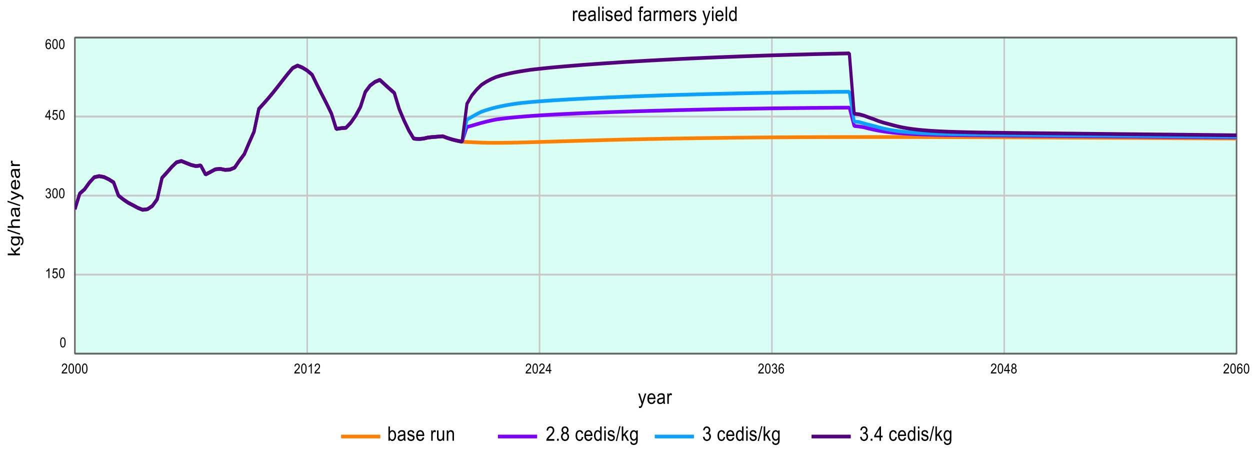

Figure 36: farmers yield after price increase policy.

10.2 Aftermath of removal rate policy

We can also look at the removal rate policy after 20 years of implementation. When the policy is stopped after 20 years, the yield did not sharply reduce as that of the price. The yield reduces slowly overtime because it takes time for old to trees to increase in the farm. So as the old trees start to increase the yield also starts to fall. So, removal rate policy that must be implemented consistently to achieve a continuous increase in yield.

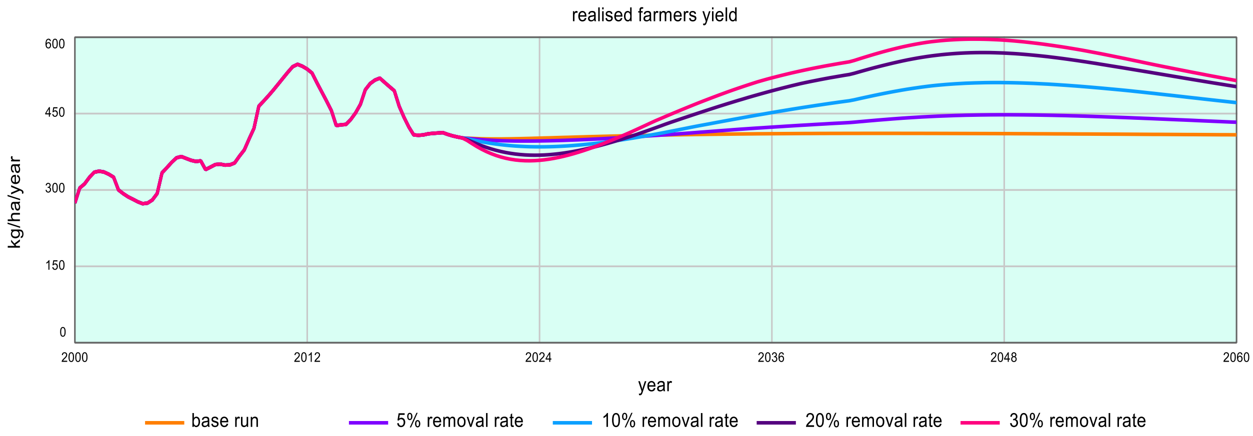

Figure 37: Farmers yield after removal rate policy.

10.3 Combination of Removal and Price Increase Policy

Considering the combination of removal and price increase policy, the policy was stopped after 20-year period, there was a small dropped in the yield, and for the first 8 years after policy, yield slowly picked up before slowly declining. Results from figure 38 and figure 39 shows that the combination of price and removal rate policy gives does not allow a sharp drop after the policy has been stopped. The yield picks up for a few years after the drop before declining slowly.

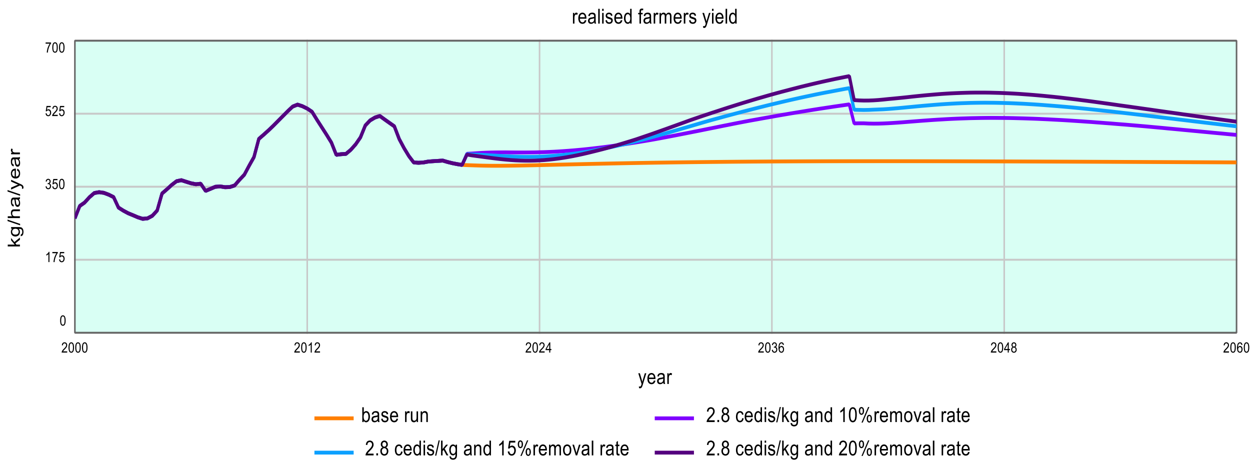

Figure 38: farmers yield after combination of 2.8 cedis/kg price and removal rate policy.

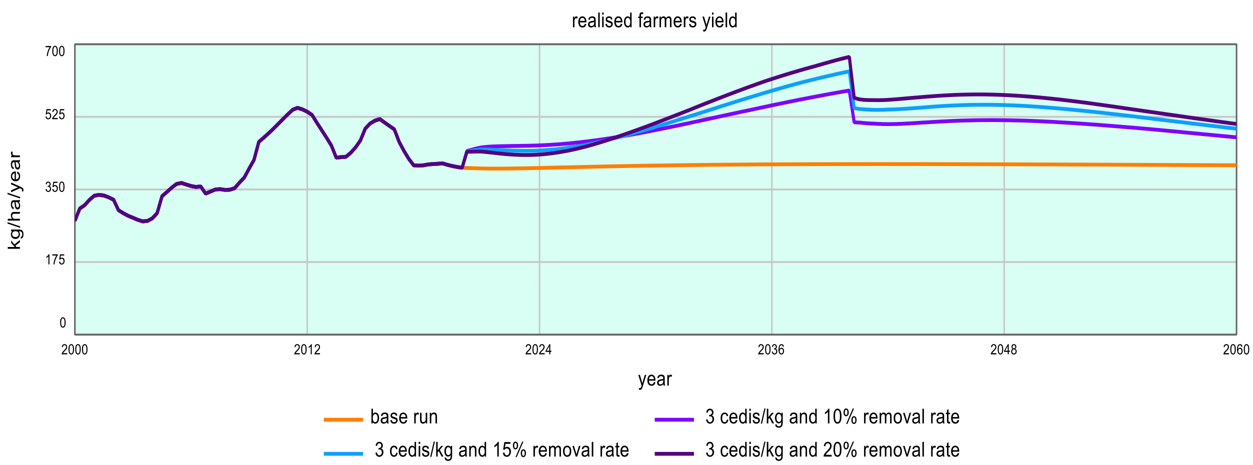

Figure 39:farmers yield after combination of 3 cedis/kg price and removal rate policy.

11. CONCLUSION

11.1 Summary:

This thesis attempted to investigate into the relationship between farmers living income and cocoa production in Ghana. Based on literature, it was found that the major factors that affect farmers productivity are their ability to weed, spray and apply fertilizers adequately on their farms and these factors are all affected by their level of income. Income plays a major role as it determines whether farmers will choose to apply fertilizers or sell their fertilizers to care for their families, and whether farmers will have the ability to spray and maintain their farms. Because of low-income levels of cocoa farmers, farmers are afraid to even cut down old trees which are less productive in their farms because they know that they may not be able to deal with the initial consequences that comes with it even though old trees are less productive. Farmers with low-income levels tend to sell their freely given fertilizers from the government to get cash to provide for their basic needs. Thus, most farmers apply less or no fertilizers on their cocoa every year. With low levels of income, they also tend not weed or spray their farms adequately contributing to lower levels of yield.

11. 2 RECOMMENDATION

Based on the policy analysis, these are the recommendation,

1. Government should increase the price of cocoa to atleast 3 cedis/kg and above. This is because by increasing the price of cocoa, farmers will be able to get more money for their yield which will allow them to get enough income for their basic needs and also be able to focus on maintaing and investing in their farms.

2. Government should also incentivise the cutting of old cocoa trees for farmers by absorbing the cost of cutting these trees. Farmers have been afraid to cut down their old cocoa trees either because they don’t have money to go through the process or afraid of loosing yield for the initial period of the process. Governent can provide incentive for farmers who cut

down their trees to compensate for the initial loss of yield in the first few years of cutting down these trees.

3. Farmers can also focus on increasing the frequency by which they sprayin and weed their farms. This can be done by increasing the share of cash allocated to weeding and spraying. This of couurse will reduce the money needed for other production process but farming community can come together in assisting each other rather than paying for these things.

11.3 ANSWERING RESEARCH QEUSTIONS

Can system dynamics be used to identify the relationship between farmers living income and its relationship with cocoa productivity?

Yes. Based on literature, relationship between farmers living income and cocoa productivity was able to be established. The major factors that were found to affect farmers productivity in Ghana are low frequency of weeding, low frequency of spraying, low level of income of farmers and low level of fertilizer application. Weeding has a positive impact of the productivity of cocoa. As the frequency of weeding increase the productivity of cocoa also increase. Spraying of cocoa farms also has a positive effect on the productivity of the farm. Farmers increase their yield per hectare when they adequately spray their farms. The ability of the farmers to weed or spray their farms is affected by the income levels of the farmers. The higher the household available cash of farmers, the higher they can weed and spray their farms. The higher the household cash, there is less likelihood that farmers are going to sell the fertilizers freely given to them by government. Even though the model could not produce the exact behaviour, the behaviour that was produced was within range. The dynamic relationship that exists between farmers living income and their productivity was able to be modelled using system dynamics approach.

Could the behaviour arising from the model be explored?

Yes. The parameters and variables that was used to generate the behaviour of the simulation model could be explored and tested on to see which part of the model could be improved. Exploring the model through testing led to policies that can be used to alleviate the problem in the system.

Were there policies tested to alleviate the problem behaviour?

Through the exploration of the model structure, key leverage points were found withing model structure which affected the behaviour of the model. Yes, policies were tested to alleviate the problem behaviour of the system. The policies that were tested was increase in the price of cocoa, removal of old cocoa trees, increase in the share of cash for both weeding and spraying. These policies were found to alleviate the behavioural problem. Aftermath of the policies was also tested to see how the system will hold after the policy period ends. Through system dynamics model approach, visualization of these policies and its effect on the system in general was possible.

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APPENDIX

MODEL DOCUMENTATION

THESIS 2.8.3.3.stmx
Top-Level Model:
old_trees(t) = old_trees(t - dt) + (turning_unproductive_tree - unproductive_tree_removal - natural_death_of_cocoa_plant) * dt
INIT old_trees = 200
UNITS: tree

productive_trees(t) = productive_trees(t - dt) + (turning_productive_tree - turning_unproductive_tree - productive_tree_death) * dt
INIT productive_trees = 150
UNITS: tree

seedings(t) = seedings(t - dt) + (nursing_seedlings - turning_young_trees - seedling_death) * dt
INIT seedings = 50
UNITS: tree

Soil_Organic_Matter(t) = Soil_Organic_Matter(t - dt) + (SOM_addition - SOM_mineralization) * dt
INIT Soil_Organic_Matter = 14.8
UNITS: ton/ha
DOCUMENT: Total organic matter in the soil.

young_trees(t) = young_trees(t - dt) + (turning_young_trees - turning_productive_tree - young_tree_death) * dt
INIT young_trees = 50
UNITS: tree

natural_death_of_cocoa_plant = old_trees/time_to_die
UNITS: tree/Years

nursing_seedlings = "number_of_death/removal" {UNIFLOW}
UNITS: tree/year

productive_tree_death = productive_trees*productive_tree_death_rate {UNIFLOW}
UNITS: tree/year

seedling_death = seedings*seedling_death_rate {UNIFLOW}
UNITS: tree/year

SOM_addition = yield_in_tons*SHARE_OF_PLANT_RESIDUES_REMAINING_ON_THE_FIELD {UNIFLOW}
UNITS: TON/ha/year
DOCUMENT: the process of adding organic matter to the soil.

SOM_mineralization = Soil_Organic_Matter/SOM_MINERALIZATION_TIME {UNIFLOW}
UNITS: TON/ha/year
DOCUMENT: process of converting organic matter into nutrients. it takes about 30 years for the process to complete.

turning_productive_tree = young_trees/time_to_productive_tree {UNIFLOW}
UNITS: tree/year

turning_unproductive_tree = productive_trees/time_to_unproductive_tree {UNIFLOW}
UNITS: tree/year

turning_young_trees = seedings/time_to_young_tree {UNIFLOW}
UNITS: tree/year

unproductive_tree_removal = old_trees*removal_rate {UNIFLOW}
UNITS: tree/year

young_tree_death = young_trees*young_tree_death_rate {UNIFLOW}
UNITS: tree/year

"gov._removal_rate" = 0.1
UNITS: dmnl/year

"prod._tree_normal_prductivity" = 1800
UNITS: kg/ha/year

adequacy_of_revenue_from_cocoa = (available_household_cash-living_expenditure)
UNITS: cedis/year/farmer
DOCUMENT: this compares the money available for farmers to their expenditure.
if this variable falls below 1000 cedis then farmers decide to sell their fertilizer.

Age_of_the_farm = young_tree_production+productive_tree_production+old_tree_production

UNITS: dmnl

DOCUMENT: productivity of the farm base on the age of the farm.
amount_of_fertilizers_sold = IF adequacy_of_revenue_from_cocoa <1000 THEN (total_amount_of_fertilizer_given_in_a_year)*0.8 ELSE 0
UNITS: kg/year/farmer
DOCUMENT: The total amount of fertilizers that farmers are able to sell to get extra income. this is a decision rule for farmers. Farmers tends to sell their free fertilizers in order to get money for day to day living.

Area_harvested = GRAPH(TIME)
Points: (2000.00, 1500000), (2001.05555556, 1350000), (2002.11111111, 1195000), (2003.16666667, 1500000), (2004.22222222, 2000000), (2005.27777778, 1850000), (2006.33333333, 1835000), (2007.38888889, 1463000), (2008.44444444, 1822500), (2009.50, 1600000), (2010.55555556, 1600200), (2011.61111111, 1600300), (2012.66666667, 1600300), (2013.72222222, 1600300), (2014.77777778, 1683765), (2015.83333333, 1683765), (2016.88888889, 1856680), (2017.94444444, 1689846), (2019.00, 1478462)
UNITS: ha
DOCUMENT: total land area that was used in the production of cocoa in Ghana.

Area_per_farmer = 4
UNITS: ha/farmer
available_household_cash = SMTH1((farming_profit-living_expenditure)+income_from_selling_fertilizer, 1, 1000) {DELAY CONVERTER}
UNITS: cedis/farmer/year
DOCUMENT: Cash available after subtracting the living expenditure from the profits from farming.

"cocoa_prices(cedis/kg)" = GRAPH(TIME)
Points: (2000.00, 1.620), (2000.86956522, 1.680), (2001.73913043, 1.140), (2002.60869565, 0.910), (2003.47826087, 1.070), (2004.34782609, 1.780), (2005.2173913, 1.750), (2006.08695652, 1.550), (2006.95652174, 1.540), (2007.82608696, 1.590), (2008.69565217, 1.950), (2009.56521739, 2.580), (2010.43478261, 2.890), (2011.30434783, 3.130), (2012.17391304, 2.980), (2013.04347826, 2.390), (2013.91304348, 2.440), (2014.7826087, 3.060), (2015.65217391, 3.140), (2016.52173913, 2.890), (2017.39130435, 2.030), (2018.26086957, 2.290), (2019.13043478, 2.340), (2020.00, 2.370)
UNITS: cedis/kg
DOCUMENT: The prices of cocoa per kg since 2000

"consumer_price_index_(CPI)" = GRAPH(TIME)
Points: (2000.00, 21.1), (2001.00, 28.1), (2002.00, 32.2), (2003.00, 40.8), (2004.00, 46.0), (2005.00, 52.9), (2006.00, 58.7), (2007.00, 65.0), (2008.00, 75.7), (2009.00, 90.3), (2010.00, 100.0), (2011.00, 108.7), (2012.00, 116.5), (2013.00, 130.0), (2014.00, 150.2), (2015.00, 176.0), (2016.00, 206.7), (2017.00, 232.3), (2018.00, 250.4), (2019.00, 268.4)
UNITS: dmnl

cost_of_spraying = spraying_cost_per_year*Area_harvested
UNITS: cedis

cost_of_weeding = Area_harvested*cost_of_weeding_per_ha
UNITS: cedis

cost_of_weeding_per_ha = GRAPH(TIME)
Points: (2000.00, 20.0), (2001.00, 24.6), (2002.00, 28.9), (2003.00, 31.3), (2004.00, 36.0), (2005.00, 38.4), (2006.00, 39.8), (2007.00, 39.3), (2008.00, 38.85), (2009.00, 38.4), (2010.00, 38.4), (2011.00, 41.2), (2012.00, 46.0), (2013.00, 52.1), (2014.00, 56.4), (2015.00, 61.6), (2016.00, 68.2), (2017.00, 69.2), (2018.00, 71.1), (2019.00, 72.0), (2020.00, 73.9)
UNITS: cedis/ha
DOCUMENT: living income report.pdf

drying = GRAPH(TIME)
Points: (2000.00, 20.00), (2001.00, 23.20), (2002.00, 26.40), (2003.00, 29.60), (2004.00, 32.80), (2005.00, 36.00), (2006.00, 39.20), (2007.00, 42.40), (2008.00, 45.60), (2009.00, 48.80), (2010.00, 52.00), (2011.00, 55.20), (2012.00, 58.40), (2013.00, 61.60), (2014.00, 64.80), (2015.00, 68.00), (2016.00, 71.20), (2017.00, 74.40), (2018.00, 77.60), (2019.00, 80.80), (2020.00, 84.00)
UNITS: cedis/ha/year
DOCUMENT: The amount of money farmers spend on the process of drying their cocoa beans before sale.

effect_of_fertilizer_application_ratio = GRAPH(relative_nutrient_uptake)
Points: (0.000, 0.7000), (0.125, 0.711260281844), (0.250, 0.723246789472), (0.375, 0.736006360424), (0.500, 0.749588853001), (0.625, 0.764047341088), (0.750, 0.77943832154), (0.875, 0.795821934949), (1.000, 0.813262200639), (1.125, 0.831827266829), (1.250, 0.851589676918), (1.375, 0.872626652952), (1.500, 0.895020397372), (1.625, 0.918858414223), (1.750, 0.944233851071), (1.875, 0.971245862989), (2.000, 1.0000)
UNITS: dmnl

effect_of_frequency_of_weeding_on_yield = GRAPH(weeding_frequency)
Points: (0.000, 0.4500), (0.400, 0.634707001419), (0.800, 0.758519807113), (1.200, 0.841514012725), (1.600, 0.897146692452), (2.000, 0.934438392888), (2.400, 0.959435767241), (2.800, 0.976192008368), (3.200, 0.987424052691), (3.600, 0.994953117159), (4.000, 1.0000)
UNITS: dmnl

effect_of_spraying_rate_on_yield = GRAPH(frequency_of_spraying_against_capsid_and_blackpod)
Points: (0.000, 0.4400), (0.400, 0.474275933754), (0.800, 0.512156698928), (1.200, 0.554021418953), (1.600, 0.600289090019), (2.000, 0.651422774527), (2.400, 0.70793423558), (2.800, 0.770389058873), (3.200, 0.839412313271), (3.600, 0.915694806702), (4.000, 1.0000)
UNITS: dmnl

emergency = GRAPH(TIME)
Points: (2000.00, 15.00), (2001.00, 16.6411221105), (2002.00, 18.3663863508), (2003.00, 20.1801067803), (2004.00, 22.0868186447), (2005.00, 24.0912897169), (2006.00, 26.1985322186), (2007.00, 28.4138153537), (2008.00, 30.742678484), (2009.00, 33.1909449802), (2010.00, 35.7647367839), (2011.00, 38.4704897152), (2012.00, 41.3149695659), (2013.00, 44.3052890171), (2014.00, 47.448925425), (2015.00, 50.7537395183), (2016.00, 54.2279950534), (2017.00, 57.8803794788), (2018.00, 61.7200256582), (2019.00, 65.7565347069), (2020.00, 70.00)
UNITS: cedis/year/farmer
DOCUMENT: On average the cost of dealing with emergency situation on yearly basis.

expected_spraying_rate = 4
UNITS: dmnl/year
expected_weeding_frequency = 4
UNITS: dmnl/year

factors_affecting_yield = effect_of_spraying_rate_on_yield*effect_of_fertilizer_application_ratio*effect_of_frequency_of_weeding_on_yield*Age_of_the_farm
UNITS: dmnl
DOCUMENT: Factors that contribute to the yield of cocoa. these factors affects the how much cocoa is produced in a given season.

farmers = GRAPH(TIME)
Points: (2000.00, 258000), (2001.00, 260000), (2002.00, 266000), (2003.00, 289000), (2004.00, 320000), (2005.00, 341000), (2006.00, 352000), (2007.00, 362000), (2008.00, 375000), (2009.00, 401000), (2010.00, 417000), (2011.00, 448000), (2012.00, 469000), (2013.00, 495000), (2014.00, 534000), (2015.00, 555000), (2016.00, 576000), (2017.00, 646000), (2018.00, 696000), (2019.00, 722000), (2020.00, 756000), (2021.00, 777000), (2022.00, 782000), (2023.00, 774000), (2024.00, 756000), (2025.00, 745000), (2026.00, 745000), (2027.00, 740000), (2028.00, 719000), (2029.00, 709000), (2030.00, 704000), (2031.00, 701000), (2032.00, 701000), (2033.00, 698000), (2034.00, 693000), (2035.00, 691000), (2036.00, 688000), (2037.00, 688000), (2038.00, 685000), (2039.00, 675000), (2040.00, 651000)
UNITS: farmer
DOCUMENT: The number of farmers in Ghana.

farming_expenditure_per_farmer = total_farmers_expenditure/farmers
UNITS: cedis/farmer/year
DOCUMENT: this the average farming expenditure per farmer in Ghana.

farming_profit = revenue_per_farmer-farming_expenditure_per_farmer
UNITS: cedis/farmer/year
DOCUMENT: Average farming Profits per farmer in Ghana. this is calculated by subtracting the farmers production expenditure from profits.

fertilizer = GRAPH(TIME)

Points: (2000.00, 10.00), (2002.00, 12.769), (2004.00, 15.538), (2006.00, 18.307), (2008.00, 21.076), (2010.00, 23.845), (2012.00, 26.614), (2014.00, 29.383), (2016.00, 32.152), (2018.00, 34.921), (2020.00, 37.69)
UNITS: cedis/ha/year
DOCUMENT: The cost of purchasing fertilizers that is applied on the farm every year.

fertilizer_application = GRAPH(TIME)
Points: (2000.00, 5.00), (2002.00, 6.101), (2004.00, 7.202), (2006.00, 8.303), (2008.00, 9.404), (2010.00, 10.505), (2012.00, 11.606), (2014.00, 12.707), (2016.00, 13.808), (2018.00, 14.909), (2020.00, 16.01)
UNITS: cedis/ha/year
DOCUMENT: the cost of applying fertilizers on the farms
fertilizer_available = total_amount_of_fertilizer_given_in_a_year-amount_of_fertilizers_sold
UNITS: kg/year/farmer
DOCUMENT: fertilizer available for farmers at the end of the year for application.

fertilizer_cost = fertilizer_application+fertilizer
UNITS: cedis/ha/year
DOCUMENT: The cost of that farmers spend in a year on private fertilizers and cost of applying fertilizer in the farm in a year.

food_expenditure = GRAPH(TIME)
Points: (2000.00, 150.0), (2001.00, 168.112020383), (2002.00, 187.152663908), (2003.00, 207.169542103), (2004.00, 228.212707588), (2005.00, 250.334779239), (2006.00, 273.591073758), (2007.00, 298.039743995), (2008.00, 323.741924359), (2009.00, 350.76188369), (2010.00, 379.16718596), (2011.00, 409.028859221), (2012.00, 440.421573209), (2013.00, 473.423826061), (2014.00, 508.1181406), (2015.00, 544.591270683), (2016.00, 582.934418134), (2017.00, 623.243460794), (2018.00, 665.619192264), (2019.00, 710.167573947), (2020.00, 757.0)
UNITS: cedis/year/farmer
DOCUMENT: The cost of food every year

frequency_of_spraying_against_capsid_and_blackpod = (money_for_spraying/total_cost_of_spraying_per_year)*expected_spraying_rate
UNITS: dmnl/year

GH_cocoa_production = GRAPH(TIME)
Points: (2000.00, 389772), (2001.05555556, 340563), (2002.11111111, 493646), (2003.16666667, 735266), (2004.22222222, 599318), (2005.27777778, 740458), (2006.33333333, 614533), (2007.38888889, 680781), (2008.44444444, 710639), (2009.50, 632037), (2010.55555556, 1024552.81), (2011.61111111, 879349), (2012.66666667, 835467), (2013.72222222, 896220), (2014.77777778, 740254), (2015.83333333, 778044), (2016.88888889, 969510.7), (2017.94444444, 904740.01), (2019.00, 811746.51)
UNITS: tons/year

herbicides = 18.63

UNITS: cedis/ha/year

herbicides_application = 17.54
UNITS: cedis/ha/year

housing_cost = GRAPH(TIME)
Points: (2000.00, 50.0), (2001.00, 54.5293198174), (2002.00, 59.2842803986), (2003.00, 64.2754287864), (2004.00, 69.5137687702), (2005.00, 75.0107789001), (2006.00, 80.7784311319), (2007.00, 86.8292101224), (2008.00, 93.1761331955), (2009.00, 99.8327709974), (2010.00, 106.813268862), (2011.00, 114.132368908), (2012.00, 121.805432888), (2013.00, 129.848465812), (2014.00, 138.278140365), (2015.00, 147.111822152), (2016.00, 156.367595774), (2017.00, 166.064291785), (2018.00, 176.221514526), (2019.00, 186.859670886), (2020.00, 198)
UNITS: cedis/year/farmer
DOCUMENT: the cost of rent for farmers every year

income_from_selling_fertilizer = (amount_of_fertilizers_sold*price_of_1_kg_of_fertilizer)
UNITS: cedis/year/farmer
DOCUMENT: the money that farmers receive from selling their free fertilizers.
labour = GRAPH(TIME)
Points: (2000.00, 150.0), (2001.00, 182.963), (2002.00, 215.926), (2003.00, 248.889), (2004.00, 281.852), (2005.00, 314.815), (2006.00, 347.778), (2007.00, 380.741), (2008.00, 413.704), (2009.00, 446.667), (2010.00, 479.63), (2011.00, 512.593), (2012.00, 545.556), (2013.00, 578.519), (2014.00, 611.482), (2015.00, 644.445), (2016.00, 677.408), (2017.00, 710.371), (2018.00, 743.334), (2019.00, 776.297), (2020.00, 809.26)
UNITS: cedis/ha/year
DOCUMENT: Cost of hiring labour to farm and maintain the farm throughout the year.
living_expenditure = "non-food_non-housing_cost"+housing_cost+food_expenditure+emergency
UNITS: cedis/farmer/year
DOCUMENT: Average total living expenditure of cocoa farmers
"mineralized_nutrients_from_SOM" = SOM_mineralization*NUTRIENT_CONTENT_IN_SOM
UNITS: ton/ha/year
money_for_spraying = MIN(revenue_per_year*share_of_cash_for_spraying,total_cost_of_spraying_per_year)
UNITS: cedis/year
"money_for_weeding/maintenance" = MIN(revenue_per_year*"share_of_cash_for_weeding/maintenance", total_cost_of_weeding_per_year)
UNITS: cedis/year
"non-food_non-housing_cost" = GRAPH(TIME)
Points: (2000.00, 100.0), (2001.00, 110.115279917), (2002.00, 120.749181326), (2003.00, 131.928294519), (2004.00, 143.680573101), (2005.00, 156.035403892), (2006.00, 169.023680402), (2007.00, 182.677880089), (2008.00, 197.032145565), (2009.00, 212.122369969), (2010.00, 227.986286723), (2011.00, 244.663563881), (2012.00, 262.195903324), (2013.00, 280.627145032), (2014.00, 300.003376711), (2015.00,

320.373049031), (2016.00, 341.787096783), (2017.00, 364.299066242), (2018.00, 387.965249057), (2019.00, 412.844823011), (2020.00, 439.0)
UNITS: cedis/year/farmer
DOCUMENT: Farmers other expenditures that does not involve food or rent.
"number_of_death/removal" = seedling_death+young_tree_death+productive_tree_death+unproductive_tree_removal+natural_death_of_cocoa_plant
UNITS: tree/Years
NUTRIENT_CONTENT_IN_SOM = 0.05
UNITS: 1
nutrient_uptake = per_ha_mineral_fertilizer_application+"mineralized_nutrients_from_SOM"
UNITS: ton/ha/year
old_tree_normal_prductivity = 500
UNITS: kg/ha/year
old_tree_production = relative_old_tree_productivity*percentage_of_old_trees
UNITS: dmnl
p = 3.5
UNITS: cedis/kg
per_ha_mineral_fertilizer_application = ((fertilizer_available/Area_per_farmer)/tons_converter)
UNITS: TON/ha/year
DOCUMENT: amount of fertilizer that is applied on every hectare of the cocoa land.
perceived_capability_to_weed = SMTH1("money_for_weeding/maintenance", 1, 42.8e6)
UNITS: cedis/Years
percentage_of_old_trees = old_trees/total_number_of_trees
UNITS: dmnl
percentage_of_productive_trees = productive_trees/total_number_of_trees
UNITS: dmnl
percentage_of_seedlings = seedings/total_number_of_trees
UNITS: dmnl
percentage_of_young_trees = young_trees/total_number_of_trees
UNITS: dmnl
pesticides = 13.04
UNITS: cedis/ha/year
pesticides_application = 18.14
UNITS: cedis/ha/year
pod_breaking = GRAPH(TIME)
Points: (2000.00, 15.00), (2001.00, 18.1285), (2002.00, 21.257), (2003.00, 24.3855), (2004.00, 27.514), (2005.00, 30.6425), (2006.00, 33.771), (2007.00, 36.8995), (2008.00, 40.028), (2009.00, 43.1565), (2010.00, 46.285), (2011.00, 49.4135), (2012.00, 52.542), (2013.00, 55.6705), (2014.00, 58.799), (2015.00, 61.9275), (2016.00, 65.056), (2017.00, 68.1845), (2018.00, 71.313), (2019.00, 74.4415), (2020.00, 77.57)
UNITS: cedis/ha/year
DOCUMENT: the cost of paying people to pick up the pods after plucking them.
pod_plucking = GRAPH(TIME)
Points: (2000.00, 20.00), (2001.00, 23.80), (2002.00, 27.60), (2003.00, 31.40), (2004.00, 35.20), (2005.00, 39.00), (2006.00, 42.80), (2007.00, 46.60), (2008.00, 50.40), (2009.00, 54.20),

(2010.00, 58.00), (2011.00, 61.80), (2012.00, 65.60), (2013.00, 69.40), (2014.00, 73.20), (2015.00, 77.00), (2016.00, 80.80), (2017.00, 84.60), (2018.00, 88.40), (2019.00, 92.20), (2020.00, 96.00)
UNITS: cedis/ha/year
DOCUMENT: The cost of plucking riped pods from cocoa tree.
POLICY_ENDTIME = 2040
UNITS: years
policy_share_of_cash_for_spraying = 0.20
UNITS: dmnl
policy_share_of_cash_for_weeding = 0.30
UNITS: dmnl
policy_start_time = 2020
UNITS: years
policy_start_time_2 = 2020
UNITS: years
policy_start_time_3 = 2020
UNITS: years
policy_start_time_4 = 2020
UNITS: years
policy_status = IF policy_switch = 1 AND TIME > policy_start_time AND TIME <=POLICY_ENDTIME THEN 1 ELSE 0
UNITS: dmnl
policy_status_2 = IF policy_switch_2 = 1 AND TIME > policy_start_time_2 AND TIME <=POLICY_ENDTIME THEN 1 ELSE 0
UNITS: dmnl
policy_status_3 = IF policy_switch_3 = 1 AND TIME > policy_start_time_3 AND TIME <=POLICY_ENDTIME THEN 1 ELSE IF TIME = POLICY_ENDTIME THEN 0 ELSE 0
UNITS: dmnl
policy_status_4 = IF policy_switch_4 = 1 AND TIME > policy_start_time_4 AND TIME <=POLICY_ENDTIME THEN 1 ELSE 0
UNITS: dmnl
policy_switch = 0
UNITS: dmnl
policy_switch_2 = 0
UNITS: dmnl
policy_switch_3 = 1
UNITS: dmnl
policy_switch_4 = 1
UNITS: dmnl
price_of_1_kg_of_fertilizer = 40
UNITS: cedis/kg
DOCUMENT: the cost of 1kg of fertilizer
producer_price_as_a_%_of_ICCO_prices = GRAPH(TIME)
Points: (2000.00, 0.510), (2001.00, 0.390), (2002.00, 0.540), (2003.00, 0.660), (2004.00, 0.630), (2005.00, 0.630), (2006.00, 0.540), (2007.00, 0.390), (2008.00, 0.510), (2009.00, 0.490), (2010.00, 0.600), (2011.00, 0.850), (2012.00, 0.760), (2013.00, 0.510), (2014.00, 0.520)

UNITS: dmnl
"Producer_Price_Index_(PPI)" = GRAPH(TIME)
Points: (2000.00, 7.65), (2001.00, 11.81), (2002.00, 21.07), (2003.00, 29.87), (2004.00, 30.59), (2005.00, 30.59), (2006.00, 31.1), (2007.00, 31.1), (2008.00, 40.78), (2009.00, 55.46), (2010.00, 81.56), (2011.00, 93.15), (2012.00, 90.35), (2013.00, 127.02), (2014.00, 104.57), (2015.00, 93.9), (2016.00, 101.53), (2017.00, 100.69), (2018.00, 105.29)
UNITS: dmnl
production_cost = fertilizer_cost++pod_plucking+pod_breaking+labour+working_capital_rate+transportation+pruning+drying
UNITS: cedis/ha/year
DOCUMENT: Production cost is the cost of maintaining and growing cocoa trees in a year.

This is made up of all the cost involved in the cocoa farming activity.
productive_tree_death_rate = 0.001
UNITS: dmnl/year
productive_tree_production = relative_productivity*percentage_of_productive_trees
UNITS: dmnl
pruning = GRAPH(TIME)
Points: (2000.00, 10.00), (2001.00, 12.50), (2002.00, 15.00), (2003.00, 17.50), (2004.00, 20.00), (2005.00, 22.50), (2006.00, 25.00), (2007.00, 27.50), (2008.00, 30.00), (2009.00, 32.50), (2010.00, 35.00), (2011.00, 37.50), (2012.00, 40.00), (2013.00, 42.50), (2014.00, 45.00), (2015.00, 47.50), (2016.00, 50.00), (2017.00, 52.50), (2018.00, 55.00), (2019.00, 57.50), (2020.00, 60.00)
UNITS: cedis/ha/year
DOCUMENT: the cost of cutting unwanted branches and infected parts of the cocoa tree in order to get more productive tree.
realised_farmers_yield = yield_potential*factors_affecting_yield
UNITS: kg/ha/year
DOCUMENT: the yield per hectare achieved in a year
"reference_total_production_(kg)" = GRAPH(TIME)
Points: (2000.00, 353523204.0), (2001.05555556, 308890641.0), (2002.11111111, 447736922.0), (2003.16666667, 666886262.0), (2004.22222222, 543581426.0), (2005.27777778, 671595406.0), (2006.33333333, 557381431.0), (2007.38888889, 617468367.0), (2008.44444444, 644549573.0), (2009.50, 573257559.0), (2010.55555556, 929269398.7), (2011.61111111, 797569543.0), (2012.66666667, 757768569.0), (2013.72222222, 812871540.0), (2014.77777778, 671410378.0), (2015.83333333, 705685908.0), (2016.88888889, 879346204.9), (2017.94444444, 820599189.1), (2019.00, 736254084.6)
UNITS: kg
"Reference_Yield_(kg/ha)" = "reference_total_production_(kg)"/Area_harvested
UNITS: Kilograms/Hectares
relative_nutrient_uptake = nutrient_uptake/INIT(nutrient_uptake)
UNITS: dmnl
relative_old_tree_productivity = old_tree_normal_prductivity/yield_potential
UNITS: dmnl
relative_productivity = "prod._tree_normal_prductivity"/yield_potential

UNITS: dmnl
relative_young_productivity = young_tree_normal_prductivity/yield_potential
UNITS: dmnl
removal_rate = (1-policy_status_2)* 0.03 +policy_status_2*"gov._removal_rate"
UNITS: dmnl/year
revenue = revenue_per_year*revenue_share
UNITS: cedis/Years
DOCUMENT: total amount of revenue that farmers received from selling their cocoa.
revenue_from_cocoa = (1-policy_status)*total_farm_production*"cocoa_prices(cedis/kg)" +policy_status*(p*total_farm_production)
UNITS: cedis/year
DOCUMENT: this the product of the prices per kg of cocoa and the total amount of kg that was produced in the year.
revenue_per_farmer = revenue/farmers
UNITS: cedis/farmer/year
DOCUMENT: Revenue per farmer in Ghana
revenue_per_year = SMTH1(revenue_from_cocoa, 1/12, 285000000) {DELAY CONVERTER}
UNITS: cedis/year
DOCUMENT: total amount of revenue that is left after subtracting the share of revenue for maintenance and spraying.
revenue_share = 1-share_of_maintenance_and_spraying_cost_1
UNITS: 1
DOCUMENT: share of the revenue that farmers take home after subtracting the cost of spraying and maintenance.
seedling_death_rate = 0.5
UNITS: dmnl/year
share_of_cash_for_spraying = 0.1*(1-policy_status_3) +policy_status_3*policy_share_of_cash_for_spraying
UNITS: dmnl
"share_of_cash_for_weeding/maintenance" = 0.15*(1-policy_status_4) +policy_status_4*policy_share_of_cash_for_weeding
UNITS: dmnl
share_of_maintenance_and_spraying_cost_1 = share_of_cash_for_spraying+"share_of_cash_for_weeding/maintenance"
UNITS: 1
DOCUMENT: the percentage of the revenue that is use for the maintenance of the farm.
SHARE_OF_PLANT_RESIDUES_REMAINING_ON_THE_FIELD = 0.65
UNITS: 1
DOCUMENT: the share of plants residues adding to the soil every year.
SOM_MINERALIZATION_TIME = 30
UNITS: year
DOCUMENT: time it takes for plant residues to be in the soil before it is used by plant as nutrients

spraying_cost = herbicides_application+herbicides+pesticides_application+pesticides
UNITS: cedis/ha/year

spraying_cost_per_year = GRAPH(TIME)
Points: (2000.00, 69.29), (2001.00, 68.86), (2002.00, 67.58), (2003.00, 67.58), (2004.00, 67.58), (2005.00, 67.58), (2006.00, 68.01), (2007.00, 69.29), (2008.00, 70.57), (2009.00, 71.00), (2010.00, 71.85), (2011.00, 72.27), (2012.00, 73.13), (2013.00, 73.98), (2014.00, 74.83), (2015.00, 74.83), (2016.00, 75.69), (2017.00, 75.69), (2018.00, 76.97), (2019.00, 78.25), (2020.00, 80.81)
UNITS: cedis/ha

time_to_die = 60
UNITS: year

time_to_productive_tree = 5
UNITS: year

time_to_unproductive_tree = 30
UNITS: year

time_to_young_tree = 5
UNITS: year

tons_converter = 1000
UNITS: kg/tons
DOCUMENT: converting kilograms to tons

total_amount_of_fertilizer_given_in_a_year = 40
UNITS: kg/year/farmer
DOCUMENT: the amount fertilizers on average that government gives to farmers every year.
total_cost_of_spraying_per_year = cost_of_spraying*expected_spraying_rate
UNITS: cedis/Years
total_cost_of_weeding_per_year = cost_of_weeding*expected_weeding_frequency
UNITS: cedis/year
total_farm_production = Area_harvested*realised_farmers_yield
UNITS: Kilograms/year
DOCUMENT: the total amount of cocoa produced in the year based on the area of land harvested and the yield per hectare that year.
total_farmers_expenditure = (total_production_cost)
UNITS: cedis/Years
DOCUMENT: this the average farming expenditure of farmer in Ghana.
total_number_of_trees = seedings+young_trees+productive_trees+old_trees
UNITS: tree
total_production_cost = (production_cost/3.5)*Area_harvested
UNITS: cedis/Years

transportation = GRAPH(TIME)

Points: (2000.00, 3.000), (2001.00, 3.450), (2002.00, 3.900), (2003.00, 4.350), (2004.00, 4.800), (2005.00, 5.250), (2006.00, 5.700), (2007.00, 6.150), (2008.00, 6.600), (2009.00, 7.050), (2010.00, 7.500), (2011.00, 7.950), (2012.00, 8.400), (2013.00, 8.850), (2014.00, 9.300), (2015.00, 9.750), (2016.00, 10.200), (2017.00, 10.650), (2018.00, 11.100), (2019.00, 11.550), (2020.00, 12.000)

UNITS: cedis/ha/year

DOCUMENT: The cost that farmers incurred for transporting their cocoa seeds from the farms to the market.

weeding_frequency = (perceived_capability_to_weed/total_cost_of_weeding_per_year)*expected_weeding_frequency

{ ("money_for_weeding/maintenance"/total_cost_of_weeding_per_year)*expected_weeding_frequency

UNITS: dmnl/year

working_capital_rate = GRAPH(TIME)

Points: (2000.00, 10.00), (2001.00, 12.136), (2002.00, 14.272), (2003.00, 16.408), (2004.00, 18.544), (2005.00, 20.68), (2006.00, 22.816), (2007.00, 24.952), (2008.00, 27.088), (2009.00, 29.224), (2010.00, 31.36), (2011.00, 33.496), (2012.00, 35.632), (2013.00, 37.768), (2014.00, 39.904), (2015.00, 42.04), (2016.00, 44.176), (2017.00, 46.312), (2018.00, 48.448), (2019.00, 50.584), (2020.00, 52.72)

UNITS: cedis/ha/year

DOCUMENT: this the cost additional cost of working on the farms every year.

Yield = GRAPH(TIME)

Points: (2000.00, 291.1), (2001.00, 288.6), (2002.00, 285.0), (2003.00, 331.3), (2004.00, 368.5), (2005.00, 400.0), (2006.00, 400.0), (2007.00, 420.0), (2008.00, 373.5), (2009.00, 444.1), (2010.00, 395.0), (2011.00, 437.4), (2012.00, 549.5), (2013.00, 522.1), (2014.00, 510.0), (2015.00, 510.0), (2016.00, 510.0), (2017.00, 522.1), (2018.00, 535.4), (2019.00, 549.0)

UNITS: hg/ha

yield_in_tons = realised_farmers_yield/tons_converter

UNITS: TON/ha/year

DOCUMENT: total yield per hectare measured in tons.

yield_potential = 1800

UNITS: kg/ha/year

DOCUMENT: the yield potential per hectare of cocoa areas. This is the amount cocoa per hectare that farmers are suppose to get every year

young_tree_death_rate = 0.05

UNITS: dmnl/year

young_tree_normal_prductivity = 100

UNITS: kg/ha/year

young_tree_production = percentage_of_young_trees*relative_young_productivity

UNITS: dmnl

{ The model has 138 (138) variables (array expansion in parens).

In root model and 0 additional modules with 7 sectors.

Stocks: 5 (5) Flows: 11 (11) Converters: 122 (122)

Constants: 38 (38) Equations: 95 (95) Graphicals: 27 (27)

There are also 15 expanded macro variables.
}