Master Thesis

Exploring Policies to Enhance the Diffusion of Conservation Agriculture in Zambia through Understanding Dynamic Behavior

by

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ABSTRACT

The state of food security depends on the ratio of food supply and demand. In Zambia, the constant arable land and the effect of climate change threaten the continuity of food supply in Zambia while at the same time population growth increases the food demand. Those conditions force farmers to find a way to increase yield productivity. Conservation agriculture has been highly promoted as a sustainable agricultural practice that can mitigate the effect of climate change and at the same time increase yield productivity. Despite all the advantages, farmers do not consider this practice as the substitute for conventional farming practice. A number of studies have introduced important factors in conservation agriculture adoption yet those studies do not capture the dynamics of adoption and diffusion process. This study aims to analyze the dynamics of diffusion process based on economic and social determinants using system dynamics. The determinants are identified based on documents analysis and data calibration from previous adoption studies and reports. The result of this study indicates that there is one long-term and one single-moment determinants that govern adoption process. The policy recommendations to foster conservation agriculture diffusion in Zambia are made based on those identifications.

TABLE OF CONTENTS

TABLE OF FIGURES

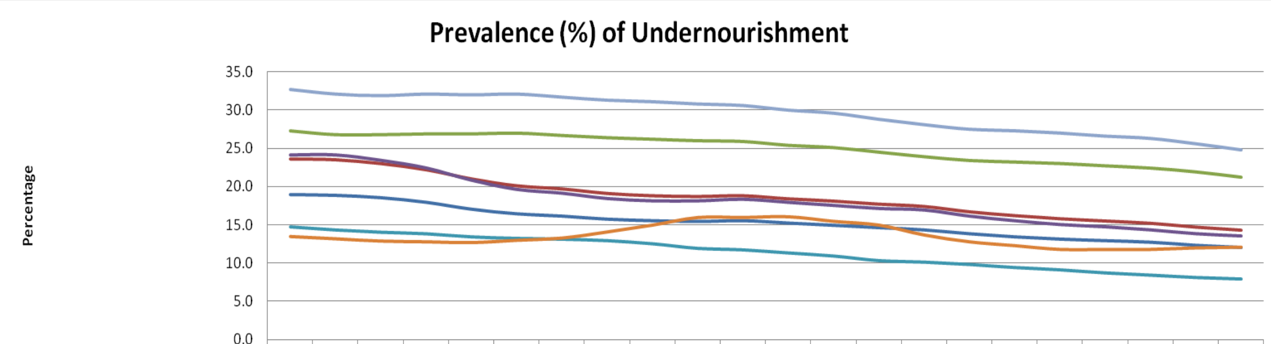
LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

"Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food [...]" (UN, 1948).

While the aim of both the World Food Summit (FAO, 1996) and the Millennium Development Goals (UN, 2013) for halving the number of people living in food insecurity in the world has been nearly attained in developing countries in general, this has not been realized in sub Saharan Africa. On average, developing countries were able to reduce the prevalence of undernourishment from 23.6% in 1990 to 14.3% in 2011. During the same time period, Africa in total could only reduce undernourishment from 27.3% to 21.2% and sub-Saharan African countries reduced their prevalence of undernourishment from 32.7 % to 24.8% (FAO, 2013c). On Figure 1.1 the prevalence of undernourishment data are presented.



	1990-92	1991-93	1992-94	1993-95	1994-96	1995-97	1996-98	1997-99	1998-00	1999-01	2000-02	2001-03	2002-04	2003-05	2004-06	2005-07	2006-08	2007-09	2008-10	2009-11	2010-12	2011-13
World	18.9	18.8	18.5	17.9	17.0	16.4	16.1	15.7	15.5	15.4	15.5	15.2	14.9	14.6	14.3	13.8	13.4	13.1	12.9	12.7	12.3	12.0
Developing Regions	23.6	23.5	23.0	22.2	21.0	20.1	19.7	19.1	18.8	18.7	18.8	18.4	18.1	17.7	17.4	16.7	16.2	15.8	15.5	15.2	14.7	14.3
Africa	27.3	26.8	26.8	26.9	26.9	27.0	26.7	26.4	26.2	26.0	25.9	25.4	25.1	24.5	23.9	23.4	23.2	23.0	22.7	22.4	21.9	21.2
Sub-Saharan Africa	32.7	32.1	31.9	32.1	32.0	32.1	31.7	31.3	31.1	30.8	30.6	30.0	29.6	28.8	28.1	27.5	27.3	27.0	26.6	26.3	25.6	24.8
Asia	24.1	24.1	23.4	22.4	20.8	19.6	19.1	18.4	18.1	18.1	18.3	17.9	17.5	17.1	16.9	16.1	15.5	15.0	14.7	14.3	13.8	13.5
Latin America and the Caribbean	14.7	14.3	14.0	13.8	13.4	13.2	13.1	12.9	12.5	11.9	11.7	11.3	10.9	10.3	10.1	9.8	9.4	9.1	8.7	8.4	8.1	7.9
Oceania	13.5	13.2	12.9	12.8	12.7	13.0	13.3	14.1	15.0	16.0	16.0	16.1	15.5	15.0	13.7	12.8	12.3	11.8	11.8	11.8	12.0	12.1

Source: FAO (2013c) (tabulated)

Figure 1.1. Prevalence of Undernourishment in Region with High Prevalence of Undernourishment including Sub-Saharan Africa

Population growth (Sitko et al., 2011), poverty (Bain et al., 2013; FAO, 2013d; Vermeulen, Campbell, & Ingram, 2012), value chain of food (FAO, 2013d; Sitko et al., 2011), soil nutrient depletion (Gruhn, Goletti, & Yudelman, 2000), different gender access to productive resource (FAO, 2012), and other issues considerably affect the state of food security in sub-Saharan

Africa. Climate change (Bain et al., 2013; Brown, 2004; Lobell et al., 2008; Parry, Rosenzweig, Iglesias, Livermore, & Fischer, 2004; Vermeulen et al., 2012) exacerbates them and causes drought, flood and heat waves that negatively affect both quality and quantity of crop yields. While many factors together affect the state of food security, policies aimed at enhancing agricultural productivity and increasing food availability, especially when smallholders are targeted, can achieve hunger reduction even where poverty is widespread (IFAD, WFP, & FAO, 2013).

A number of studies (e.g., Jones and Thornton (2003); Lobell et al. (2008)) has projected the declines of maize, the staple food in most of the sub-Saharan, as the effect of climate change. A wide range in adaptation options to counter the impacts of climate change on agriculture production have been implemented, such as technological developments, governments programs and insurance schemes, farm production practices, and farm financial management (Smit & Skinner, 2002). Although several food system activities (ranging from agricultural production through processing, distribution and consumption) affect food system outcomes including food security, an emphasis on farm production technology and practices is preferable because such strategy decreases the dependency of farmers on other entities such as suppliers, governments or other organizations.

One of the farm production technology and practices as climate change adaptation strategy that is highly promoted in sub-Saharan Africa countries and still maintains farmer's independency to external stakeholders is conservation agriculture (CA). Africa has more rapid and extensive soil degradation and erosion than other continents which are caused by overgrazing, agriculture, 'over exploitation' and deforestation (Mortimore & Harris, 2005) that leads to the decline of soil organic matter, reduced fertility, water runoff (reduced rainfall infiltration), and soil erosion (Gowing & Palmer, 2008; Hobbs, 2007). CA implementation attempts to overcome those effects. Conservation agriculture's principles are to apply crop rotation, retain soil coverage and minimum soil disturbance (Baudron, Mwanza, Triomphe, & Bwalya, 2007; Coughenour & Chamala, 2000; Hobbs, 2007; Twomlow, Urolov, Jenrich, & Oldrieve, 2008). Those practices cause soil to retain minerals better than conventional agriculture practices, reduce soil erosion, increase water absorption and generate higher and more stable yields (Haggblade & Tembo, 2003a; Kassam, Friedrich, Shaxson, & Pretty, 2009). If this practice is adopted widely, higher food supply in current field area can be attained and therefore will reduce the prevalence of undernourishment.

Zambia is one of sub-Saharan Africa countries where CA adoption and implementation is highly promoted. Zambia has also been reported to have reduced the intensity of food shortages during peak hunger periods because of early green harvests from conservation agriculture practice

(Nyanga, 2012c). In spite of increases in productivity from conservation agriculture practices (Haggblade & Tembo, 2003a), conservation agriculture in Zambia is only partially adopted by Zambian smallholder farmers, meaning that, they only implement the farming principles on parts of their farm (Baudron et al., 2007; IFAD, 2011). Several evaluations about the diffusion of conservation agriculture practice have been conducted (e.g., Arslan, McCarthy, Lipper, Aswaf, and Cattaneo (2013) and Nyanga (2012c)). However, those evaluations do not capture the dynamics of the conservation agriculture diffusion. Policy implications arising from these studies make no statement about the timing and calibration of different options to support the adoption and diffusion of conservation agriculture.

As a new[1] agricultural practice in Zambia, knowledge transfer happened as the implication of intention to apply innovation. Adoption and diffusion are the processes governing the utilization of innovations (Kopainsky, Tröger, Derwisch, & Ulli-Beer, 2012). Diffusion is the process in which innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003). While diffusion shows aggregate phenomena of innovation dispersion among users, adoption shows individual action of starting to use innovation (Kopainsky et al., 2012).

This research has two main objectives, first is to explain the economic and social determinants of conservation agriculture diffusion from a dynamic perspective. This involves developing a structural explanation of the behavioral patterns observed in the past. Second, by understanding the root causes of the observed dynamic behavior, the implications over time of plausible interventions to foster the implementation of conservation agriculture in Zambia can be analyzed and thus the preconditions for enhancing diffusion of conservation agriculture in Zambia can also be determined. In this study, the introduction and implementation process of conservation agriculture is analyzed based on stakeholder's involvement and the determinants of farmers' adoption of conservation agriculture.

"*Nutritional outcomes depend on many factors, but food systems and the policies and institutions that shapes them are a fundamental part of the equation"* (FAO, 2013d)

1.2 RESEARCH OBJECTIVE & RESEARCH QUESTIONS

1.2.1 RESEARCH OBJECTIVE

As stated in the research background, many evaluations have been made about conservation agriculture diffusion yet existing evaluations do not capture the dynamics of conservation

[1] Conservation Agriculture was introduced to Zambian farmers in mid 1990's; it is a new practice as it is not the original practice that was commonly used in Zambia.

agriculture diffusion. This research aims to (1) evaluate the dynamics of conservation agriculture diffusion. The evaluation is made based on social and economic influence in Zambian farmer society together with implemented policies. From the evaluation (2) effective policy is proposed to achieve goal of increasing conservation agriculture adopters in Zambia.

1.2.2 Research Question

The research questions of this research are:

"How is the condition of Conservation Agriculture diffusion in Zambia based on the area under conservation agriculture?"

"What are the determinants of and leverage points for conservation agriculture diffusion in Zambia?"

"What policy would achieve a successful Conservation Agriculture diffusion in Zambia?"

Those research questions encompass several sub-questions:

1. How is the condition of Conservation Agriculture diffusion in Zambia according to the number of adopters?
2. What are the influence factors of Conservation Agriculture diffusion in Zambia?
3. What are the implemented policies for promoting Conservation Agriculture diffusion in Zambia?
4. What policy would increase Conservation Agriculture adopters in Zambia?
5. What policy would maintain Conservation Agriculture adopters in Zambia?

1.3 OUTLINE OF THE THESIS

This thesis is prepared in this sequence:

1. Introduction
   This part consists of the research background, the importance of this research and general research planning. Research objectives and questions are also mentioned in this part.
2. Literature Research
   This chapter explains all theories used in the model. The theories cover general explanation about food security, farming system, conservation agriculture, innovation diffusion and system dynamics structure. This chapter also explains research gap and research position.

3. Methodological Approach

   This section explains about the way this research is conducted. This chapter also consists of research strategy completed with data sources' information, measurement and procedure to collect the data used in research process.

4. Framework Development and Conceptualization

   In this part the state of food security, agriculture system condition and conservation agriculture practice in Zambia are explained. In this section dynamics issue of conservation agriculture is explained. The underlying hypothesis that governs the behavior will be discussed based on existing literature. The hypothesis results causal loop diagram (CLD) that is also shown in this chapter.

5. Model Analysis, Validation and Policy Analysis

   In this chapter, simulation result is shown and compared with reference mode. The model is also tested through model validations which are also shown in this chapter. This section also discusses possible policy that can be taken to increase the adoption of conservation agriculture based on the resulting model.

6. Summary of the Thesis

   This section consists of contribution to research field and managerial implication of the research. In this section, suggestions for further research are also explained.

CHAPTER 2
THEORETICAL CONCEPT

2.1 FOOD SECURITY

2.1.1 CONCEPT

"Food Security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 2009). FAO (2009) also mentioned that the nutritional dimensions are integral to the concept of food security.

While food insecurity is "[a] situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing ability, inappropriate distribution or inadequate use of food at the household level. Food insecurity, poor conditions of health and sanitation and inappropriate care and feeding practice are the major causes of poor nutritional status. Food insecurity may be chronic, seasonal or transitory" (FAO, IFAD, & WFP, 2013).

2.1.2 ASPECTS

Food Security is built on four aspects (FAO, 2012):

1. Food availability
   "Food availability means sufficient quantity of food is available on a consistent basis".
2. Food access
   Food access means "having sufficient resources, both economic and physical, to obtain appropriate foods for a nutritious diet".
3. Food utilization
   Food utilization means "appropriate use, based on knowledge of basic nutrition and care, as well as adequate water and sanitation".
4. Food stability
   Food stability refers to "the stability of the first three dimensions of food security over time".

The aspect this study focuses on is *food availability* which means that the model captures the occurrence whether the food supply can fulfill the demand.

2.1.3 INDICATOR

FAO, IFAD, and WFP (2013) mentioned food security indicators are as following:

Table 2.1. Indicator of Food Security

Food Security Indicators	Dimension	Function
Average dietary energy supply adequacy Average value of food production Share of dietary energy supply derived from cereals, roots, and tubers Access protein supply Average supply of protein of animal origin	Availability	Static and Dynamic Determinants
Percentage of paved roads over total roads Road density Rail lines density	Physical Access	
Domestic food price index	Economic Access	
Access to improve water source Access to improve sanitation facilities	Utilization	
Cereal import dependency ratio Percentage of arable land equipped for irrigation Value of total import over total merchandise export	Vulnerability	
Political Stability and absence of violence/terrorism Domestic food Price volatility Per capita food production variability Per capita food supply variability	Shocks	
Prevalence of undernourishment Share of food expenditure of the poor Depth of the food deficit Prevalence of food inadequacy	Access	Outcomes
Percentage of children under 5 years of age affected by wasting Percentage of children under 5 years of age who are stunted Percentage of children under 5 years of age who are underweight Percentage of adults who are underweight Prevalence of anemia among pregnant women Prevalence of anemia among children under 5 years of age Prevalence of vitamin A deficiency (forthcoming) Prevalence of iodine deficiency (forthcoming)	Utilization	

Consistent with the aspect in food security being focuses on, the food security indicator this thesis focuses on is inclusive in availability dimension which is *average dietary energy supply adequacy*.

2.2 FARMING SYSTEM

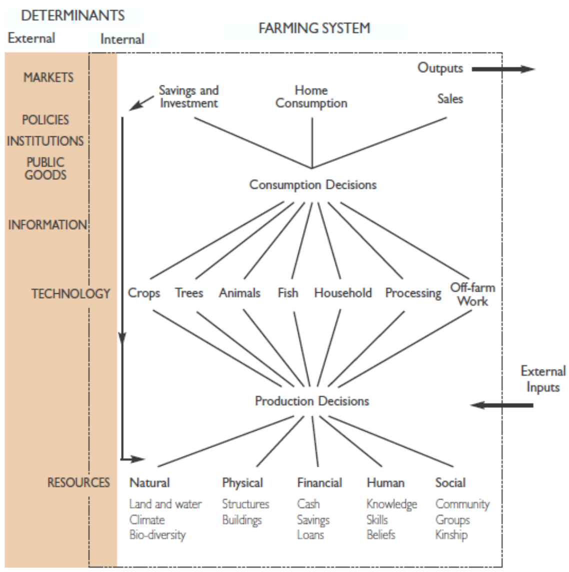


Figure 2.1. Determinants of Farming System

Source: Dixon, Gibbon, and Gulliver (2001)

Farming system is a socio-economy system which does not only depend on farmers but also other determinants such as markets, policies institutions, public goods, and information as the source of technology and resources for the farming process as one can see in Figure 2.1. With these conditions, it means that the farming system is not a closed box which is only governed by farmers but a complex system and the result of it does not merely depend on farmers but also on other support entities.

Coughenour and Chamala (2000) divided farming system into five levels which shows more complexity as the level gets higher. This classification shows that higher level of farming system creates more complexity and higher need to integrate more aspects in the process.

Table 2.2. Agri-family System and Subsystem

System Level	System Type	System Integration	Goals
5	Agri-family system	Individual, family, farm, off-farm work	Lifestyle, human development, savings, and investment
4	Farming system	Cropping, livestock	Crop and livestock production
3	Tillage system	Technical frames and scripts for weed control and cropping	Landscape management, soil resource development, and conservation
2	Technical Scripts	Instructions for using implements (tools)	Weed and pest control, planting, fertilizing, harvesting
1	Tools	Components	Potential uses

Source: Coughenour and Chamala (2000)

As one can see in Figure 2.1, the farming system approach does not capture the feedback process in agriculture system yet it shows both internal and external determinants in agriculture system. The agricultural system being studied is concentrated to farming system which includes only crop production and excludes farmers' lifestyle, savings, and investment. This study of crop production is completed by include investment in equipment.

2.3 CONSERVATION AGRICULTURE

2.3.1 DEFINITION OF CONSERVATION AGRICULTURE

Conservation Agriculture consists of minimal soil disturbance (no-till), and permanent soil cover (mulch) with combination of crop rotation (Hobbs, 2007; Kassam et al., 2009) to reduce loss of soil or water relative to conventional tillage (Mannering and Fenster, 1983 as stated in Coughenour & Chamala, 2000). Conservation agriculture strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment [by] enhancing natural biological processes above and below the ground (Kassam et al., 2009: 299). Conservation tillage and cropping agriculture embody new knowledge and understanding of soils, the environment, the biology, and ecology of economic plants and pests, and ways of managing these elements with new technology […] result[ing in] a new agriculture – relative to plow culture – which is more efficient, more productive, and more conservable for key resource of soil and water (Coughenour & Chamala, 2000:ix).

There are several similar terms that can be used reversibly with conservation agriculture which are minimum tillage, conservation tillage, conservation farming, and conservation agriculture.

Conservation agriculture is any tillage sequence that minimizes or reduces the loss of soil and water while conservation farming is a particular technology which uses planting basins and soil cover (Twomlow, Urolov, Jenrich, & Oldrive, 2008: 2-3).

Conservation Farming Unit (CFU) in Zambia defines minimum tillage (MT) as the term used for conversion from overall tillage to minimum tillage or zero tillage; Conservation tillage (CT) is a term used for MT and also retention of crop residue to the possible extent; Conservation farming (CF) is a term used for CT together with incorporation of the legumes as rotations, intercrops or fallows to the possible extent; Conservation agriculture (CA) is a term used for CF completed with establishment of *Faidherbia albida* (P. J. Aagaard & CFU, 2011).

2.3.2 PRINCIPLES OF CONSERVATION AGRICULTURE

Conservation Agriculture's basic principles are (Baudron et al., 2007; Coughenour & Chamala, 2000; Hobbs, 2007; Twomlow et al., 2008):

1. Permanent organic soil coverage

   Soil coverage retention usually uses crop residue (mulch) from previous harvest period. FAO (2014) considered it conservation agriculture practice if the mulch provides at least 30% of soil coverage. Crop residues are applied on the soil surface in the dry season, soon after harvesting. The residues must provide at least 30% soil cover. The mulch buffers the soil against extreme temperatures (thereby reducing soil evaporation), cushions the soil against traffic (and therefore reduce soil erosion), suppresses weeds through shading and improves soil fertility (as it results in higher surface soil organic matter if applied in the long run) (Gowing & Palmer, 2008; Twomlow et al., 2008).

2. Diversified crop rotations of annual crops and plant associations of perennial crops (crop rotation)

   Rotating crops is one of the key principles of CF. Cereal/legume rotations are desirable because there is optimum plant nutrient used in the synergy between different crop types. The advantages of crop rotation include improvement of soil fertility, controlling weeds, pests and diseases, and producing different types of outputs, which reduce the risk of total crop failure in cases of drought and disease outbreaks(Twomlow et al., 2008).

3. Continuous minimal mechanical soil disturbance/Minimum Soil disturbance

   There are two common ways of conducting minimum soil disturbance: planting basins or rip lines. Planting basins are holes dug in a weed-free field into which a crop is planted and are prepared in the dry season from July to October. The recommended dimensions of the basin are 20 cm deep, 30 cm long, and the same width as the blade of the hoe with 70 cm spaces along the row and each row has 90 cm apart (CFU, 2007). With that dimension 15.850 basins can fit in one hectare. While rip lines are created with the same deep dimensions and row distance as basin.

   Umar, Aune, Johnsen, and Lungu (2012) mentioned that by creating basins 30% of soil is tilled while creating rip lines only about 10-12% of the land. The basins enable farmers to plant the crop after the first effective rains when the basins have captured rainwater and drained naturally. The advantage of using basins is that they enhance the capture of water from the first rains of the wet season and enable precise application of both organic and inorganic fertilizer as it is applied directly into the pit and not broadcasted (Twomlow et al., 2008; Umar, Aune, Johnsen, & Lungu, 2011). Baudron et al. (2007) also mentioned that basins improve water infiltration and are often described as a water harvesting technique. In one hectare full of basins, 57.000 plants are expected to stand (90% germination) (CFU, 2007)

2.3.3 BENEFIT OF CONSERVATION AGRICULTURE

CFU (2007) mentioned several short-term benefits for farmers from implementing conservation agriculture:

1. Saving money and time and also spread labor needed over several months from minimum tillage practice.
2. Early land preparation which leads to early planting and more chance to catch rainfall compared to conventional tillage.
3. Effective usage of fertilizer and seed by using basin that also concentrates rainfall reception.
4. Availability of cowpea and gram that can be the source of protein in February when food is scarce.

While the long term benefit from conservation agriculture implementation, which is related with improved soil potential, includes(CFU, 2007; Kassam et al., 2009):

1. *Physical*, better characteristics of porosity for root growth, movement of water and root-respiration gases; retaining soil cover reduces soil and water loss; improves infiltration; reduces soil temperatures and improves soil fertility.
2. *Chemical*, greater control/release of nutrients.
3. *Biological*, more organic matter organism and its transformation products
4. *Hydrological*, more water available

2.3.4 Implementation of Conservation Agriculture

Conservation agriculture was developed to encounter soil degradation as the negative effect of green revolution. After the widespread adoption and ideal conservation agriculture in several countries in America, CA is promoted in several countries in South Africa (Bolliger et al., 2006). To encounter the risk of food security all over the world especially sub-Saharan Africa where the prevalence of food insecurity is high, conservation agriculture is continuously promoted.

In sub-Saharan Africa conservation agriculture is promoted with the support from donor funding; World Bank, European Union (EU), Canadian international Development Agency (CIDA), Food and Agriculture Organization (FAO), Norwegian Catholic relief Services (CRS), Agence Française Développement (AFC), French Agricultural Research Centre for International Development (CIRAD), and Deutsche Gessellschaft fűr Internationale Zusammenarbeit (GIZ) are some organizations who support the implementation of CA in Africa. The support is mostly conducted by forming a unit in each donor-recipient-country that trains, supports, and directs farmer to implement CA in their farm.

However, in the diffusion process, new knowledge needs to be adapted to different environment, circumstances and context which makes the success of CA implementation in the new environment is quite complex to be attained. In conservation agriculture case, it needs principles transformation in farmers' understanding about farming system, their habit in conducting agricultural practices and also ability to think forward. Due to those change, CA promotions do not always end successfully.

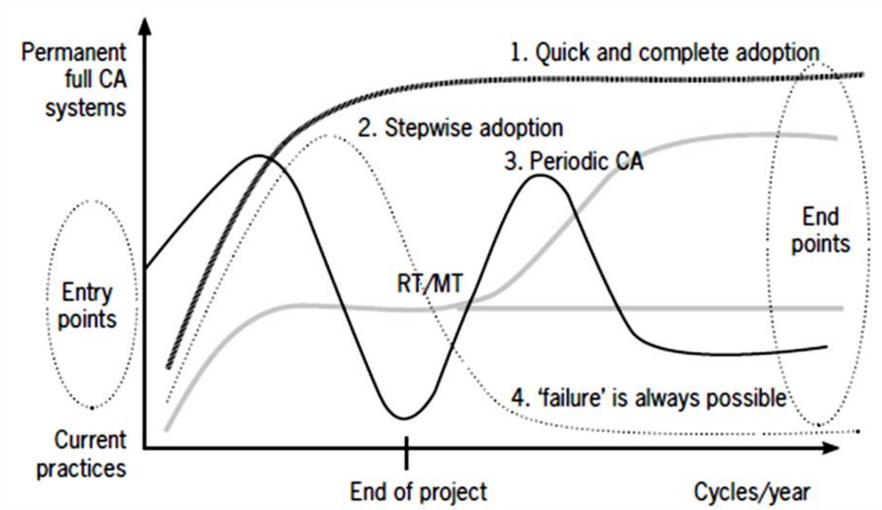


Figure 2.2. Entry Points and Four Hypothetical Pathways towards Adopting Conservation Agriculture

Source: Baudron et al. (2007)

Figure 2.2 shows entry points and four hypothetical pathways towards adopting conservation agriculture:

1. Quick and complete adoption of conservation agriculture in its fullest form.
2. Stepwise adoption of conservation agriculture practices, which may or may not lead to complete adoption over time (RD=reduced tillage, MT=minimum tillage).
3. Conservation agriculture practiced during some cycles but not for the whole period.
4. Use of conservation agriculture practices stops soon after the end of the project, perhaps because incentives are no longer available.

CFU (2007) also classified 3 levels of adoption from partial adoption to full adoption of Conservation Farming:

Table 2.3. Levels of Adoption

No	Definition	Criteria
1	Improved reduced tillage (IRT)	• Correctly spaced permanent planting basins established before the rains • Early planting of all crops • Early weeding

No	Definition	Criteria
2	Conservation tillage (CT)	• No burning of residues • Correctly spaced permanent planting basins established before the rains • Early planting of all crops • Early weeding
3	Conservation Faming (CF)	• No burning of residues • Correctly spaced permanent planting basins established before the rains • Early planting of all crops • Early weeding • Rotation with a minimum of 30% legumes in the system

Source: CFU (2007)

This study focuses on improved reduced tillage (IRT) level. The further discussion in this study will distinguish CA and CV practice based on basin or ripping practice and hand-hoe or plough tillage being implemented in the farm.

2.4 INNOVATION DIFFUSION

Rogers (2003) defined innovation as an idea, practice or object that is perceived new by an individual or society. Meanwhile diffusion is the process in which an *innovation* is *communicated* through *certain channels over time* among the members of a *social system* (Rogers, 2003: 49). The complexity of innovation diffusion lies in the development and flow of knowledge and technology which involves diverse stakeholders (Kingsley, Bozeman, & Coker, 1996). Main elements of innovation diffusion are innovation, communication channels, over time, and social system (Rogers, 2003) and those will define the process and result of innovation diffusion. Some degree of differences is needed to make innovation diffusion occur through communication channel; the difference can be knowledge, value, or education (Rogers, 2003). Process of innovation diffusion is depicted in Figure 2.3 which forms S-shaped growth. That process shows that time does not have linear

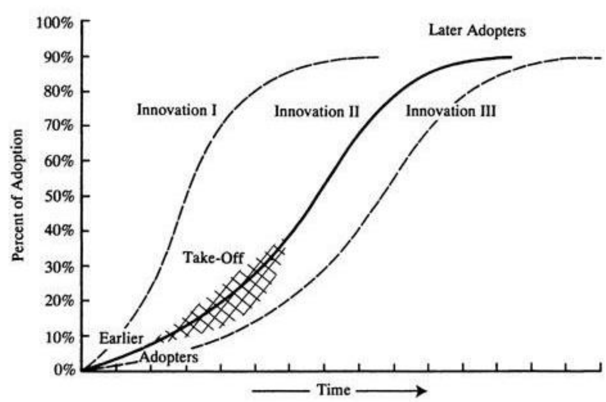


Figure 2.3. Innovation Diffusion Process

Source: Rogers (2003)

correlation with the degree of adoption. The time an innovation is adopted in a society also related to innovation decision process which consists of: (1) knowledge, (2) persuasion, (3) decision, (4) implementation, and (5) confirmation (Rogers, 2003).

2.4.1 ISSUES IN INNOVATION DIFFUSION

Rogers (2003) classified several characteristics of innovation which influence rates of innovation diffusion in a new society:

1. Relative advantage. How one perceives an innovation is significant. Advantage is not always seen in economic terms but also can be seen in prestige, convenience, and satisfaction terms.
2. Compatibility. Suitability of an innovation in existing society's condition determines whether an innovation can be accepted in a new society.
3. Complexity. Innovation's difficulties to be used or understood specify rapidity of innovation adoption.
4. Trialability. Possibility of an innovation to be experimented also influences how fast an innovation can diffuse in new community.
5. Observability. This characteristic means the visibility of the innovation's result.

Rogers (2003) also mentioned several keys that influence innovation adoption including indigenous knowledge and perceived image of change agent from potential adopters' perspective. One of the significant problems of innovation diffusion is the different attributes of participants which leads them to communicate ineffectively, yet some degree of differences (e.g., information) is needed to make diffusion occurs (Rogers, 2003). Change agents are usually innovation-oriented, meaning that they concentrate on how one new idea can spread in a new population, instead of client-oriented, meaning that they spread new knowledge by adapting to people's condition (Rogers, 2003).

2.5 SYSTEM DYNAMICS MODEL AND VALIDATION

2.5.1 CAUSAL LOOP DIAGRAM

Causal Loop Diagram (CLD) is one type of structure in system dynamics model which is mainly used to show feedback structure from the system (Sterman, 2000). CLD is also excellent for capturing dynamic hypothesis of the system, eliciting mental model of person or group, and communicating important feedback (Sterman, 2000). The simplicity of CLD makes it easy to understand and gives preliminary idea about the system.

For showing the relationship in the model, CLD uses two types of polarity:

1. Positive link

   Positive link is used when the increase of a variable causes another variable to increase compared to the condition when the first variable does not change.

Figure 2.4. Example of Positive Relationship between Two Variables

   Figure 2.4 above shows that assuming the other affecting variables remain constant; the increase of birth rate will raise the number of population compared to when the birth rate does not increase. Assuming the other affecting variables remain constant, population will also decrease if there is a decrease in birth rate.

2. Negative link

   Negative link is used when the increase of a variable causes another variable to decrease compared to the condition when the first variable does not change.

Figure 2.5. Example of Negative Relationship between Two Variables

   Figure 2.5 above shows that assuming the other affecting variables remain constant, the increase of death rate will lessen the number of population compared to when the death rate does not increase. Assuming the other affecting variables remain constant, population will also increase if there is a decrease in death rate.

2.5.2 STOCK AND FLOW DIAGRAM

While CLD has several disadvantages including the inability to capture different type of variable and inability to show behavior of the model, Stock and Flow Diagram (SFD) fulfills those need. The structure in SFD is not as simple as CLD; structure in SFD consists of stock, flow, variable, and link. Stock shows accumulation over time while flow shows the input and/or output of stocks therefore net flow shows the net changes of the stock. Variable is any instant calculation that does not have any accumulation over time which means that when an independent variable change, the dependent variable will change at the same time.

Figure 2.6 shows an example of stock and flow diagram. Population as a stock is changed by birth rate and death rate as flows. Fractional birth rate and fractional death rate are variables that influence birth rate and death rate.

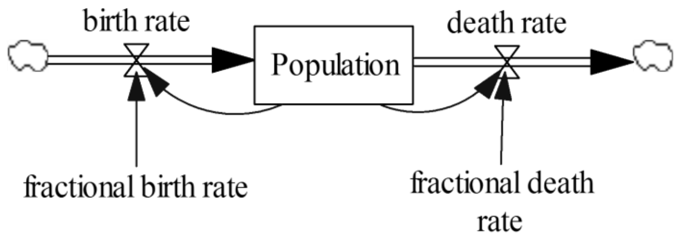


Figure 2.6. Example of Stock and Flow Diagram

2.5.3 VALIDATION

Validation is a model testing process that can build confidence of model purposes (Sterman, 2000). Confidence in model's soundness and usefulness as a policy tool is built gradually as model passes more test (Forrester & Senge, 1978). Barlas (1996) classified model validation test into three distinct test groups: direct structure test, structure-oriented behavior test, and behavior pattern test. One of the most common tests is behavior pattern test using Theil's Inequality Statistics.

Theil's Inequality Statistics is calculated by decomposing mean square error (MSE) into three components: bias (U^M), unequal variation (U^S), and unequal co-variation (U^C) (Sterman, 2000). Sterman (2000) also explained that bias arises on different means between reference mode and model output while unequal variance arises on difference in variation between data and model and unequal co-variation shows the correlation between data and model output.

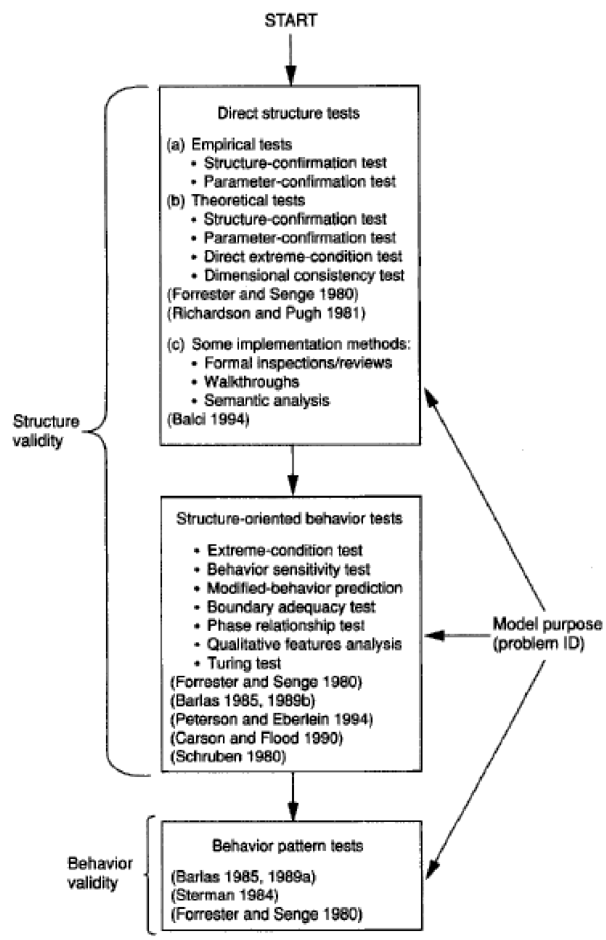


Figure 2.7. Validation in System Dynamics
Source: Barlas (1996)

2.6 RESEARCH GAP

There are many researches that study agricultural technology diffusion in general or conservation agriculture adoption in particular. Different authors explored the diffusion process using various modeling tools. However, literature that captures the *dynamics of conservation agriculture diffusion* is rather scarce. The unexplained dynamics of diffusion process in existing literature makes ineffective policy implementation because they tend to target one issue without realizing the feedback of that issue. Below one can find some studies about different agricultural technology diffusions using different modeling tools:

Table 2.4. Past Researches in Agricultural Technology Diffusion

Study	Modeling tools	Technology	Country	Purposes
D'Souza, Cyphers, and Phipps (1993)	Logit model	Sustainable agricultural practices	US	Analyzing factors affecting adoption
Berger (2001)	Spatial multi-agent programming model	Water-saving innovations	Chile	Reducing the weakness of mathematical programming and providing insights into the innovation process.
Chomba (2004)	Logit model	Conservation practice	Zambia	Assessing factors influence the implementation of conservation practice.
Knowler and Bradshaw (2007)	Ordinary least square (OLS), logit, probit, stepwise regression, linear probability model (LPM), multinomial logit	Conservation tillage	Mostly US, with addition of Canada, Panama, Nigeria, Rwanda, Peru, Honduras, Burkina Faso	Synthesizing 31 past researches in mathematical modeling to identify independent variables that regularly explain adoption.
Kopainsky and Derwisch (2009)	System dynamics	Improved varieties seed	West Africa	Integrating findings from existing studies into coherent framework

Study	Modeling tools	Technology	Country	Purposes
G. Kabwe (2010)	Logistic regression	Agro forestry technologies	Zambia	Investigating adoption rates and analyzing factors that influence decisions to try and adopt agro forestry technologies
Kopainsky et al. (2012)	System dynamics	Improved varieties seed	Malawi	Analyzing adoption process of hybrid seed in Malawi.
Nyanga (2012b)	Binary Logistics Regression	Conservation agriculture	Zambia	Analyzing the differences between adopter and non-adopter of conservation agriculture in Zambia.

Example of studies about dynamics in agricultural technology diffusion is even rarer. Only a few studies research in this topic (see e.g., Kopainsky and Derwisch (2009); Kopainsky et al. (2012)). Therefore the author attempts to use system dynamics model to understand the dynamic in conservation agriculture diffusion. The dynamics of technology diffusion will be analyzed based on farmers' perspective. To conduct this research, author uses Conservation Agriculture Project (CAP) Phase I survey data as reference of farmers under CAP project. The position of this research will be:

Table 2.5. Research Position

Study	Modeling tools	Technology	Country	Purposes
Amelia (2014)	System dynamics	Conservation agriculture	Zambia	Analyzing and giving recommendation of the policy for conservation agriculture diffusion in Zambia by understanding the dynamics of diffusion process based on economic and social determinants.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 RESEARCH STRATEGY

As most of the system dynamics models, this model was developed based on qualitative information for constructing the structure and quantitative information for building a simulation model. This research was established using qualitative research strategy and based on the acquired information, necessary calculation was made. *Discourse analysis*, of expert interview and existing reports and researches about conservation agriculture (CA) adoption and implementation in the world, sub-Saharan Africa, and Zambia, was used to understand the relations in the system and also numerical data that builds the system. Detailed explanation of research strategy is further described in 3.2.1. Literature Study and Interview.

3.2 RESEARCH PROCESS

This research was an empirical research with non-participatory practice oriented. This section explains about the process of conducting this research including data gathering process. Figure 3.1 shows research process in an organized manner.

3.2.1 LITERATURE STUDY AND INTERVIEW

In this process discourse analysis was conducted based on two types of information sources:

1. Open interview

Open interview using several questions as guideline was held with a researcher named Progress Nyanga on conservation farming adoption and implementation in Zambia. Progress Nyanga has been conducting research about CA adoption and implementation in Zambia (e.g., Nyanga (2012b, 2012c); Nyanga, Johnsen, Aune, and Kalinda (2011)) and also joined CAP Phase I project as researcher. From the interview, tacit knowledge about the system was obtained.

2. Documents analysis

Documents analysis was performed based on numerous studies (e.g., Baudron et al. (2007); Coughenour and Chamala (2000); Haggblade and Tembo (2003a); Hobbs (2007); Rockström et al. (2009); Thierfelder et al. (2013); Umar (2013); Umar et al. (2012); Umar et al. (2011); Umar and Nyanga (2011)) which explain about CA implementation and maize farming in the world, sub-Saharan Africa, and Zambia. Based on those documents, comprehensive understanding about the system and relations among factors inside the system were obtained. Literature about food security and farming system was also read to build strong background of this research.

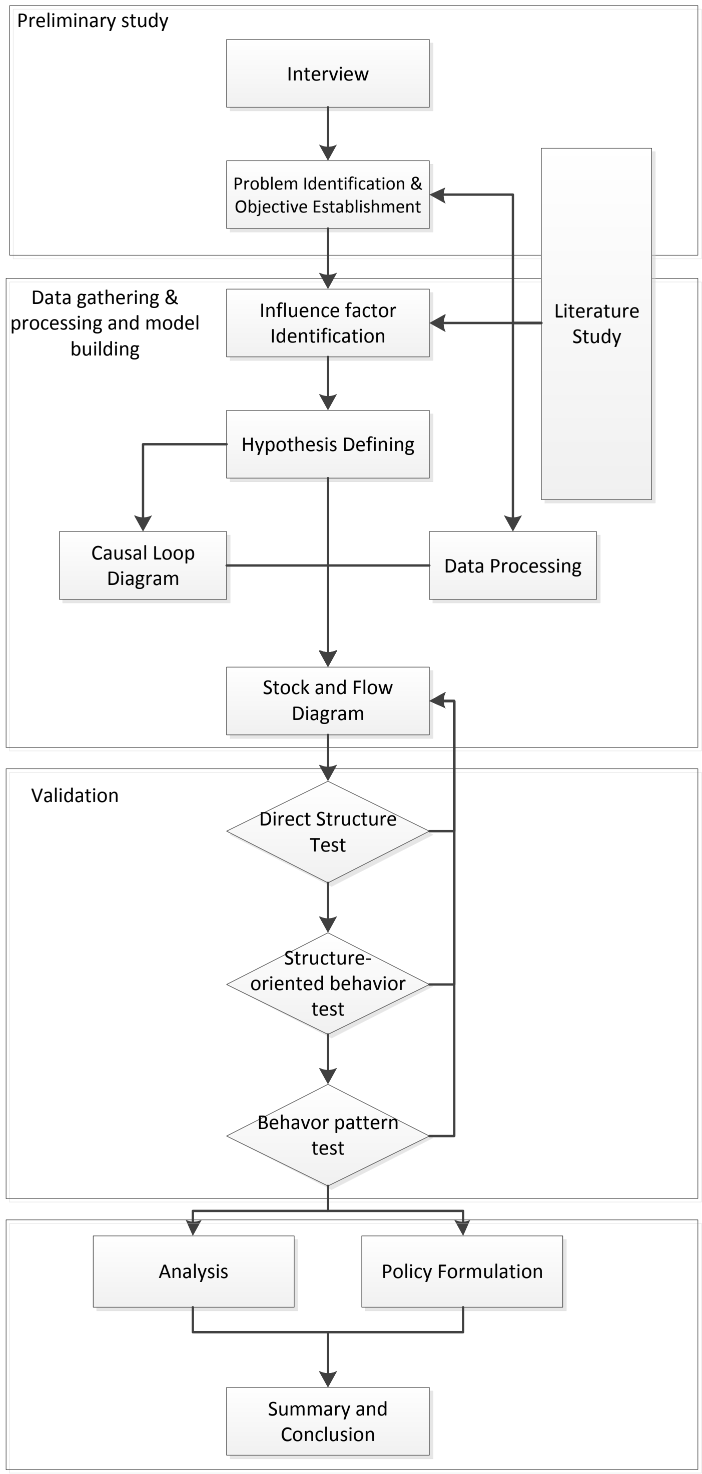


Figure 3.1. Research Process

Little numerical information about development of CA adoption in Zambia had been documented; this documentation was limited to CAP Phase I project result during 2006-2010 (Nyanga & Johnsen, 2010). CAP is a project for promoting CA adoption and implementation in Zambia that is supported by NORAD (Norwegian Agency for Development Cooperation). Aside from the report of CAP Phase I, a number of researches (e.g., Aune, Nyanga, and Johnsen (2012); Nyanga (2012b); Nyanga and Johnsen (2010); Umar (2013); Umar et al. (2012); Umar and Nyanga (2011)) also supported documents analysis to fulfill data requirement for building a simulation model.

3.2.2 Problem Identification and Objective Establishment

After understanding current system's condition together with desired and achievable condition by implementing CA, problem of the system was identified. After understanding farmer's perspective through interview, objective of this research was established. In this process, population for model building process was also defined.

The population used in the model is farmers under Conservation Agriculture Programme (CAP). This project aims to promote and increase CA adoption among farmers in Zambia. CAP is implemented by Conservation Farming Unit (CFU) of Zambian National Farmers Union (ZFNU) (Aune et al., 2012) and sponsored by NORAD since 2006 until 2010 for CAP Phase I and since 2011 until 2015 for CAP Phase II (MFA, 2011). The selection of this population is based on several reasons:

1. Largest Conservation Agriculture promotion and adoption project

   This project covers largest area compared to other projects. CAP operates in four administrative regions: Southern, Central, Western, and Eastern which encompasses 16 districts out of 73 districts in Zambia (CFU, 2012). Those districts are Choma, Kalomo, Monze, Mazabuka, and Sinazeze from Southern region Chibombo, Chongwe, and Kapiri Mposhi from Central region; Mumba from Western region, and Chipata, Katete, and Petauke from Eastern region (Nyanga, 2012a).

2. Data availability

   Although CAP covers most farming area in Zambia, the data about the whole population under CAP is not available. Nevertheless there are several researches, monitoring, evaluations, and reports about CA adoption in area under CAP project. Those researches mostly consisted of four years survey in four districts in AER I and IIa. Those two AER's are where CA is practiced (Umar et al., 2011) under CAP project (Nyanga & Johnsen, 2010).

From those literatures the result of four years survey is used to explain the population condition of CA adoption under CAP project.

3.2.3 INFLUENCE FACTOR IDENTIFICATION

From various literatures, similar issues or factors were gathered and formed a more general factor to become the part of the system dynamics model. Research objective was used as a guideline to determine whether an issue or a factor was relevant or not.

3.2.4 DEFINING HYPOTHESIS

From the factors and issues that have been found, the relationship among factors was depicted using Causal Loop Diagram. After CLD and data processing, Stock and Flow Diagram (SFD) was built based on the hypothesis depicted in CLD and also additional structure. In the process those three activities were conducted simultaneously means after SFD was finished, CLD can be revised based on new relation depicted in SFD and vice versa.

3.2.5 DATA PROCESSING

In this section, sample and data sources, procedures of data collection and data analysis are explained.

3.2.5.1 Sample and Data Sources

This research gathered qualitative and numerical information by performing discourse analysis from open interview and existing documents. There were two types of data used in model development: four years and single moment surveys. Existing yearly data about CA adoption and implementation in Zambia, which were also used as reference to construct historical data of CA diffusion in Zambia, are limited to farmers survey in Nyanga and Johnsen (2010). The existing yearly data is based on surveyed farmer during the first four year of CAP Phase I implementation (640 farmers in 2006/2007 survey, 535 farmers in 2007/2008 survey, 486 farmers in 2008/2009 survey, and 440 farmers in 2009/2010 survey) but based on the calculation of sample adequacy, the survey's result could represent the farmers' population under CAP Phase I project.

Calculation of sample adequacy was performed using Cochran's sample size formula (Kotrlik & Higgins, 2001):

$$n_0 = \frac{t^2 \times p \times (1-p)}{d^2}$$

With

n_0 : number of sample:

t : value for selected alpha level of 0.025 in each tail=1.96

p : estimate of standard deviation = 0.5

d : acceptable margin of error for mean being estimated = 0.05

this results to:

$$n = \frac{1.96^2 \times 0.5 \times (1 - 0.5)}{0.05^2} = 384.16$$

This means that to ensure that the sample is representative, minimum number of sample is 384.16≈385 respondents. That minimum sample requirement had been fulfilled from data in Nyanga and Johnsen (2010). The data consists of characteristics of farmers in CAP project during 2006-2010 which covers average household size, average number of owned cattle and agricultural tools, farm size for each farming practice, average area in maize, average maize production, average fertilizer used, average starting date of tilling and the state of food security. The survey was conducted in six districts from three provinces which are Monze and Sinazongwe in Southern Province; Katete, Chipata and Petauke in Eastern Province; and Mumbwa in Central Province (Nyanga, 2012a). Nyanga (2012a) explained the reason those districts were chosen as surveyed location was because CA had been implemented there for at least five years. Those six districts also represented two area where CA was implemented and also suitable area for CA which are Agro-Ecological Region (AER) I and AER IIa. Further explanation about AER in Zambia can be found in sub-Chapter 4.1 Framework Development.

Beside yearly data, single moment data were also used to build the model. Those data are yield productivity from each farming method (Umar et al., 2012; Umar et al., 2011), cost for practicing each farming practice (Umar et al., 2012), labor for each farming practice (Umar et al., 2012), number of farmers who are aware of climate change effect (Nyanga et al., 2011), and effect of rainfall to yield productivity (Munodawafa, 2012). Nyanga et al. (2011); Umar et al. (2012); Umar et al. (2011) surveyed farmer in the same area as yearly surveys only this one was conducted in one year period and completed with interviews. Research by Munodawafa (2012) was conducted in Malawi; this research could be used in CA adoption model in Zambia since Malawi and Zambia have similar climate and soil characteristics. More explanation about data usage for model construction is explained in sub-Chapter 4.3 Model Calibration.

3.2.5.2 Procedure of Data Collection

Collected data was used to answer research questions as well as constructing model. There were two types of data that was collected along the research process: primary data and secondary data.

Secondary data in this research consists of existing research and report about CA implementation in the world, sub-Saharan Africa, and Zambia (e.g., Aune et al. (2012); Nyanga (2012b); Nyanga and Johnsen (2010); Umar (2013); Umar et al. (2012); Umar and Nyanga (2011)). Both numerical data and relations among attributes in the system were acquired from secondary data. Reliability of sources was taken into account to determine the utilization of certain sources in this research.

Primary data which were obtained from interview was the source to understand farmers' behavior in faming practice. Interview was conducted semi-structured by making preliminary open and general questions list that relates to interviewee's expertise which made the interview process structured yet quite flexible to add more specific questions. Main interview was conducted with Progress Nyanga, a researcher on CA adoption and implementation in Zambia. Skype was used as the means to do the interview. Additional information was also acquired from two researchers in University of Bergen, Birgit Kopainsky and Andreas Gerber, who conducted a number of researches in agriculture practice adoption and food security in Zambia (e.g., Gerber (2014); Saldarriaga, Kopainsky, and Alessi (2013); Saldarriaga, Nyanga, and Kopainsky (2014)). Expert interview is important to elicit tacit knowledge about the system which may not be available in existing documents.

The correlation between collected data and research questions are as followed:

1. First research question about the condition of CA adoption and implementation in Zambia according to number of adopters during period 2006-2010 were answered based on calculation of secondary data from Nyanga and Johnsen (2010). The calculation also used several assumptions so that the result is representative for the population. The calculation was explained in sub-Chapter 4.3. Model Calibration.
2. Second and third research questions about the influence factors in CA adoption and implementation was answered by acquiring information from interview and documents analysis. The influence factors were described in sub-Chapter 4.2.3. Variable Influencing the System.

3.2.5.3 Data Analysis

Two types of data were used in this research:

1. Secondary quantitative data

This data was available from previous researches and existing reports about CA adoption and implementation. Some of this type of data was used directly while some of them needed to be re-calculated to obtain key information. The data was calculated using simple calculation. Data context, meaning and relationship of data need to be understood to give correct formulation about variables' relation in the model.

2. Qualitative data

Qualitative data was used to construct model structure. This type of data was analyzed using content analysis based on explicit statements in documents or from interview. Qualitative data was validated by creating hypothesis based on several literatures. A statement was accepted when more than one literature mentioned similar issue. In interview, validation was conducted by repeating interviewee's statement and sent the interview transcript to interviewee to ensure information's accuracy.

3.2.6 Validation

Validation was conducted using at least one validation test from each type of validation group.

3.2.7 Analysis and Policy Formulation

Analysis was conducted based on model result. Besides analysis, policy was made to achieve the desired target.

3.2.8 Summary and Conclusion

This chapter explained resume of the research and also suggestion for future research.

CHAPTER 4
FRAMEWORK DEVELOPMENT & CONCEPTUALIZATION

4.1 FRAMEWORK DEVELOPMENT

4.1.1 ZAMBIA

Since 2004, Zambia has been growing from a country that has GDP of US$ 5.5 Million to US$ 20.6 Million (WB, 2014c). In spite of agriculture was only the third biggest sources of GDP[2], agriculture was recorded as the occupation of most Zambian[3]. As the other sub-Saharan Africa countries, Zambia also has positive population growth. Figure 4.1 shows that population growth in Zambia has been about 300.000 people annually or 2.7% on average in the last 11 years. In 2010, 61% of Zambia population was under national poverty line (WB, 2014b).

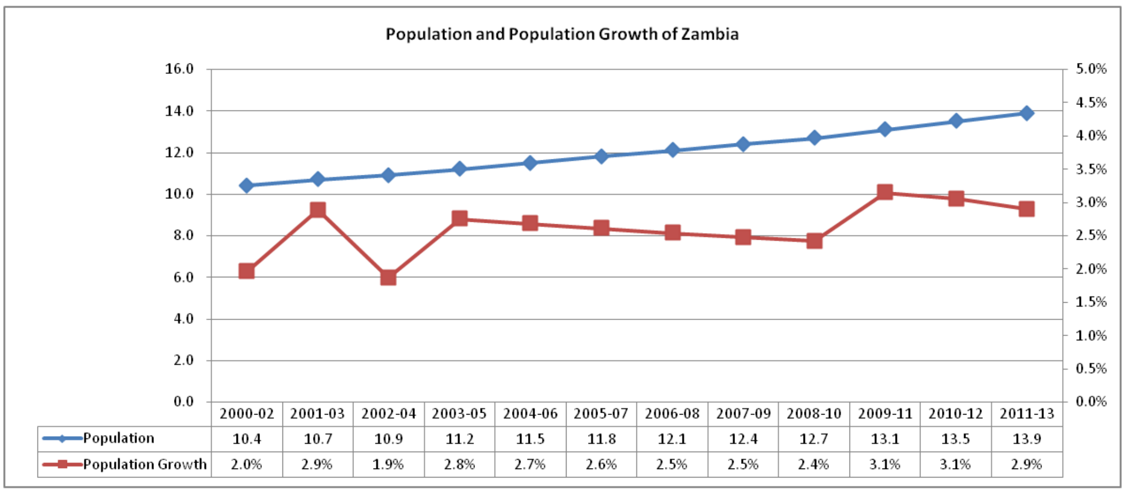


Figure 4.1. Population and Population Growth Graph

Source: FAO (2013c), tabulated

From the food security perspective, while the prevalence of undernourishment has been decreasing 0.1 % on average in the last 11 years, the undernourishment level is still relatively high on 43.1% among whole population during period of 2001-2013 FAO (2013c). Population growth makes the need of agricultural production for consumption is even higher whilst the population growth is not counterbalanced by the increase of arable land[4].

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[2] Based on WB (2011), service, industry, and agriculture were accounted for 43%, 37%, and 20% of GDP respectively.

[3] Based on WB (2005), agriculture was accounted for 72% of employment in Zambia

[4] Arable land is land under temporary crops (double-cropped area are counted once), temporary meadows for mowing or pasture, land under market or kitchen gardens, and land temporarily fallow (WB, 2014a).

4.1.2 Environmental Condition in Zambia

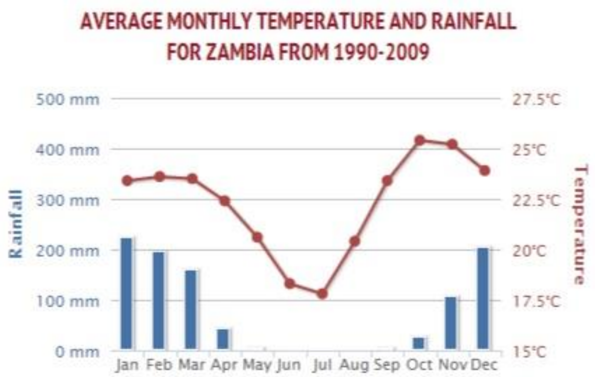

Figure 4.2 Average Monthly Temperature

Source: CRU (2014)

Zambia is located in 15° 25' S and 28'17' E (source) which makes Zambia has tropical wet-dry climate controlled by moist, warm equatorial and maritime tropical air masses. Rainy season in Zambia is mostly happened in between October and April and that makes Zambia's agriculture is extremely affected by seasons changes. The fluctuation of rainfall intensity is also worsened the condition since maize, as the staple food of Zambian, is highly depended on soil moisture. The issue is added by studies that predict the maize production will be decreased as the effect of climate change (Jones & Thornton, 2003; Lobell et al., 2008).

Zambia has total area of 752,618 km^2 with around 4.6% (WB, 2014a) of those area consists of arable land or about 34.000 square km (FAO, 2013a). During period of 2009-2011, there was no significant change in the percentage of arable land.

Figure 4.3. Administrative Map of Zambia

Source:CIA (2014); UN (2004)

Figure 4.4 shows the agro-ecological zone in Zambia. The Agro-Ecological Region (AER) in Zambia is divided into 4 zones: AER I, AER IIa, AER IIb, and AER III. AER I is consisted of 12% of Zambia's land area which covers Southern and Western province where the annual rainfall is below 800 mm (Umar et al., 2011). AER IIs are located in medium-rainfall zone which covers east-west through the center of the country on the plateau of the Central, Lusaka, Southern, and Eastern Provinces (Siegel, 2008). This area has the most favorable agro-ecological conditions in terms of rainfall and soil quality (Siegel, 2008:9). However the western part of this zone, which corresponds to central/northern parts of Western Province, receives low-rainfall and this area is referred to AER IIb. Zone III which constitutes about 46 % of Zambia's land area is a high-rainfall area and relatively urbanized (Siegel, 2008). The Zone III consists of northern part of Zambia, Copperbelt, Luapula, and Northwestern Province (Siegel, 2008).

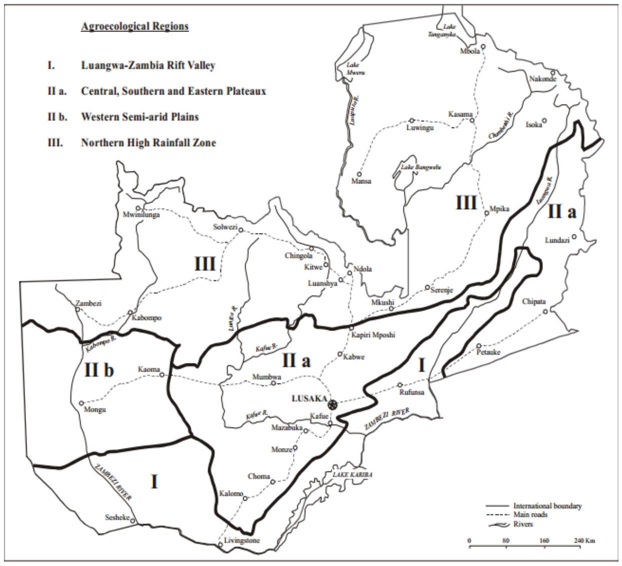

Figure 4.4. Zambian Agro-Ecological Zone

source: FAO (2005) as shown in Siegel (2008)

The ratio between a growing population and constant arable land makes the availability of soil become even more important. Figure 4.5 shows that maize production is highly affected by the area harvested with maize which means constant arable land will limit maize production in the future while the increase of population makes the state of food security in Zambia will be more threatened.

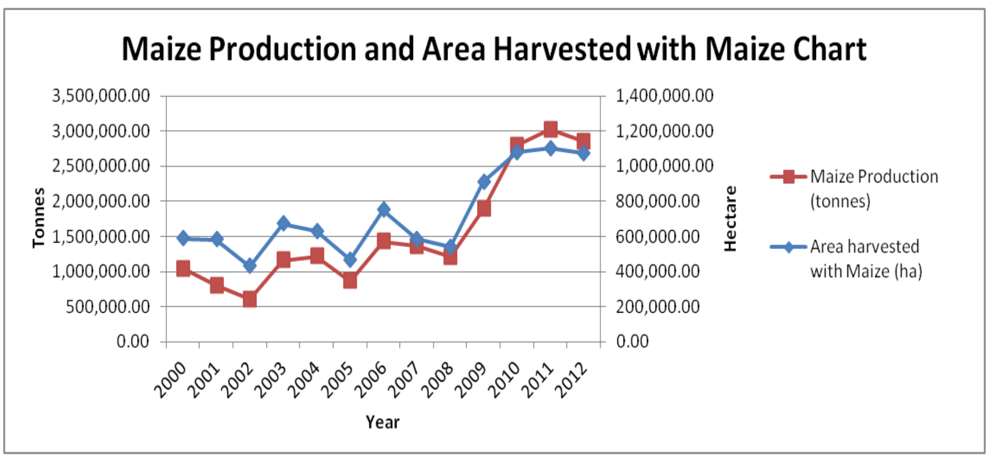

Figure 4.5. Maize Production and Area Harvested with Maize Chart

Source: FAO (2013b)

4.1.3 *AGRICULTURAL PRACTICE IN ZAMBIA*

Soil is a renewable resource that needs to be conserved for fulfilling its manifold functions. However, soil in Zambia is severely damaged as the result of indigenous[5] and conventional farming practices[6]. In this sub-chapter several farming practices that have been implemented in Zambia in the past years will be shortly explained. The difference of farming practices is in the land preparation method.

Zambian early farming practice (indigenous faming practice) is slash and burn. This practice was implemented by opening new agricultural land in forest area and abandoning the land after several harvest periods. After the harvest period, farmer will move to another forest area and repeat slash and burn practice. This practice is not sustainable for environment because instead of preserve SOM (soil organic matter) in the soil, farmers move to another area and utilize the soil until the SOM is depleted. This practice was not cause significant environmental damage but with current issue of population growth, this practice can cause extensive deforestation in Zambia. Besides slash and burn, Zambian farmers also implemented direct sowing; in this practice plow is not needed and seed is only sowed by being spread on the top of the soil. In the interview on 1st of March 2014, Progress Nyanga explained that both indigenous farming practices in Zambia use commercial seeds and organic fertilizer which cause relatively low production compared to modern practices.

After the introduction of plowing practice to farmers in Zambia, conventional agriculture was started to widespread among farmers. This practice uses fertilizer and also hybrid seed as inputs therefore this practice can produce higher yield compared to indigenous farming practice. The three main methods of conventional agriculture are soil inversion, ridging, and extensive tillage (CFU, 2007). This practice is also characterized by plowing, ridging, burning residue, mono-cropping[7], and overall digging with hoe after the rain comes (CFU, 2007).

However, this practice also gives implication to the environment and the farmer itself, such as (CFU, 2007; Gowing & Palmer, 2008; Hobbs, 2007):

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[5] Indigenous farming practice in Zambia is slash and burn. The practice is implemented by opening new agricultural land in forest area and abandoning the land after several harvest periods.

[6] Conventional agriculture is tilling-based agricultural practice

[7] Mono-cropping is plant same kind of crop in the same field year after year.

1. Decline of soil organic matter and nutrients[8]

   The over exploitation of soil, which is characterized by unsustainable farming system over long term, without adequately conserving the soil organic matter and nutrition in it causes depletion of soil organic matter and nutrients and that obstruct the growth of crop which leads to decrease of yield crop (Gruhn et al., 2000) in harvest period. Figure 4.6 shows the plant nutrient balance system that sums up the source of soil nutrient and how it is used.

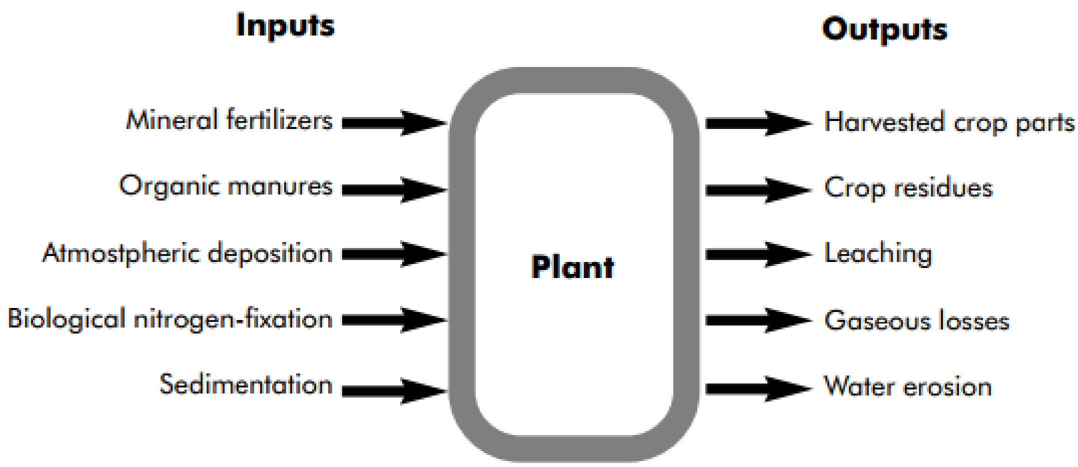

Figure 4.6. The Plant Nutrient Balance System

source: Smaling (1993) in Gruhn et al. (2000)

2. Land degradation.

   The extensive plowing and overall digging lead to severe soil erosion. The overall digging to the same depth each year causes hoe pans which restrict root growth and make plants more susceptible to dry spells. The practice of burning residues also eliminates crop residue which can protect the soil surface from sheet erosion, rain splash and capping, improve infiltration, and reduce soil temperature which can rise above 50° in October (CFU, 2007). Baudron et al. (2007) also mentioned that the land degradation as a result of conventional tillage and extreme use of organic fertilizer is especially seen in Southern Province.

3. Soil compaction

   The medium term effect of continuous ploughing during periods of high moisture content is soil compaction (Baudron et al., 2007; CFU, 2007). While slightly and medium

[8] Primary nutrients for plant growth are nitrogen, phosphorus, and potassium (known collectively as NPK). In addition to that, secondary nutrients, which consist of sulfur, calcium and magnesium, are also used less intensively. A number of micronutrients such as chlorine, iron, manganese, zinc, cooper, boron, and molybdenum also influence plant growth Gruhn et al. (2000)

compacted soil have desirable effect, excessive and beyond optimum soil compaction lead to undesirable effect of preventing root to grow (Dejong-Hughes, Moncrief, Voorhees, & Swan, 2001). Short roots limit the explored area for plant to absorb nutrient and water from the soil and in the end that will decrease yield production. Other undesirable effect happens in seasons of heavy rainfall that compacted soils do not drain properly and become waterlogged (CFU, 2007)

4. Abandoned land and/or migration

   Degraded land makes the land is not interesting anymore for farmers since farmers cannot expect to get yield productivity as it should be. That issue makes farmers left the land by shifting to another area or even opening another farm in new forest area which creates deforestation. The continuous practice of conventional agriculture will create similar damage in the new area which extends soil damage in arable land area.

5. Late planting

   The need of rainfall before the soil is being tilled makes conventional agriculture is highly depend on the availability of rain. Climate change makes rainy season sometimes comes late or rainy season becomes shorter. The tardiness of rainy season makes land preparation also starts late which leads to the delay of planting while for each days of delay after the first planting rains, 1.5% of potential maize yield is lost (CFU, 2007). Late start combines with short of rainy season leads to low production.

Due to those implication together with drought and disease, Southern Province who used to be maize exporter became maize importer after the drought in 2000/2001 (Baudron et al., 2007).

There are several agricultural producers in Zambia. The list with each of its characteristic is shown in Table 4.1. This study uses small-scale farmers as the population of the system.

Table 4.1.Typology of Agricultural Producers in Zambia

Characteristics	Small-scale farmers	Emergent farmers	Large-scale commercial farms	Large Corporation Operations
Number of farmers	≈800.000 households	40.000-60.000 households	600-750 farms	≤12 farms
Cultivated Land (ha)	1.45	5-20	50-150	Several thousand hectares of crops
Input	Low-input	Hybrid seed & fertilizer	Hybrid seed & fertilizer	Hybrid seed & fertilizer
Technology	Hand hoe	Draught power	Extensive mechanization	Vertical integration with agro-processing
Primary labor	Family	Family and hired	Family owned with permanent and casual staff	Hired professional

Characteristics	Small-scale farmers	Emergent farmers	Large-scale commercial farms	Large Corporation Operations
Use of production	Household consumption (subsistence)	Predominantly for sale	Commercial sale and feeding of staff	Commercial sale
Major constraints	Lack of timely availability of inputs Weak market information Vulnerability to drought (in the south)	Labor bottlenecks (especially in land preparation) Access to finance Weak market information Non-availability of affordable working capital	High indebtedness Limited access to and high cost of working capital Lack of capacity to store crops Weak market information	

Source: adapted from WB (2003)

This study focuses on small-scale farmers as they are the target of CA promotion in Zambia.

4.1.4 CONSERVATION AGRICULTURE PRACTICE IN ZAMBIA

Since 1980, seven out of nine provinces in Zambia have received active support for implementing Conservation Farming (CF), those provinces are Eastern, Central, Lusaka, and Southern Province from AER I and IIa and also Northern, Luapula, and Copperbelt Provinces from AER III (Arslan et al., 2013). Several key management practices of conservation agriculture (minimum tillage, crop rotation, and crop association) have been promoted in the late 1980 by a growing coalition of stakeholders from private sector, government, and donor communities (Baudron et al., 2007) as a means to encounter soil degradation as the effect of conventional agriculture and indigenous farming. While in overall the practices have been supported by stakeholders in farming system from government, donor community, civil society, research institutions, and farmers as the practitioner (Nyanga, 2014).

CFU (2007) sees CT as a combination of practices that conserves soil, moisture, fertilizer, seeds, energy, time, and money. Conservation farming Unit (CFU) under (ZFNU) and Ministry of Agriculture and Cooperatives (MACO – now become Ministry of Agriculture and Livestock-MAL) are the major institutions who support the implementation of CA; beside those two among stakeholders who also have promoting CA are Institute of Agricultural and Environment Engineering, Golden Valley Agricultural Research Trust (GART), Dunavant, Cooperative League of the USA (CLUSA), Land Management and Conservation farming (LM&CF), and (Baudron et al., 2007). Since 2000, MACO has been formally embracing CA as official policy in Zambian government (MAFF, 2001 as stated in Baudron et al., 2007). In the process of promoting CA in Zambia, input packs of seeds, fertilizers, and lime were provided free or on a cost sharing basis (Baudron et al., 2007: 10). Besides incentives in the form of input, farmers are also given training and monitoring during the project.

In the interview on 1st of March 2014, Progress Nyanga explained that, there are several principles that have been added to existing key management practice of conservation agriculture which create key management practice of CA implementation in Zambia, those key management practices are:

1. Early land preparation

   Farmers start to cultivate the land before the rainy season starts (make basins and/or create rip lines). The different of starting time for land preparation is shown in Figure 4.7.

2. Early planting

   Early land preparation is continued by early sowing so the seed can catch rain early, receive enough water compared to conventional which waits for the rain to come to start for land cultivation. The combination between early land preparation and early planting are actually critical for response to climate change. Because of the effect of climate change, rain becomes even shorter, with this key management practice, the chance of the planted seed to get rainfall increases. The different of this practice between conservation farming and conventional farming is shown in Figure 4.7.

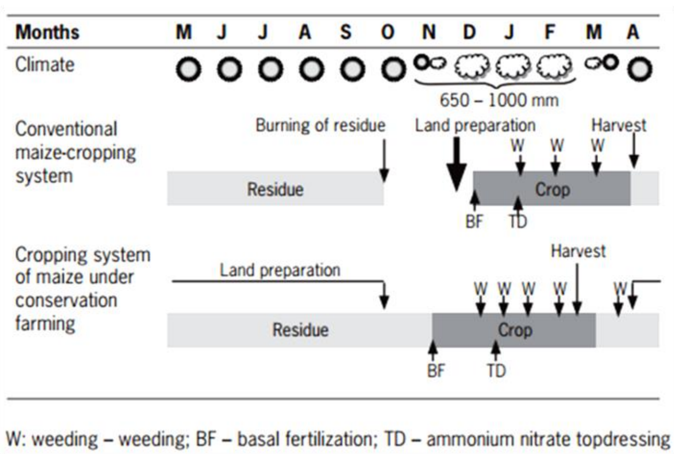

Figure 4.7. Comparison of Maize Cultivation under Conventional Farming and Conservation Farming in Zambia

Source: Baudron et al. (2007)

3. Continuous weeding

   In CA implementation weed growth need to be highly controlled; weed is not as highly controlled in conventional farming practice since soil tilling decrease the possibility of weed growth.

4. Minimum tillage

   This practice means minimum soil disturbance with any mechanical tools.

5. Crop rotation

   In Zambia, this practice is not really unique because it is also implemented in conventional & indigenous farming practice. In Zambia's indigenous farming practice intercropping can be found in many farms. Maize is the main crop while the other (groundnuts, etc.) is optional.

6. Soil cover (crop residue retention)

   Crop residue is the result from previous harvest. Soil cover can be managed by leaving previous crop residue on the surface so they cover the soil. It is also possible to grow the cover crops (intentionally only for cover crops) they give a lot of biomass & material to cover the surface.

There are two main variations in land preparation of conservation agriculture implementation. The basic idea of land preparation is to minimize the area of tilled land. The variations are (Thierfelder & Wall):

1. Manual tillage

   There are two practices that are considered as manual tillage: creating planting basins using chaka-hoe or common hand-hoe and direct sowing using jab planter. Due to the nature of work, in Zambia planting basin is generally made by women. P. Aagaard (2007) mentioned that 3 adults can dig about 500 basins in 3 hours and 1 hectare can be finished in 4 weeks. Basically, to create planting basins a special tools called chaka-hoe is used yet many farmers still use common hand-hoe for creating planting basins. Haggblade and Tembo (2003a) mentioned that based on research among 125 farmers, 1.5 tons more maize can be produced compared to hand-hoe tillage practice.

Figure 4.8. Conservation Tillage with Basins

Source: Nyanga (2012b)

   Essentially, direct sowing practice using jab planter is similar as indigenous practice that the seed is sowed directly to the soil however in conservation agriculture this activity is helped by a more modernized tools called jab planter.

2. Mechanical Tillage

   Mechanical tillage is consisted of two types: ox-drawn ripper or tractor and animal traction direct seeders. Ox-drawn ripping is conducted by using magoye ripper[9] (S. Kabwe & Donovan, 2005). Whilst the usage of animal traction direct seeders manage the seed to be directly placed by seeder. However, the need of oxen, ripper or tractor make this practice is conducted only in several farm in Zambia with ox-drawn ripping is the most popular among other two methods. Different as planting basin, this practice is mostly conducted by men. The idea of practicing ripper instead of ploughing is to increase precision of water infiltration (Baudron et al., 2007) and also to preserve humidity of the soil.

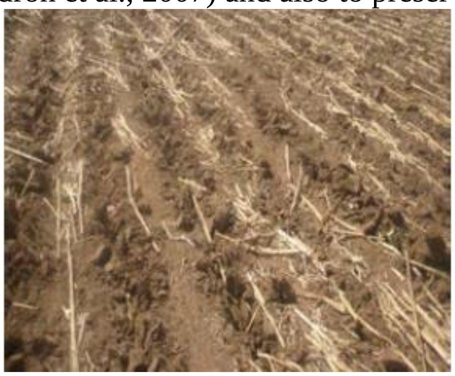

Figure 4.9. Conservation Tillage with Ox-drawn Ripper

Figure 4.10. Conservation Tillage with Animal Tractor

Source: Nyanga (2012b)

4.1.5 STAKEHOLDERS OF AGRICULTURAL SYSTEM IN ZAMBIA

Albeit the early idea of no-tilling practice stems from farmers, conservation agriculture is not implemented by isolated farmers but by innovative farmers who participate in a social network of agency advisors and farmers together with researchers, policy makers and farm supply companies (Coughenour & Chamala, 2000). The list of stakeholders in conservation agriculture promotion, diffusion, and implementation process are:

1. Farmers

   Farmers act as implementers of CA in the field on daily practice. Farmers correspond directly with civil society's officers and with research institution. Farmers involvement in CA is depend on project which means even though a farmer joins a farmer organization if he does not want to join project he is not involved in any activity related to that project.

[9] A locally developed tools for oxen farmers in Zambia which is used only in dry season and disturbing a limited area of topsoil (S. Kabwe & Donovan, 2005).

2. Donor Communities

   Donor communities commit as source of financial support for every activities in promoting CA. Donor communities in Zambia are, among other, Norwegian Agency for Development Cooperation (NORAD), Finnish International Development Agency (FINNIDA), United States Agency for International Development (USAID), Food and Agriculture Organization of the United Nations (FAO), and European Union (EU).

3. Governments

   Government, especially Ministry of Agriculture and Livestock (MAL), acts as regulator. MAL is in charge to create conducive environment to operate, create policy guideline for implementation for agriculture policy in Zambia, create guidelines for participation in CA promotion and also make decision whether government will accept or reject offered aid from donor communities. Besides as regulator, government also has organization that provides support and training to farmer. Government also acts as the biggest buyer of maize.

4. Civil Society of Farming Advisory

   In the relation with farmers, farming advisory acts as guides for conducting ideal CA; advise are given by conducting field days which show the real implementation of CA in the real farmer's field, personal visit is also held by field officer and lead farmers. In the early year of CA promotion incentives are also heavily given for conditioning the farmers to practice conservation agriculture. Incentives were given in the form of input packages ((high-yielding-variety seeds; fertilizer, and herbicide) however as the more farmers realize the benefit of CA, less incentives are given.

   In the relation with donor agencies, farming advisory is assigned to use the donor aid for promoting CA directly to farmers and through media. Farming advisory also often lobbies government in suggesting policy in certain issues on behalf of the farmers. Some farming advisory in Zambia are Zambian National Farmers Union (ZNFU), Conservation Farming Unit (CFU), The Golden Valley Agricultural Research Trust (GART), Dunavant (also become donor agencies for cotton farmers), and Agriculture Support Programme of MAL.

5. Research Institution

   This entity conducts researches on farmer implementation of CA and sometimes also answers certain question from farmers. There are two kinds of research that have been conducted by research institution which are on farm research and on station research. On farm research is direct research in field area and related with the real practice by farmer while on station research is conducted in laboratory. Many studies have been conducted about the adoption of conservation agriculture with the purpose of providing farming advisors with suggestions for increasing the adoption of conservation agriculture practice in the region.

6. Agrochemical Dealers

   This entity act as input supplier such as agriculture equipment, seed, fertilizer, and herbicide however this entity does not support CA promotion directly

Based on the explanation above, one can summarize that the first five entities are the most important entity in conservation agriculture implementation. The relationship of the entities can be seen on Figure 4.11.

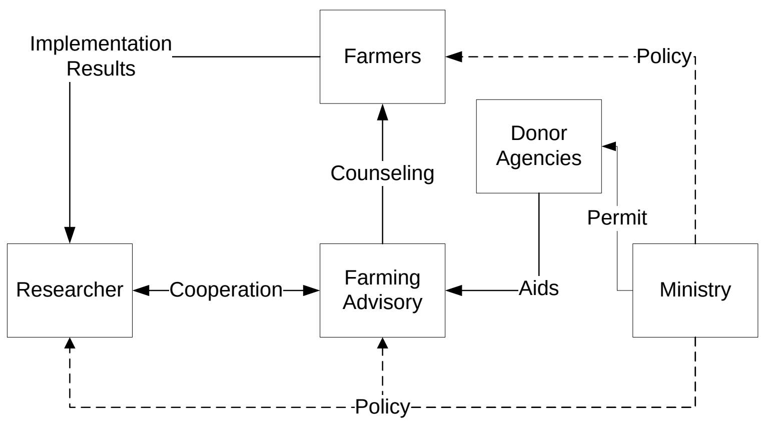

Figure 4.11. Entities Relationship in Conservation Agriculture Implementation

4.2 CONCEPTUAL FRAMEWORK

This sub-chapter explains about conceptual framework used to build the model. In this section dynamic problem of the system is explored. Also in this section, the boundary of the system is set to restrict the system being captured in the model. This part explains the limitation of the model and analyzes influencing variable in the system under system boundary as well.

4.2.1 DYNAMIC PROBLEM

From the explanation of relations in the system, the identified dynamic problems of the system are:

1 There is indication of lower adoption rate of CA practice which leads to slowing down of CA adoption's development.

2 The promotions of conservation agriculture highly depend on donor aid, in the form of input packages.

3 The feedback processes in the system is not realized by actors in the system.

4.2.2 SYSTEM BOUNDARY

Boundaries of the system being studied are:

1. The food security aspect being assessed is food availability using average dietary energy supply adequacy as the indicator.
2. The agri-family system being discussed is limited to farming system in crop production.
3. Type of farmer being discussed in this study is limited to small-scale farmers.
4. The only innovation under discussion is conservation agriculture and in this study conservation agriculture is defined based on agricultural practice implemented in the farm which means CA and CV are only divided between basin – ripping which represent CA and hand-hoe – plowing practice which represent CV.
5. The processed being studied are those directly related with farmer, therefore the cost of promotion process, the aid limitation of the project, and distribution process are not discussed in the model.
6. The time horizon being studied is period after CAP project which started in 2006.
7. The population being studied is limited to farmers under Conservation Agriculture Project (CAP).

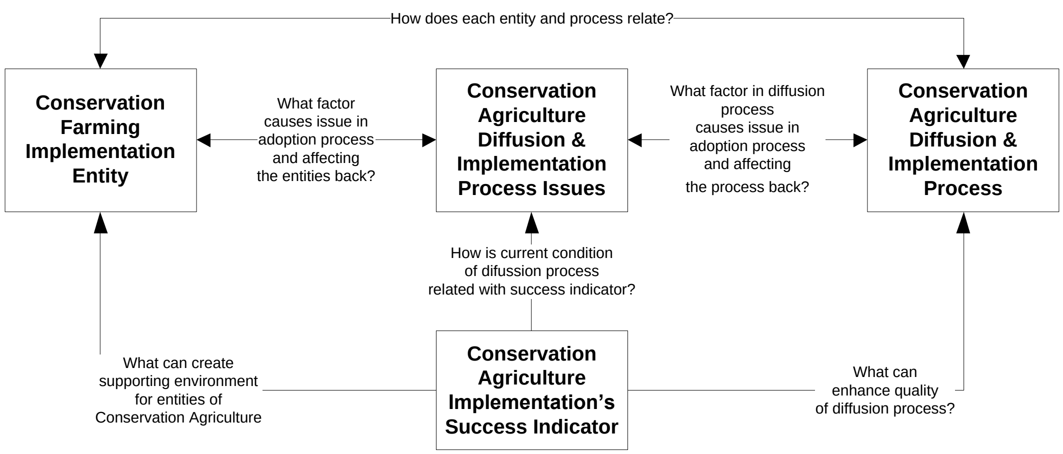

Figure 4.12. Subsystem Diagram

Figure 4.12 shows causal relations in the system. This research is focused on entity, process, issue, and indicator that directly relate to conservation agriculture diffusion. This focused also set the boundary of system being studied which is limited to conservation agriculture practice without discussing about other agricultural technologies.

4.2.3 VARIABLE INFLUENCING THE SYSTEM

In this sub-chapter, variable influencing the system in the boundary is hypothesized. The variables are collected from various resources.

1. **Variable affecting conservation agriculture adoption**

   a. ***Adoption of conservation agriculture is affected by perceived advantages of the practice. The advantages include input packages as support from farmer organization and profitability from implementing CA.***

Adoption rates are time sensitive as they tend to be tied to active promotion of technologies by NGOs and research institutions (Umar et al., 2011); Adoption rates prove highest regions of sporadic rainfall, with strong extension and input supply system (Haggblade & Tembo, 2003b); The biggest challenge of using fertilizer which was cited by 92% respondents was the high cost of fertilizer (Umar et al., 2011); Adoption rates of CA in Zambia often decrease substantially after projects end (Haggblade & Tembo, 2003b); Development of Conservation Agriculture has often been associated with some material incentives given to farmers (Nyanga et al., 2011: 78); Smallholder households have two separate goals of higher income and greater security which are traded off in order to maximize utility (Umar et al., 2012: 924).

   b. ***Adoption of conservation agriculture is affected by trust of farmer in the farming practice***

Farmers converted all of the fields to CA over time as they become convinced of its benefits (Umar et al., 2011); Crop residue retention conflicted with the socio-cultural practices of the communities and was hardly practiced while crop rotation seemed difficult in light of the dominance of maize cultivation and the lack of market for crop legumes (Umar et al., 2011); Less likeliness of good farmer to adopt CA because the definition they have as a good agricultural practice (Nyanga, 2012b); Besides profitability (e.g., return to land and return to labor) there may be other important criteria to adopt a certain farming practice (Baudron et al., 2007).

   c. ***Adoption of conservation agriculture is affected by labor requirements***

Despite of promising yield productivity from this practice, due to high need of labor, this practice is only implemented in small portion of farmers' land. Lack of labor and are mentioned as reasons of not increasing land area under CA (Umar et al., 2011); Six weeding operations per season during first years acts as a significant disincentive to adopting conservation farming because the increase in labor requirements may be incompatible with the labor bottlenecks most smallholder face (Baudron et al., 2007: 16).

   d. ***Investment in tools affects adoption of conservation agriculture***

The usage of ripper met the condition of limitation in the availability of labor force (Baudron et al., 2007; Nyanga, 2012b); Weed management, crop residue retention, timely planting, and soil fertility management were the most challenging for CA farmers especially those without reliable access to oxen (Umar et al., 2011); Farmers tend to collect residue or allow livestock herds to graze freely on crop residue (Baudron et al., 2007). "Farmers who own ripper do not always use them properly; […] farmers use ripper as a furrower or even as a plow after the rains have begun" (Haggblade & Tembo, 2003: 25); Animal draft powered conservation farming using rippers still promise further gains though realization of this potential will require improved extension support to ensure effective off-season land preparation. (Haggblade & Tembo, 2003b).

e. Prestige affects adoption of conservation agriculture

Farmers see CA as something for vulnerable households and not as a modern and commercial way to farm (Baudron et al., 2007:23); Most farmers acknowledge that harvest per unit area was higher in CA than other tillage methods, prestige was more important to some men than the productivity benefits of CA (Nyanga, 2012: 54) .

f. Perception of climate change affects conservation agriculture adoption

Climate change does not directly affect adoption of CA yet it is their perception of floods and droughts that were associated with adoption of conservation agriculture (Nyanga et al., 2011); Despite of conservation agriculture is one of adaptation strategies of climate change, the perception of CA as an adaptation strategy were very low (Nyanga et al., 2011: 78).

2. Factor affecting yield productivity

a. Availability of water

Progress Nyanga in interview mentioned that early land preparation is the key point of CA implementation in Zambia, if there is any delay in land preparation that will lead to late catch of rainfall, that makes the practice of CA is less useful than it should be. Also based on the interview rainfall is the important contributor to yield productivity in CA; Conservation farming is a technology of water harvesting and drought mitigation (Baudron et al., 2007: 24); The clear superiority of basins may be attributed to their water harvesting ability and precise and efficient input application (Umar et al., 2011:58); Maize yields in Conservation Agriculture is highly affected by rainfall (Thierfelder et al, 2013:47).

b. Knowledge to practice conservation agriculture

A lack proper knowledge results in the misallocation of inputs, poor soil fertility management resulting in low crop yield (Umar et al., 2011); Weeds are often a major initial problem that required integrated weed management over time to get them under control (Hobbs, 2007) yet GART (2007) reported that planting a cover crop (e.g. cowpea) within 10 days of the main crop resulted in effective weed suppression and high grain and biomass yields of both the main and cover crops (Umar et al., 2011); Soil physical and biological health also takes time to develop. Three to seven years may be needed for all the benefits to take hold (Hobbs, 2007).

3. **Factors affecting conservation agriculture practice are availability of livestock and tools.**

Livestock results in production of more manure and less dependence on externally procured fertilizers, it also eliminates the bottleneck at weeding; With labor already very limited, it was difficult to frame a strategy on how farmers could allocate more of their activities towards weeding (Umar et al., 2011); Basin digging, hand hoeing, ploughing, and ripping practice lead to different need in labor for land preparation, weeding, and harvesting (Umar et al., 2012); Basins digging is explicitly cater for smallholder farmers without reliable access to draught power (Umar et al., 2011). Challenge associated with retaining crop residues in the field is that crop residues were routinely fed to the livestock (Umar et al., 2011) which means the ownership of livestock also affect the discharge of CA practice; The use of oxen weeding reduces weeding time by 22.6 man-days/ha when compared to hand weeding (Umar et al., 2011).

4.2.4 DYNAMIC HYPOTHESIS

Dynamic hypothesis shows the hypothesis used in building the model. Dynamic hypothesis was captured through causal loop diagram (CLD). The CLD was built based on the system analysis based on documents analysis and interview which was described in 4.2.3. Variable Influencing the System.

The core structure in this study was built based on previous study review about adoption and diffusion of agricultural technology framework in Kopainsky et al. (2012). Kopainsky et al. (2012) explained that innovation diffusion process in agriculture was governed by trust of a specific technology. This model replicates a norm-building structure that addresses the phenomenon of a tipping point[10] or a critical mass[11], and applies it to the case of an agricultural management practice and the question whether conservation agriculture as a new management practice will fail or succeed in the market in the long run.

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[10] A condition when a society adopts previous practice rapidly.

[11] A condition when an innovation has a number of adopters that creates a self-sustaining diffusion process.

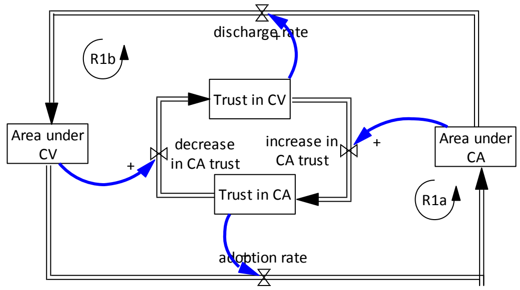

Figure 4.13. Core Structure of the Adoption and Discharge Process of Conservation Agriculture

Adoption and diffusion process of any new technology in a society, including conservation agriculture, depend on confidence of farmers to certain practice which is shown by trust in the technology. Figure 4.13 shows core structure of adoption and discharge process of conservation agriculture. The core structure shows that trust in each of the technology govern the adoption of that technology. Trust is not created in one moment process instead it is created over time through experiences. Different with adoption and diffusion process in Kopainsky et al. (2012), this research shows trust in substitute technologies complements each other, means the decrease in trust of one technology will increase trust level of other technology and vice versa. The trust structure also describes *peer-pressure* or prestige among farmers means another farmer will adopt CA when (s)he sees other farmers adopted it as well regardless of the first farmer's actual success in implementing CA. The links between each technology adopters stock and trust create loop which are shown by R1a for loop that governs adoption process of CA and R1b for loop that governs adoption rate of CV (similar as discharge rate of CA adopters). Trust variable was also explained in previous sub-chapter as important variable that influences adoption.

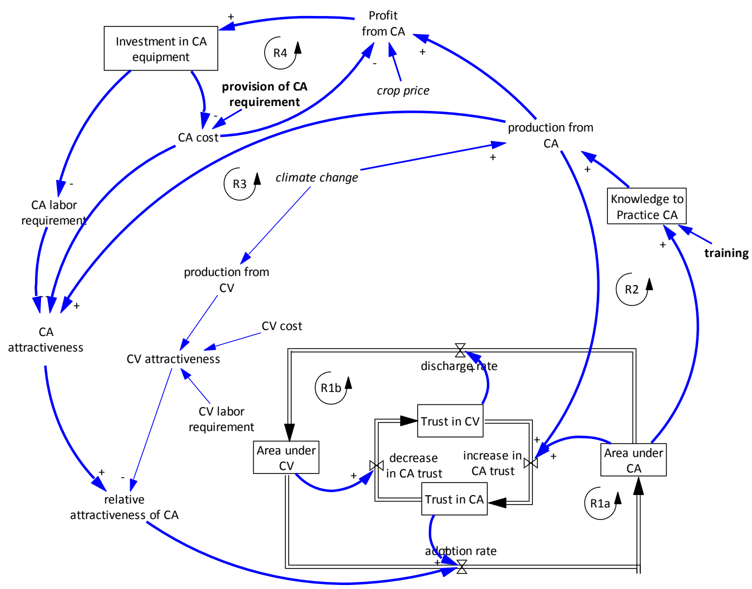

Figure 4.14. Loops Enhance Adoption Process of Conservation Agriculture

Trust of CA itself is increased by yield productivity which is the result of knowledge and skills in practicing CA. Those variables together create reinforcing loop R2 (Figure 4.14). From documents analysis in previous sub-chapter, knowledge was also mentioned as governing factor of yield productivity.

Besides trust, farmers' perceived relative attractiveness also governs CA adoption rate which is shown by R3 (Figure 4.14). Relative attractiveness shows farmers' comparative assessment of three aspects in each farming practice. The comparative assessment covers labor, cost, and yield productivity aspect of each farming practice. The assessment of cost and yield productivity also creates assessment of profit for each farming process. Profit from each farming practice is used to invest in farming tools (ripper in CA practice) that will increase profit of implementing that specific farming practice. This reinforcing loop is shown by loop R4 in Figure 4.14.

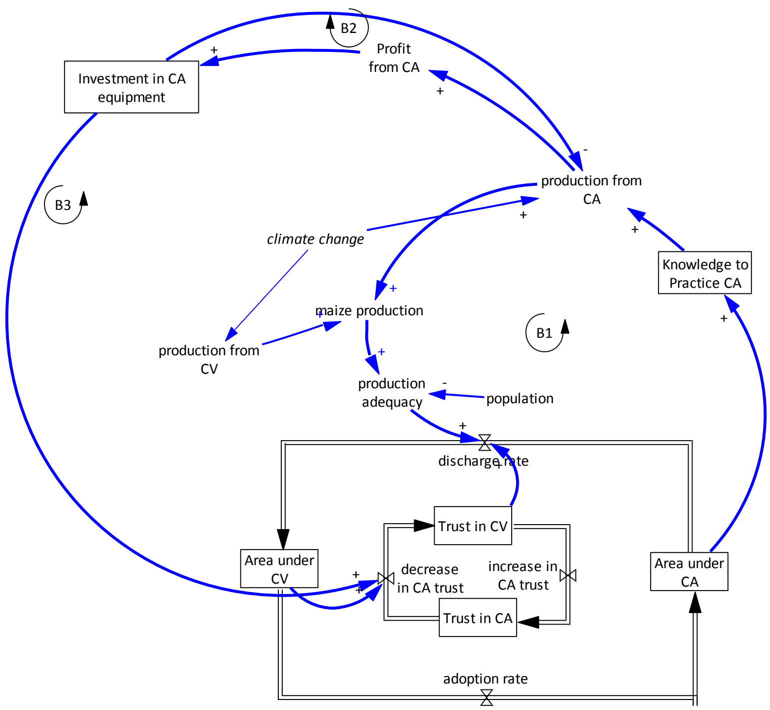

Figure 4.15. Loops Enhance Discharge Process of Conservation Agriculture

Besides reinforcing loops that govern adoption process, there are also balancing loops affecting discharge rate. The first balancing loop is shown by B1 (Figure 4.15). Loop B1 explains that the increase of CA yield productivity will enhance the state of food security in the region, while the improvement of food security increase farmers prestige and as farmers see CA as farming practice for poor farmers, the farmers in food secure condition tend to discharge CA adoption and return to practicing CV. That condition will happen as long as farmers still have quite high trust on CV.

The second balancing loop (B2) shows that the practice of CA using tools produces lower yield productivity compared to basin practice. Lower productivity will decrease the profit of doing such practice and will decrease the rate of tool investment.

The last balancing loop (B3) captures the documents analysis' result in previous chapter that farmers tend to use CA tool for practicing conventional agriculture. This connection is shown by the link from investment in CA equipment to decrease in CA trust.

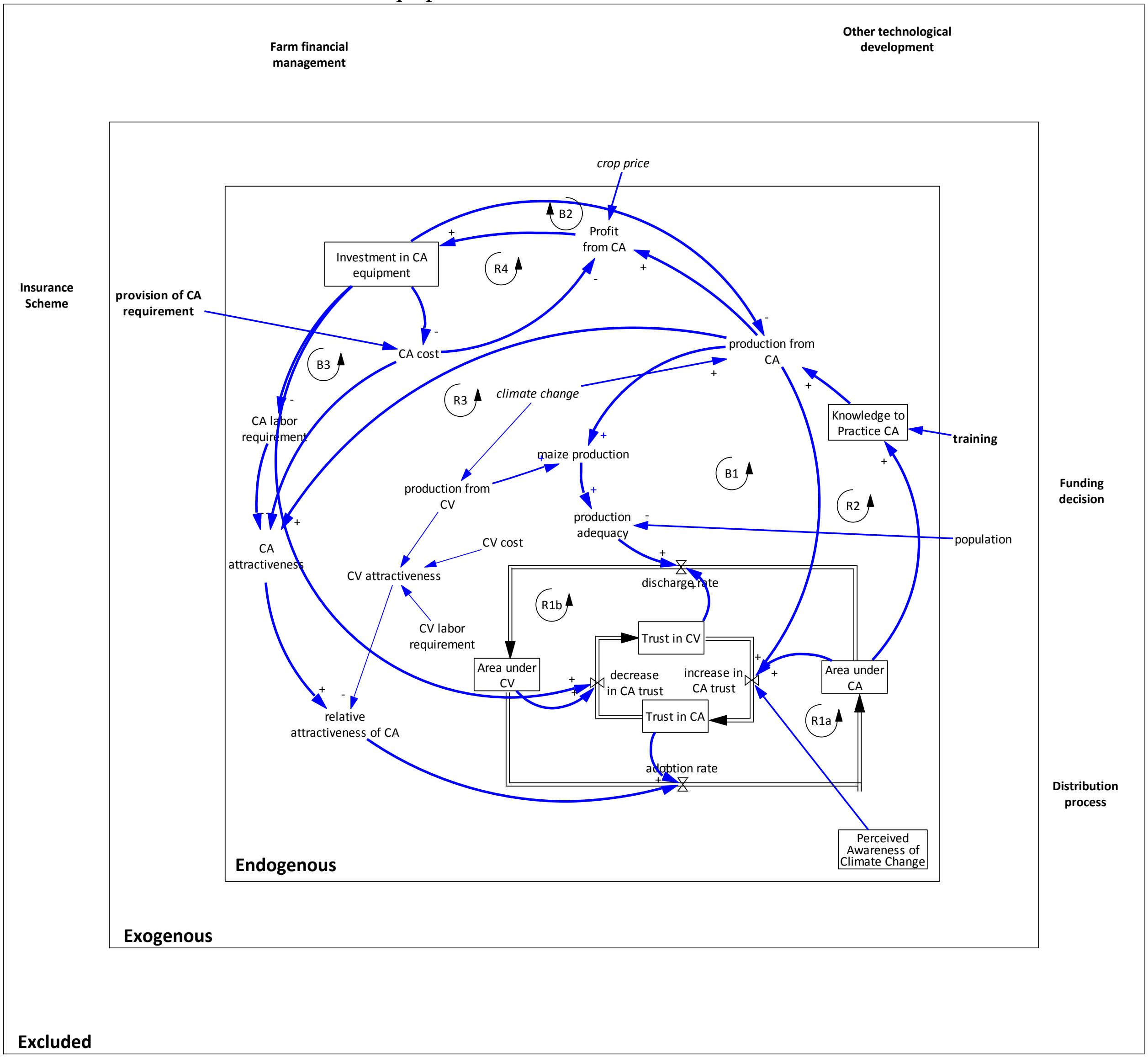

Figure 4.16. Boundary of the System under Study

Figure 4.16 shows the boundary of the system. Provision of CA requirement, crop price, training and population are governed exogenously while the rests that have been mentioned are governed endogenously. Farm financial management, other technological development, insurance scheme, funding decision and distribution process of crop production is excluded in the model.

4.2.5 MODEL LIMITATION

Limitations of the model are:

1. This model only captures the condition of maize farmers thus the product of farms in the model is only maize.
2. All members under the project receive similar treatment from the project without any differences on gender or living area.
3. Only input subsidy is captured in the model as support from CFU for promoting CA in Zambia.
4. The effect of implementing conservation agriculture practice on soil is not captured in the model.
5. Effect of livestock grazing is not shown in the model.
6. Food aid is not captured in the model

4.2.6 ASSUMPTION

Assumptions used in the model are:

1. All area under study has similar mean rainfall intensity.
2. Input package is only used for conservation agriculture practice.
3. Profit from each farming practice will only be devoted for the tools for that specific farming practice.
4. All farmers in the population enter the project as conventional agriculture adopters.
5. Dietary need/person/day can be fulfilled by maize. This can be assumed because Zambian prefers maize above other staple foods.

4.3 MODEL CALIBRATION

1. *Number of farmer each year who join CAP project*

Most of literature about CAP project (e.g., Aune et al. (2012); Nyanga (2012b); Nyanga and Johnsen (2010); Umar (2013); Umar et al. (2012); Umar and Nyanga (2011)) mentioned 120.000 farmers are targeted for CAP yet MFA (2011) mentioned that in the end of CAP Phase I, the number of CA adopters are 171.000 farmers with total area of CA is 120.000 hectare. Furthermore, during 2002/2003 (before CAP Phase I is conducted) roughly 75,000-78,000 Zambian smallholders farmers practiced CF in approximately 3% of cultivated area (Baudron et al., 2007; Haggblade & Tembo, 2003a).

Based on those literatures, number of CA adopters over time was estimated by:

Table 4.2. Number of Conservation Agriculture Adopters Over Time

Variable	Unit	Before 2006	2006/2007	2007/2008	2008/2009	2009/2010
Number of CA Adopters	farmers	75,000.00 [1]	120,000.00	*133,000.00**	*146,000.00**	*159,000.00**

- *:estimated*

1 : Haggblade and Tembo (2003a)

2. *Total area of farmers' field*

Total area of farmer's field was estimated by multiplying the number of farmers with average area of each farmer. Average area per farmer was calculated based on (Nyanga, 2012b). In Nyanga (2012b) the total 876.1 hectare (ha) was owned by 415 farmers which resulted to 2.1 ha/farmer. The result of this approach is also supported by the calculation of total area during 2006-2010[12] from Nyanga and Johnsen (2010) the average area of each farmers fluctuated between 1.92, 2.54, 1.69, and 2.17 ha/farmer for year 2006/2007, 2007/2008, 2008/2009, and 2009/2010 respectively which resulted to average of 2.08 ha/farmer. Therefore, 2.1 ha/farmer is a representative number to show the average area of smallholder farmer.

The average area of each farmer is multiplied by number of CA adopters in area under CAP which resulted to:

Table 4.3. Total Farmers' Area

Variable	Unit	Before 2006	2006/2007	2007/2008	2008/2009	2009/2010
Total Area of Farmers	hectare	157,500.00	252,000.00	279,300.00	306,600.00	333,900.00

3. *Cultivated area under conservation agriculture*

This variable was calculated by multiplying percentage cultivated area under conservation agriculture based on data of each farming practice during 2006-2010 in Nyanga and Johnsen (2010) with total area of farmers in respective year. The percentage of cultivated area under CA was calculated by:

$$Percentage\ area\ under\ CA\ in\ respective\ year = \frac{(average\ area\ under\ basins \times respondents) + (average\ area\ under\ ripping \times respondents)}{(total\ area\ under\ all\ farming\ practice \times respondents)} \quad 4.1$$

Calculation 4.1 resulted to 12%, 16.5%, 24.9%, and 26% for year 2006/2007, 2007/2008, 2008/2009, and 2009/2010 respectively. The percentage is multiplied by total area of each year and resulted to:

[12] The calculation is conducted by summing up area of each farming practice in one year.

Table 4.4. Conservation Agriculture Area

Variable	Unit	Before 2006	2006/2007	2007/2008	2008/2009	2009/2010
Percentage of cultivated area under CA	percent	3%[1]	12.0%	16.5%	24.9%	26.0%
Conservation Agriculture Area	hectare	4,725.00	30,187.50	46,183.46	76,196.45	86,814.00

1 : Haggblade and Tembo (2003a)

4. *Effect of awareness of climate change to conservation agriculture adoption as climate change adaptation strategy*

In the research among 469 farmers which tried to find out farmers awareness of climate change, 346 farmers realized the negative effect of climate change is related to food production yet only 37 out of 469 farmers who consciously adopted conservation agriculture as responses to climate change (Nyanga et al., 2011). From the data mentioned, the effect of climate change awareness to CA adoption was calculated as:

$$Effect\ of\ climate\ change\ awareness\ to\ CA\ adoption = \frac{number\ of\ farmer\ who\ adopt\ CA}{number\ of\ farmer\ who\ aware\ of\ negative\ effect\ from\ climate\ change\ to\ food\ production} = \frac{37}{345} = 0.11$$

5. *Average rainfall intensity*

Average rainfall intensity was calculated based on data rainfall intensity of surveyed area in Umar et al. (2011). The mean annual rainfalls in surveyed area are:

Table 4.5. Mean Annual Rainfall Data

Study Area	AER	Mean Annual rainfall (mm)
Monze	IIa	732
Mumbwa	IIa	804
Petauke	IIa	932
Chipata	IIa	1033
Katete	IIa	983
Sinazongwe	I	789

Source: Umar et al. (2011)

From those data, the resulted average rainfall intensity in those areas is:

$$Average\ rainfall\ intensity = \frac{732 + 804 + 932 + 1033 + 983 + 789}{6} = 878.83$$

Thus, the average rainfall is 878.83 mm/year.

6. Effect of rainfall to maize yield productivity

The effect of rainfall to maize yield productivity was a non-linear function which is built based on maize yield under different tillage systems over nine seasons at Makoholi Contill site from Munodawafa (2012:5). The relation between rainfall and resulting yield productivity is captured in Figure 4.17 and is tabulated in Table 4.6.

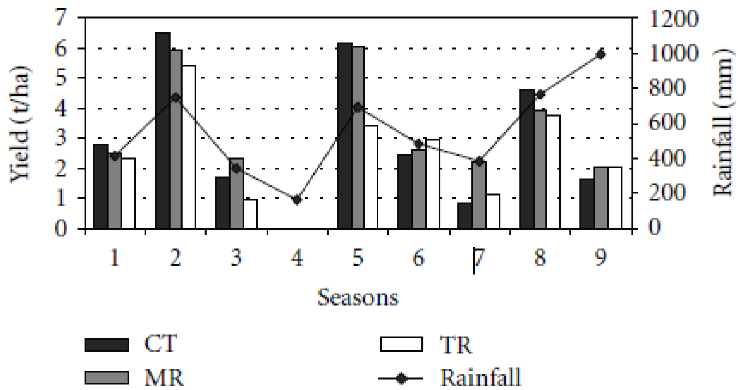

Figure 4.17. Maize under Different Tillage System in Zimbabwe

Source: Munodawafa (2012)

The graph above was translated into tabulated data in Table 4.6.

Table 4.6. Relation between Rainfall and Maize Yield Productivity

Rainfall (mm)	Yield (t/ha)				Rainfall-Yield Productivity plot	Percentage of yield productivity (compared to 7 t/ha*)
	Yield 1	Yield 2	Yield 2	Average		
200	0	0	0	0.00	0.00	0.00
350	1.7	2.4	1	1.70	1.70	0.24
400	2.8	2.5	2.3	2.53	1.93	0.28
400	0.8	2.2	1	1.33	1.93	0.28
500	2.4	2.6	2.9	2.63	2.63	0.38
750	6.6	6	5.5	6.03	5.60	0.80
750	6.1	6	3.4	5.17	5.60	0.80
770	4.6	4	3.8	4.13	4.13	0.59
1000	1.6	2	2	1.87	1.87	0.27

* The 7 tons/ha which was used as yield productivity comparative was the level when fertilizer was used extensively in the farm.

Critchley, Siegert, and Chapman (1991) also supported findings in Munodawafa (2012) that the need of maize crop of rainfall is approximately 500-800 mm/total growing period. By combining that information, 800 mm/year is used as point for getting 0.8 productivity level. The 7 tons/ha which was used as yield productivity comparative was the level when fertilizer was used extensively in the farm.

7. Percentage of farm with maize

This variable was measured based on four years research on average area under maize from Nyanga and Johnsen (2010). The percentage was calculated by:

$$Percentage\ of\ farm\ with\ maize = \frac{average\ area\ under\ maize\ in\ four\ years}{average farmers'area}$$
$$= \frac{average\ (1.66; 1.58; 1.59; 2.07)}{2.1} = 0.82$$

The calculation results 82% of farm was under maize cultivation.

8. Effect of investment in tools to type of farming practice

Availability of tools influenced how farmers conducted their farm (e.g., increase in ripper availability made farmers create ripping lines instead of basin) because using tools was labor saving practice. This variable was measured by analyzing minimum tools available for each farming practice with the percentage of the farming method being practiced.

For calculating the effect of ripping and oxen availability, the minimum number between ripper and trained oxen was taken and used as independent variable for ripping adoption in CA practice. As availability of ripper and oxen was the only variable used to predict ripping adoption, regression analysis was used to obtain the formula. The number of ripper/farmer and trained oxen /farmer were obtained from Nyanga and Johnsen (2010). Those numbers needed to be converted to number of ripper/hectare and number of trained oxen/hectare which was calculated by dividing the number with average area per farmer:

$$Tools/hectare = {}^{tools/farmer}\!\big/_{average\ area/farmer} = {}^{tools/farmer}\!\big/_{2.1\ hectare}$$

While percentage of ripping area was calculated based on the data of ripping area and basin area in Nyanga and Johnsen (2010).

Table 4.7. Information Related to Ripping

Year	**2006/2007**	**2007/2008**	**2008/2009**	**2009/2010**
Trained oxen/hectare	0.471	0.524	0.752	0.795
Ripper/ hectare	**0.019**	**0.029***	**0.043**	**0.076**
Ripping area/farmer	0.04	0.11	0.14	0.26
Basin area per farmer	0.19	0.31	0.28	0.31
Percentage of ripping area/farmer	**0.17**	**0.26**	**0.33**	**0.46**

*: estimated

The comparative assessment between the number of trained oxen/farmer and ripper/farmers resulted to the number of ripper was always the minimum number among both and the calculation of percentage ripping resulted to percentage of ripping area/farmer in Table 4.8. Using calculation in Microsoft Excel (Microsoft, 2010), the formula that showed the relation between ripper/farmer to percentage of ripping area/farmer and had best accuracy was obtained:

$$Percentage\ of\ ripping\ area\ /farmer = 0.2014 \times \ln(\max(trained\ oxen/farmer, ripper/farmer)) + 0.9731$$

The same calculation was conducted for conventional agriculture practice:

Table 4.8. Information Related to Ploughing

Year	2006/2007	2007/2008	2008/2009	2009/2010
Trained oxen/farmer	0.471	0.524	0.752	0.795
Plough/ farmer	**0.31**	**0.32***	**0.34**	**0.36**
Ploughed area/farmer	0.04	0.11	0.14	0.26
Han hoe area/ farmer	0.19	0.31	0.28	0.31
Percentage of ploughing area/farmer	**0.17**	**0.26**	**0.33**	**0.46**

*: estimated

The comparative assessment between the number of trained oxen/farmer and plough/farmers resulted to the number of plough was the minimum number among both and the calculation of percentage ploughed area resulted to percentage of ploughed area/farmer in Table 4.9. Using calculation in Microsoft Excel (Microsoft, 2010), the formula that showed the relation between plough/farmer to percentage of ploughed area/farmer and had the best accuracy was obtained:

$$Percentage\ of\ ploughed\ area\ /farmer = 0.5608 \times \ln(\max(trained\ oxen/farmer, plough/farmer)) + 0.927$$

Input and special calculation for model construction are listed in Table 4.9.

Table 4.9. Input and Calculation for Model Construction

Variable	Definition	Unit	Value	Source
Area under CA	Area under basin or ripping practice while CV is area under hand-hoe or plough practice	Hectare	30,187.50; 46,183.46; 76,196.45; 86,814.00	Calculated based on Haggblade and Tembo (2003a); MFA (2011); Nyanga (2012b); Nyanga and Johnsen (2010)

Variable	Definition	Unit	Value	Source
New farmer	Number of new farmer in the project each year	Farmer/ year	120,000.00; 133,000.00; 146,000.00; 159,000.00	Calculated based on MFA (2011); Nyanga (2012b); Nyanga and Johnsen (2010)
Average area/farmer	Average cultivated area of farmers	Hectare/ farmer	2.1	Calculated based on Nyanga and Johnsen (2010)
Rainfall Intensity	Current average rainfall intensity n surveyed area	Mm/year	878.83	Calculated based on Umar et al. (2011)
Effect of rainfall to maize yield productivity	Percentage of yield productivity from given rainfall intensity			Calculated based on Munodawafa (2012)
Percentage of farms with maize	Percentage of farmers' farm area under maize cultivation	%	82	Calculated based on Nyanga and Johnsen (2010)
Effect of tool to agriculture practice adoption	The increase or decrease of farming practice adoption for any increase or decrease of tools ownership			Calculated based on Nyanga and Johnsen (2010)
Average days to start planting	Average days gap from planting using CA practice and CV practice	day	8.5	Calculated based on Nyanga and Johnsen (2010)
Average training/farmer/ year	Average farmers' participation in training	Training/ year	1.15; 2.67; 2.37; 2.59	Nyanga and Johnsen (2010)
Hired labor cost for hand hoe, ploughing, basin, and ripping	Hired workforce wage for hand-hoe practice	ZMK/year/ hectare	158649; 153261; 279764; 99685	Calculated based on Umar et al. (2012)
Input cost for hand hoe, ploughing, basin, and ripping	Input price for hand-hoe practice	ZMK/year/ hectare	665505; 1,314,980; 662336; 1,459,130	Calculated based on Umar et al. (2012)
Crop Price	Current crop price in the market	ZMK/kg	900	Umar et al. (2012)

CHAPTER 5
MODEL ANALYSIS, VALIDATION, AND POLICY ANALYSIS

This section discusses the base run result and several validation tests of the model. Initial time of simulation model runs was 2005 to 2016 yet the historical data about conservation agriculture was only existed since period 2006/2007 to 2009/2010 therefore the comparative assessment between simulation and data was conducted between 2007 and 2010. The simulation period after 2010 enables to study the progress of conservation agriculture diffusion among farmers in Zambia.

5.1 BASE RUN

The comparative graph between simulation and data is shown in Figure 5.1. The area under Conservation Agriculture shows the total area under CA practice under CAP project for the whole farmers under CAP project. This variable was measured in hectare. As one can see in Figure 5.1, the simulation can follow the increase of CA adopters although it is still unable to capture the slight change in the behavior. The quantitative assessment of simulation behavior compared to data is shown in sub-Chapter 5.2.3 Behavior Pattern Test.

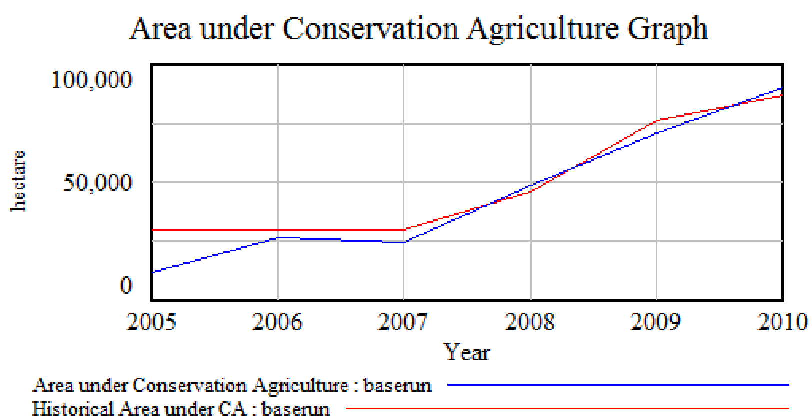

Figure 5.1. Comparative between Simulation and Historical Data

The slightly lower increase of CA adopters between 2009 and 2010 is not captured in the model. Based on historical data, the input packages, which were their major reason to practice conservation agriculture, consisted of four different types: subsidized inputs, subsidized maize seed, subsidized chemical fertilizer, and access to credit (Nyanga & Johnsen, 2010). Each of those types changed over time, and it was not clear the specific number of farmers who received each type of input package. There was no similar behavior as well between CA adopters and any input packages. Therefore input package in the model was simplified into subsidized input which is shown by the discount for buying input packages.

Figure 5.2 shows that between trust and comparative attractiveness between CV and CA, since trust in CA had small number, comparative attractiveness is the variable that governs the adoption process at the moment. This result also confirmed the documents analysis' outcome that during 2006-2010 the farmers had low trust on CA which is shown by low adoption despite of higher yield productivity and lower implementation cost.

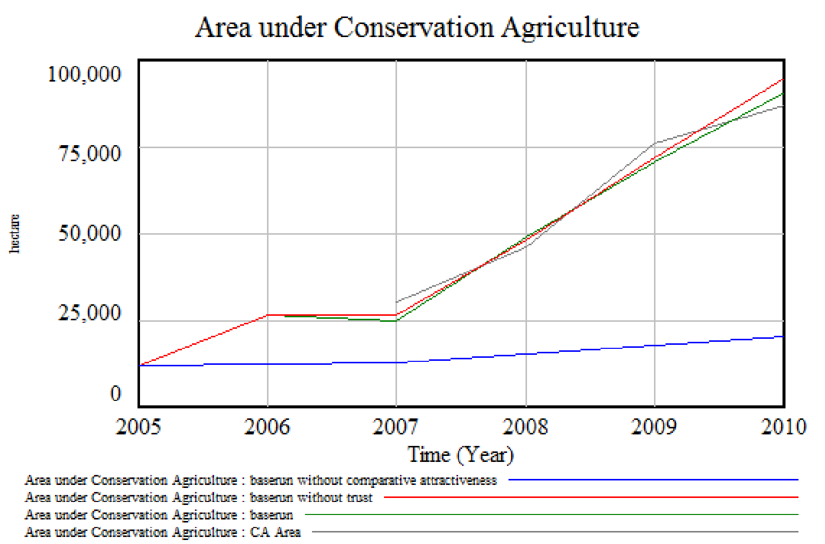

Figure 5.2. Comparative Graph with and without Influence Variable of Adoption Rate

Although trust was not significant in governing the adoption process during 2006-2010, the adoption process cannot depend entirely on comparative attractiveness as farmers' perceived assessment on labor, cost, and yield productivity was built on bounded rationality means the decision making was limited by their current knowledge. The limitedness of knowledge and time that farmers had made them using their rationality to choose the available choice. In CA adoption and diffusion issue, they chose ploughing instead of basin or ripping because they got used to it. The custom of ploughing farm area made the family labor trained to plough without any necessary help from hired labor. The minimization of workforce from family labor and hired labor was preferable for farmers as was supported by their willingness to save time in farming practice.

This result also shows the need of increasing trust so the adoption process does not depend entirely on the input packages. By increasing the level of trust in CA, without any significant input packages adoption process is expected to happen continuously.

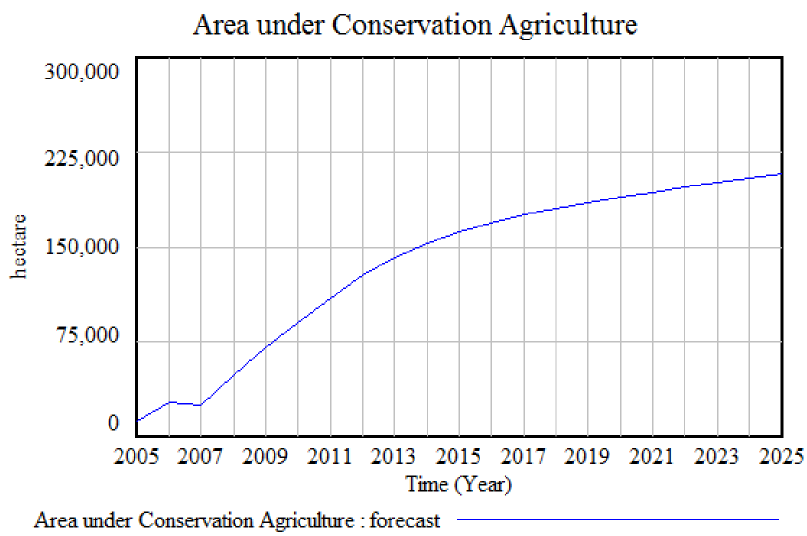

Figure 5.3. Forecast of Conservation Agriculture Area

Figure 5.3 shows forecast result of CA adopters' area. This forecast shows that if current situation (e.g., input packages, prices, and number of training) continuously happen in the future, CA adopters will still increase. The increase will be caused not only by quite similar level of comparative assessment as current condition but also higher level of CA trust although comparative assessment will still become major factor in CA adoption.

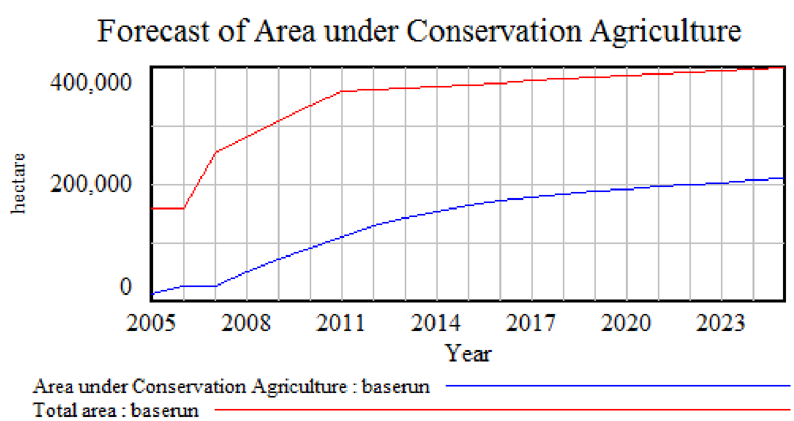

Figure 5.4. Forecast of Total Area and Area under Conservation Agriculture

The initial simulation behavior forms s-shaped growth as the result of fraction of total area in CAP (Figure 5.4). The formation of goal-seeking behavior after s-shaped growth is also the result of total area' fraction. In the reality, area under CA always increases as the project recruits new farmers. Those new farmers will implement CA in the small fraction of their farm as the requirement to receive incentives. That occurrence has been captured in the model.

This forecast's result has two meanings. First there is still quite high possibility to increase the number of CA adopter in the long period of time. Second, nevertheless the increase in CA adopters will still be governed by comparative assessment that shows CA will still be more favorable than CV yet that comparative assessment is supported by input packages which is highly depend on aid project. This result makes a good reason to increase CA trust in the future.

5.2 VALIDATION

This sub-chapter explains about validation tests that were conducted to increase confidence in the model. There are three steps of validation being conducted: direct structure test, structure-oriented test, and behavior pattern test.

5.2.1 DIRECT STRUCTURE TEST

In direct structure test, structure of the model was examined including the equation in each of the variable. The structure was examined by comparing model structure with the condition in real system. The parameters in the model were also examined and compared with realities. The equation in each of variable was checked and analyzed whether the equation reflected the realities.

The structure of the model was built based on expert interview and documents analysis. The explanation from documents was gathered and those which have similar explanation were collected into one influencing factor. The influence factor was built into structure and the structure was confirmed as well through expert interview. The structure-confirmation test was also conducted by expert of system dynamics model in agriculture practice.

Another of the tests for this validation stage test was *dimensional consistency test*. Dimensional consistency was tested using unit check in Vensim (Ventana System, 2013). The unit check reported that the model's dimension was consistent means every combination of dimension in the right side of equation is consistent with the left size of the equation.

Another direct structure test was parameter-confirmation test which examines the existence of variables used in the model with real world condition. All the parameter has been checked and also confirmed by the expert.

One last direct structure test was extreme condition test; this test checked whether the flows direct to the right direction. Based on structure examination, all flows direct to desired stock and also based on the same verification, all flow will not go negative.

5.2.2 STRUCTURE-ORIENTED BEHAVIOR TEST

There were two validation test conducted to the model: extreme validation test and parameter sensitivity test. This sub-chapter explained the result of each test.

1. *Extreme condition test*

Extreme condition test was conducted by analyzing behavior of the model under extreme condition using simulation. The inputs of the model were changed into extreme level and the behavior was captured to analyze whether there was any flaws in the behavior. The first extreme condition test was made by changing the values of utility elasticity into extreme condition. Extreme high means the value had more positive value while extreme low means the value had more negative value.

Table 5.1. Utility Elasticity Values for Extreme Condition Test

Utility Elasticity Value	Initial	Extreme high	Extreme low
Yield	0.000185	0.01	0.00000185
Labor Requirement	-0.32	-0.00032	-0.9
Cost	-0.0000022	-0.000000022	-0.00009

The result of the extreme test on utility elasticity is captured in Figure 5.5. The extreme condition test results that the model still behaved normally under any extreme condition of utility elasticity, what differs between each value was only the development of number of adopters. There is several lines overlapping the other such as the result of the test for yield in extreme high overlaps the result of the test for cost in extreme low, the result of the test for the labor and yield in extreme low condition overlaps the cost in extreme high condition.

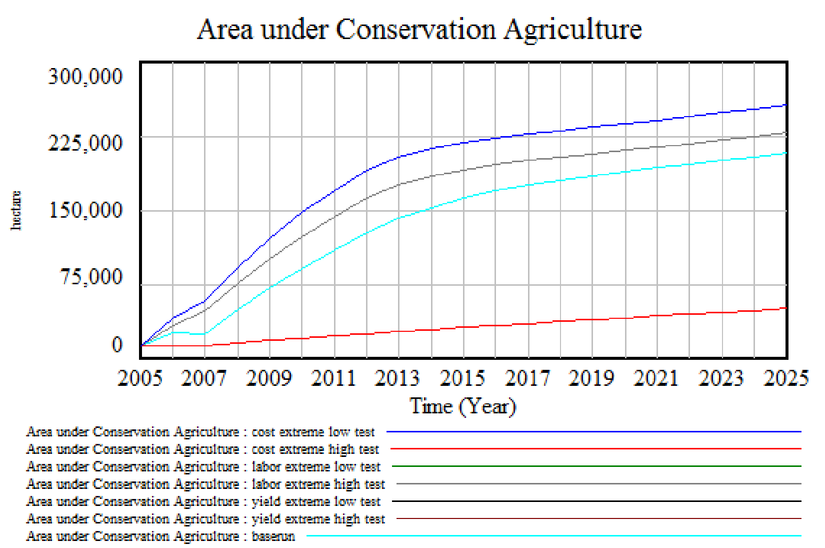

Figure 5.5. Extreme Condition Test on Utility Elasticity Values Result

Current initial value of utility elasticity represents the importance of each variable. This test results shows that when the value of utility elasticity cost become very low (-0.00009) or the value of utility elasticity yield become really high (0.01) the number of adopters will increase and since the results of both extreme changes have same value, on that changes of both variable, the level of importance of cost and yield become in the same level. The same thing was occurred when the value of utility elasticity labor is really low (-0.9), the value of elasticity yield is very low (0.00000185), and the value of utility elasticity cost become extremely high (-0.000000022). On the changes of those values, the adopter numbers is really low and on the same level which means on those changes the three variables are seen as in same importance level for deciding which agricultural practice will be chosen for the farm.

This test shows that extreme change in crop price will also derive different adoption result; the extremely low crop price will produce much higher adopters while extremely high crop price will lead to much lower adopters. This happen because on an extremely high price condition adoption rate is highly depend on trust of CA and on that condition comparative attractiveness does not have any effect on CA adoption rate. While on the condition where crop price is extremely low, adoption rate is governed by both comparative attractiveness and trust in CA.

The second extreme condition test was made on change in prices including tools price and crop price. The changes can be seen in Table 5.2.

Table 5.2. Tools Price for Extreme Condition Test

Price	Initial Value	Extreme high	Extreme low
Plough	600,000	60,000,000	1
Oxen	900,000	90,000,000	1
Ripper	400,000	40,000,000	1
Crop	900	90,000	310

The result of this extreme condition test is captured in Figure 5.6. The result of this extreme condition also shows normal behavior even on the condition where the prices were 100 times current price and the prices values 1 ZMK. This result shows that the change in prices does not mean the number of adopter would significantly increase or decrease because the presence of labor limitation restrains the over-adoption or over-discharge of CA practice.

Although there is no flaws produced in the resulting behavior of this extreme condition test, change in crop price produces extremely different number of adopters as a result of extremely high and low price. The extremely high crop price results to lowest adopters among all result. This happens as the effect of high profit of implementing CA which is used for buying more tools yet tools usage actually decreases the effectiveness of CA which leads to lower yield production and therefore lower CA trust. The same effect also happens when the price of ripper is really low thus easing the ownership of ripper among farmers.

On the contrary, the extremely low crop price condition creates a condition when both trust and comparative attractiveness govern CA adoption rate. The low price of crop creates ripper scarcity (as the effect of low profit) therefore ensures the level of CA yield productivity and makes the trust level became higher. While on the same time the scarcity of tools (ripper, ploughs, and trained oxen) makes farmers highly depend on practices without tools (basin and hand hoe practice). The comparative assessment between hired basins-labor and hired hand hoe-labor together with comparative assessment between basin yield productivity and hand hoe basin productivity produces much higher comparative attractiveness for CA than the base run.

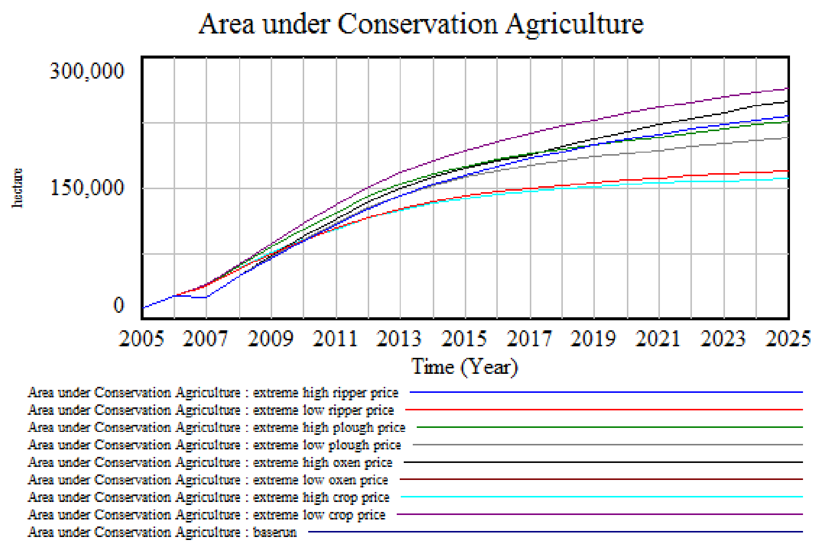

Figure 5.6. Extreme Condition Test on Tools Price Result

The third extreme condition test evaluates CA adopter under condition without trust or without comparative attractiveness (Figure 5.7). Condition without trust is divided into two states which are adoption without CV trust and CA trust and adoption without CA trust. The adoption without CV and CA trust means trust does not exist in governing adoption and discharge rate. Meanwhile the adoption without CA trust means trust in CV governs the discharge rate of CA adoption but CA trust does not influence the adoption process thus makes the adoption process of CA is governed only by comparative attractiveness of two farming practices.

This test result shows that if both trusts do not influence adoption and discharge process, the adoption is higher than current condition while when CV trust affects discharge process but CA trust does not influence adoption process, the number of CA adopters is lower than current condition. This result also shows that comparative assessment highly affects adoption process as adoption process without comparative assessment variable (only trusts governed the adoption and discharge process) produces really low number of adopters.

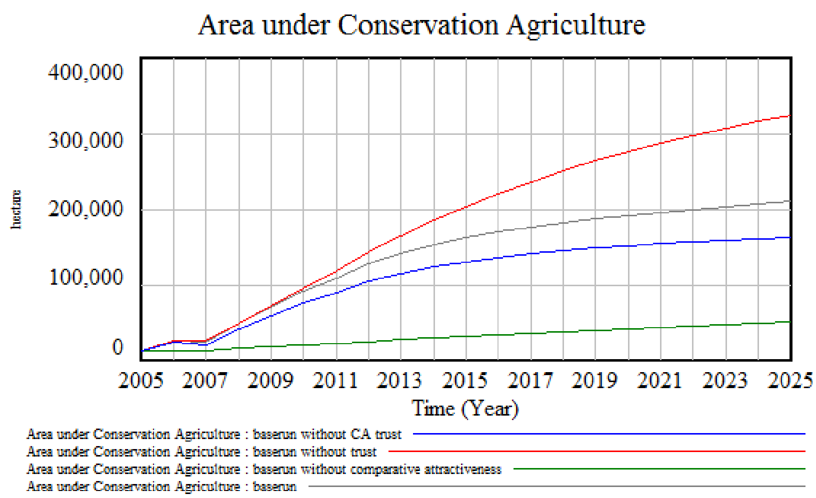

Figure 5.7. Extreme Condition Test on Influences Factors of Adoption & Discharge Rate

2. *Parameter Sensitivity Test*

The second structure-oriented behavior validation test is parameter sensitivity test. Parameter sensitivity test checks the spread of result in the case parameter changes. The result of parameter sensitivity test shows the confidence bounds of parameter changes. Parameter sensitivity test is conducted by changing the value of uncontrollable input variables or estimated variables. In this study, uncontrollable input and estimated variables are yield utility elasticity, labor requirement utility elasticity, cost utility elasticity, weight of trust for adoption and discharge rate, weight of comparative attractiveness, weight of CA tools ownership, initial area under conservation agriculture, plough price, oxen price, ripper price, investment for plough, investment for ripper, and rainfall intensity

In this study, parameter sensitivity test examines the changes of area under Conservation Agriculture under changes of mentioned variable. The test uses possible range of variable and captures the range of resulting CA area.

All sensitivity analysis in this study uses random uniform distribution since there are no indications of other type of distribution. Minimum and maximum value is used for sensitivity analysis as one can see in Table 5.3.

Table 5.3. Values for Sensitivity Analysis

Variable	Initial Value	Value for Sensitivity Analysis	
		Minimal	Maximal
Yield utility elasticity	0.000185	0.0000925	0.00037
Labor requirement utility elasticity	-0.032	-0.064	-0.016
Cost utility elasticity	-0.0000022	-0.0000044	-0.0000011
Weight of trust for adoption & discharge rate	0.5	0	1

Variable	Initial Value	Value for Sensitivity Analysis	
		Minimal	Maximal
Weight of comparative attractiveness	0.38	0	1
Weight of CA tools ownership	0.1	0	1
Initial CA area	12,000	4,725	30,180
Plough price	600,000	300,000	1,200,000
Oxen price	900,000	450,000	1,800,000
Ripper price	400,000	200,000	1,000,000
Plough Investment	0.4	0	1
Ripper Investment	0.05	0	1
Rainfall Intensity	878.83	500	1300

The ranges of utility elasticity values are determined by halving (x0.5) and doubling (x2) the initial value. The weight variables ranges are made from 0 to 1 because that was the possible value for weight variable. The initial CA area range is stipulated based on cultivated area under CA calculation on sub-Chapter 4.3 Model Calibration while the ranges of price are made by halving (x0.5) and doubling (x2) the initial value. Plough investment and ripper investment range value are fixed from 0 to 1 since 0% to 100% is the minimum and maximum limit of any investment. Lastly, rainfall intensity is estimated based on possibilities of change in intensity of rainfall as the effect of climate change.

Sensitivity analyses of 10 variables are captured in Figure 5.8 to Figure 5.17. On general, the result shows that on 50% of the sensitivity simulation, the area under conservation agriculture lays on 50% of area (yellow area); on 75% of the simulation, the area under CA lays within 75% of area (yellow and green area); on 95% of the simulation, area under CA lays within 95% of the simulation result (yellow, green, and blue area); on 100% of the simulation, the area under CA lays within 100% of area (all colored area). Sensitivity test result shows how the focused behavior will change if there is any change or any different on the actual value of tested variable.

The first sensitivity test result is captured in Figure 5.8, Figure 5.9, and Figure 5.10. These figures capture sensitivity test results on the change of three utility elasticity variables. As one can see in those figures, area under CA is highly sensitive to changes in cost utility elasticity. This is shown by the widest range of possibility for area under CA practice. Both cost utility elasticity and yield utility elasticity produce wider range of area under CA on later years while yield utility creates more focused range of area under CA. This result means on later simulation period, the area under CA is highly sensitive on changes of cost utility elasticity and labor utility elasticity while on the other hand CA adopters are less sensitive to different value of yield utility.

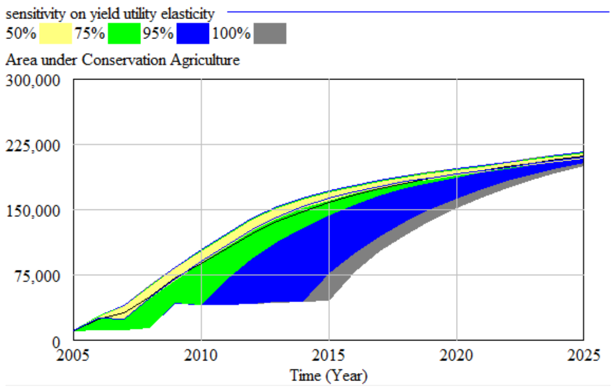

Figure 5.8. Sensitivity Test Result on Yield Utility Elasticity

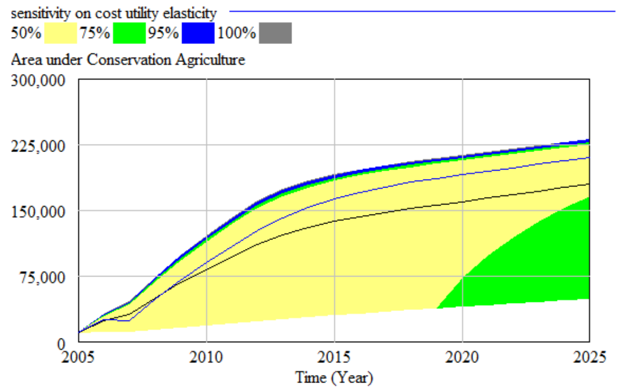

Figure 5.9. Sensitivity Test Result on Cost Utility Elasticity

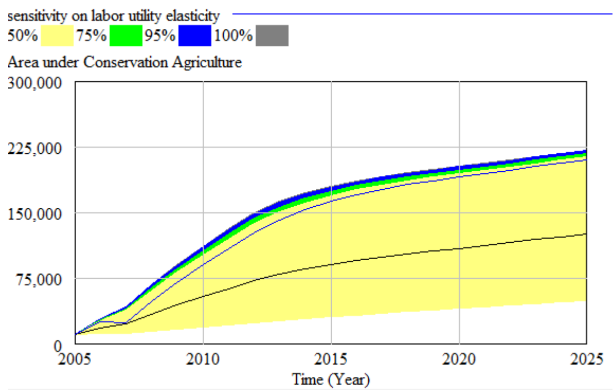

Figure 5.10. Sensitivity Test Result on Labor Utility Elasticity

The second part of sensitivity test in this study was conducted on weight of trust for adoption and discharge rate and weight of comparative assessment (Figure 5.11 and Figure 5.12). In this parameter sensitivity test trust for adoption and discharge are assumed to have similar weight which means both adoption process is affected by the level of trust in CA and discharge process is affected by the level of trust in CV; those processes were affected by the same weight of trust.

In Figure 5.11, one can see that in the beginning of simulation period (2005 to 2010) area under CA is not sensitive to any change in weight trust; however on later simulation period area under CA is quite highly affected by changes of weight trust value. This happens because on the early period of simulation, the trust level is very low therefore there will not be any significant changes in adoption rate (and therefore area under CA). However, level of trust in CA increases after 2010 that makes any change on trust level will produce significant changes in CA adoption.

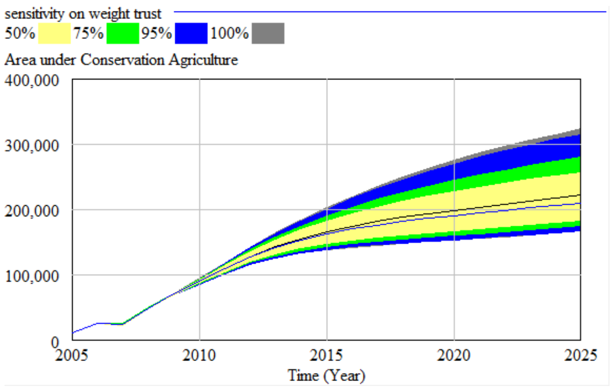

Figure 5.11. Sensitivity Test Result on Weight Trust

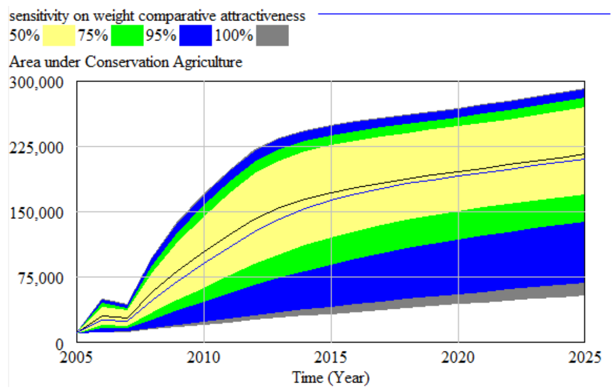

Figure 5.12. Sensitivity Test Result on Weight of Comparative Attractiveness

Figure 5.12 shows that the result of simulation for CA adopters will be highly affected by any value alteration in weight of comparative attractiveness. The CA adopters' value sensitivity is increase especially during 2007 until 2013. Besides showing sensitivity of the number of CA adopters by any modification in weight comparative attractiveness, this result also shows that on the early period of simulation the number of adopters is highly affected by comparative attractiveness therefore any shift on its weight will change the number of adopter.

As one can see also in Figure 5.12 that the highlight area after 2013 for any change in CA area is rather similar while the highlight area in Figure 5.11 still grows bigger, this means that after 2013 as the addition of comparative attractiveness, the number of CA adopters will also highly depend on the value of trust in CA.

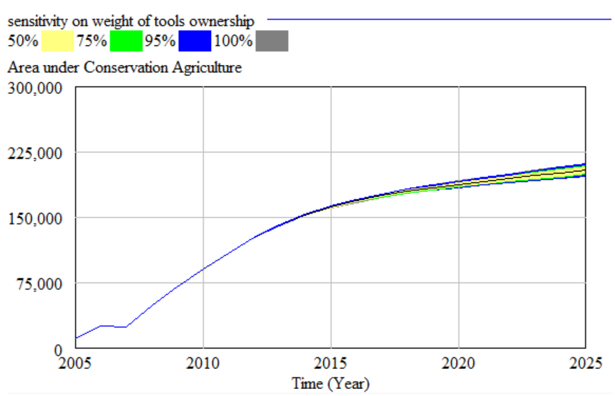

Figure 5.13. Sensitivity Test Result on Weight of CA Tools Ownership

Figure 5.13 shows any change on CA adopters as a result of different value of weight of CA tools ownership. This variable directly affects trust in CA outflow which means the higher value of this weight of high ownership of CA tools will lead to bigger decrease of trust in CA compared to the situation when the weight value does not change. However, this variable does not seem to significantly affecting area under CA in any change between 0 and 1. The only change detected only happens in the later period of simulation (after 2015) yet that is a minor change in the behavior. Therefore conclusion can be made that area under CA is not sensitive to any alteration in the weight of CA tools ownership.

The next sensitivity test was made for testing the changes in area under CA practice in any change of initial value of CA area. The result in Figure 5.14 shows that the modification of CA area create small range of possible behavior in the beginning of simulation period yet it does not produce any significant change on CA adopters' behavior in later simulation period. This result means that area under CA is not highly sensitive to any modification of initial value. It has range of possible behavior in the beginning indeed yet that is only small differences with current situation.

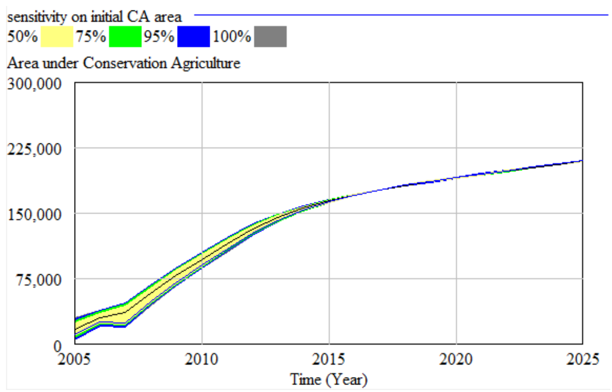

Figure 5.14. Sensitivity Test Result on Initial CA Area

Figure 5.15, Figure 5.16, and Figure 5.17 show sensitivity test result for changes in price. One of the interesting results is shown in Figure 5.16 that shows sensitivity test result in any alteration of price of oxen. This result shows no change happens if oxen price is modified. This is reasonable as the availability of oxen is plenty, oxen is never used as decision factor of practicing CA or CV so any change of oxen price will not give significant shift on current CA area.

In Figure 5.15, one can see that the change on plough price produces really small change on plough price during simulation period. This means that area under CA is not sensitive to the alteration on plough price. As can be seen also in Figure 5.15, the change of CA even becomes smaller as the effect plough price change. Different with sensitivity result of change in ripper price, in the beginning of simulation period there is only small range of possible behavior detected while in the later period of simulation, there is wider change of behavior means that CA area is more sensitive to change in ripper price in later period of simulation.

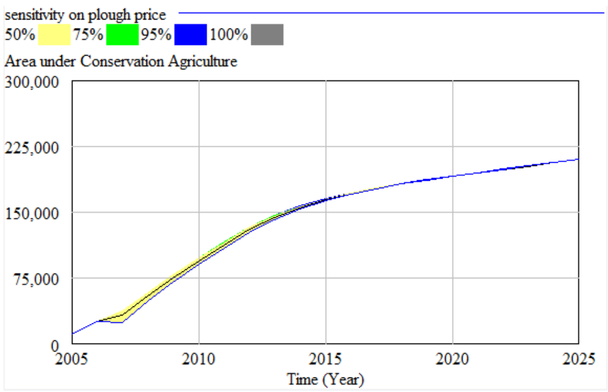

Figure 5.15. Sensitivity Test Result on Plough Price

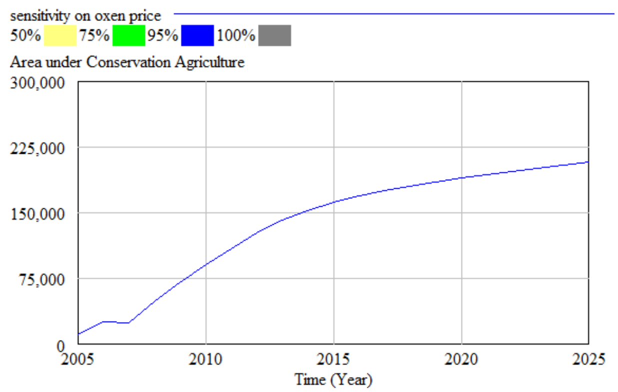

Figure 5.16. Sensitivity Test Result on Oxen Price

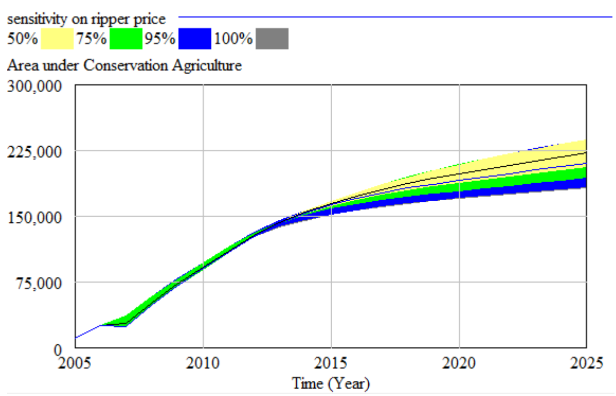

Figure 5.17. Sensitivity Test Result on Ripper Price

Figure 5.18 and Figure 5.19 show any change in the behavior of area under CA in any change of percentage of investment for plough and ripper. Apparently based on test result, the shift in plough price does not produce any extreme change on area under CA means CA adopters behavior does not highly affected by the change of CA price.

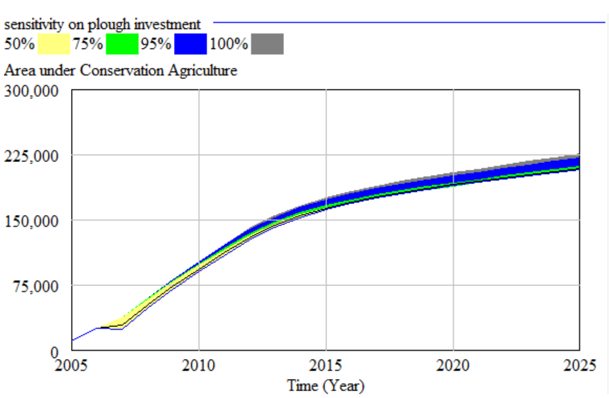

Figure 5.18. Sensitivity Test Result on Percentage Investment for Plough

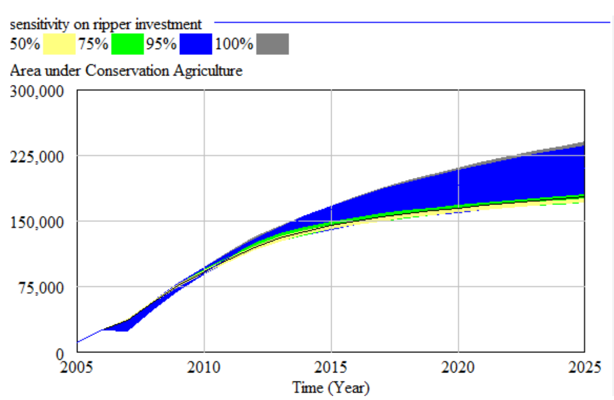

Figure 5.19. Sensitivity Test Result on Percentage Investment for Ripper

Quite different result is shown in Figure 5.19. That shows that in later period of simulation CA adopter shows fairly sensitive behavior in the different of ripper price. This happens because in the early simulation period, there are only a few ripper available so any change will not give significant effect on CA adoption however the number of ripper available among farmers continuously rises by buying new ripper therefore in the latter period the change of ripper price will affect the ownership of ripper among farmer thus consequently affect CA adoption.

The last sensitivity test was made on rainfall intensity. Figure 5.20 shows that in early period of simulation there is no significant effect on CA adopters by shift on rainfall value yet big range of possible CA adopters behavior is shown after year 2012. This behavior happens as rainfall affect trust in CA and after 2012 CA rainfall has significant effect on adoption rate. The number of CA adopters becomes more sensitive to the change of rainfall as the effect of trust in CA increases.

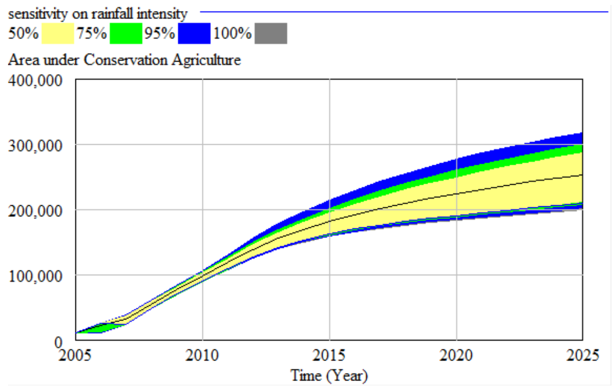

Figure 5.20. Sensitivity Test Result on Rainfall Intensity

5.2.3 Behavior Pattern Test

Behavior pattern of this research is tested using Theil's Inequality Coefficient. The historical data and model result are shown in Table 5.4.

Table 5.4. Simulation Result and Historical Data

Year	Historical Data	Simulation result
2007	30,187.50	25,700.00
2008	46,183.46	49,900.00
2009	76,196.45	72,100.00
2010	86,814.00	92,000.00

For calculating Theil's Inequality Coefficient, several calculation based on result on Table 5.4 was needed. The components are:

Table 5.5. Components for Theil's Inequality Coefficient Calculation

Year	Historical Data	Simulation result	Deviation	Deviation Square	$A_t - \bar{A}$	$S_t - \bar{S}$	$(S_t - \bar{S}) \times (A_t - \bar{A})$
2007	30,187.50	24,700.00	-5,487.50	30,112,656.25	-29,657.85	-34,000.00	1,008,366,985.00
2008	46,183.46	48,900.00	2,716.54	7,379,589.57	-13,661.89	-9,800.00	133,886,546.50
2009	76,196.45	70,700.00	-5,496.45	30,210,962.60	16,351.10	12,000.00	196,213,170.00

Year	Historical Data	Simulation result	Deviation	Deviation Square	$A_t - \bar{A}$	$S_t - \bar{S}$	$(S_t - \bar{S}) \times (A_t - \bar{A})$
2010	86,814.00	90,500.00	3,686.00	13,586,596.00	26,968.65	31,800.00	857,602,990.50
Sum				81,289,804.42			2,196,069,692.00
Average	59,845.35	58,700.00					
Standard Deviation	22,698.58	24,532.02					

To calculate Theil's Inequality Coefficient, MSE has to be calculated. MSE formula is:

$$MSE = \frac{1}{n}\sum(X_m - X_d)^2$$

$$MSE = \frac{1}{4} \times 81{,}289{,}804.42 \quad = 20{,}322{,}451.11$$

Using Theil's Inequality Coefficient formula:

Bias (U^M)

$$U^M = \frac{(\bar{S} - \bar{A})^2}{MSE} = \frac{(58{,}700.00 - 59{,}845.35)^2}{20{,}322{,}451.11} = 0.06$$

Unequal variation (U^S)

$$U^S = \frac{(S_S - S_A)^2}{MSE} = \frac{(24{,}532.02 \ - 22{,}698.58)^2}{20{,}322{,}451.11} = 0.17$$

Unequal co-variation (U^C)

$$r = \frac{\frac{1}{n}\sum(S_t - \bar{S}) \times (A_t - \bar{A})}{S_S \times S_A} = \frac{\frac{1}{4} \times 2{,}196{,}069{,}692.00}{24{,}532{,}02 \times 22{,}698.58} = 0.98$$

$$U^C = \frac{2 \times (1 - r) \times S_S \times S_A}{MSE} = \frac{2 \times (1 - 0.98) \times 24{,}532{,}02 \times 22{,}698.58}{20{,}322{,}451.11} = 0.77$$

Value of r^2 of the simulation result was also calculated:

$$r = \frac{\sum(S_t - \bar{S})(A_t - \bar{A})}{\sqrt{\sum(S_t - \bar{S})^2 \sum(A_t - \bar{A})^2}} = 0.985$$

$$r^2 = 0.98^2 = 0.971$$

Behavior pattern tests are summarized in

Table 5.6. Summary of Behavior Pattern Tests

U^M	U^S	U^C	R^2
0.06	0.17	0.77	0.97

Based on assessment on model behavior compared to historical data U^M, U^S, U^C, and r^2 are obtained. Theil's statistics (U^M, U^S, and U^C) is used to characterize the source of error. Ideal error should be small and unsystematic which is characterized by concentration in U^C (Sterman, 2000: 877) which implies U^M and U^S are better when their values are closer to 0 while U^C is better when its value is closer to 1. R^2 is uses to measure the fraction of variance in the data explained in the model, a 'good' model will have r^2 value of 1.

From Thiel's statistics assessment of this model, U^M and U^S's value are closer to 0 with 0.06 and 0.17 respectively while U^C's value is closer to 1 with 0.77. U^M value of 0.06 shows that there is relatively small systematic error detected in simulation model and the bias can be corrected by parameter adjustment (Sterman, 2000) yet the bias is not really significant. U^S value of 0.17 shows that there is little tendency that simulation result produce different trend compared to historical data but this is not a really significant different thus the bias can be accepted. U^C's value of 0.77 means that there is unsystematic error in the model result, good result should have unsystematic error which is shown by U^C's value of 1 since model U^C is closer to one so this result can be accepted.

However, the time limitation of historical data of conservation agriculture adoption makes behavior validation cannot be the only parameter of model's quality yet all validation tests have been examined on the model and the model does not have any indication to have flaws in it.

5.3 POLICY SUGGESTION

This sub-chapter explains about any scenario in the model and for each scenario possible policies are explored to find the best policy for each scenario. The scenarios are:

1. Base scenario. Base scenario is the condition when there is no change in the system. This scenario is important since there is no obvious change will happen in the system. This scenario explores leverage point for creating sustainable adoption means adoption will continue in the same level even without any additional input package.
2. Change in crop price. Change in crop price is divided into two scenarios: increase in crop price and decrease in crop price. This scenario is important since based on extreme condition test in sub-Chapter 5.2.2 Structure-oriented Behavior Test, the change in crop price can govern the CA adopter to the maximum and minimum adoption compared to the changes in tools price.
3. Change in rainfall intensity. Change in rainfall intensity is divided into two scenarios: increase in rainfall intensity and decrease in rainfall intensity. This scenario important since sub-Saharan Africa is highly affected by climate change and currently the effect of drought and irregularity of rainfall have been felt by farmers (Nyanga et al., 2011). It is clear that

farmers' desired condition is increase in rainfall intensity but the reality does not fulfill that expectation. This scenario tests future condition of CA adoption based on rainfall intensity and attempts to maintain not only adoption rate but also food sufficiency condition.

4. Change in input cost. Change in input price is divided into two scenarios: increase in input cost and decrease in input package. Input price shows the regular price of any input that farmers use in the farm. Due to different amount of input usage in each farming practice, the change in input use is shown as total percentage of price increase or decrease. This scenario tests what will happen in CA adoption process in the change of input price and find leverage point to maintain the adoption rate.
5. Project discontinuation. Project aid is the most important factor of current adoption in Zambia, yet it is an external factor that cannot be controlled and ascertained its continuation. This scenario test what will happen in CA adoption process after the termination of CAP project. The project discontinuance affects training and input package given to the farmers. This instance is assumed to happen in 2020.

All scenarios is implemented starting on 2015 because currently there is no apparent change in Zambia condition since 2010 and CAP project has been continued since 2011 which implies input package is still given to farmers.

5.3.1 SCENARIO SIMULATION

This sub-chapter explains about simulation result of each scenario.

1. Base run

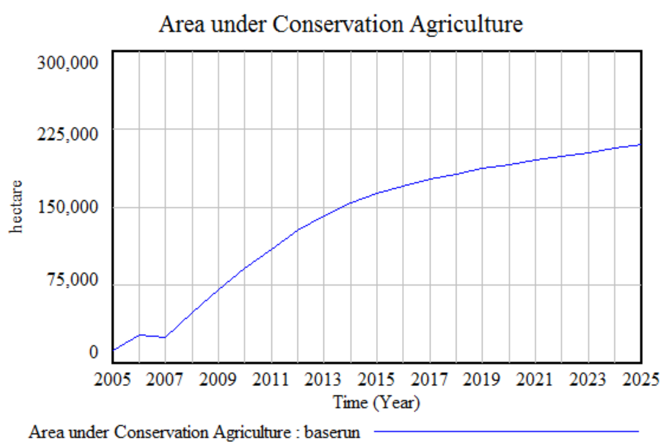

Figure 5.21. Forecast with Base Run Condition

Base run's result shows that with current condition (e.g., same percentage of input package; same prices of crop, ripper, and plough; rainfall intensity) future CA adopters will reach 210,000 hectare. While on the other hand, MFA (2011) targeted 237,000 hectare for CAP Phase II's goal by the end of 2015. Therefore this shows that CAP has to do extensive promotion or find another more effective way for increasing CA adoption among farmers in Zambia.

2. Decrease in crop price from 900 ZMK/kg to 650 ZMK/kg

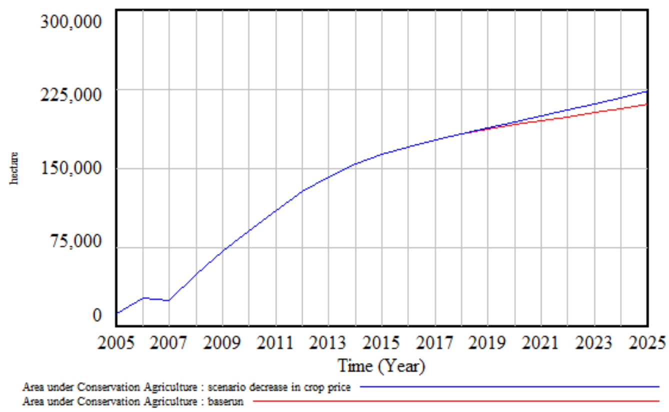

Figure 5.22. Forecast with Decrease in Crop Price Condition

Figure 5.22 shows there will be a slight increase in the area under CA practice if there is a decrease of 150 ZMK/kg in crop price. The decrease of price is undesirable for the farmers as that will decrease their revenue from farming and also limit their abilities to fulfill their daily need besides food. From the reality perspective, this increase of adoption happens as less profit leads to less investment for new tools while fewer tools actually decreases the reduction of CA trust as effect of tools together with increases CA effectiveness and the increase of CA yield productivity leads to the increase of trust. While actually the increase of yield production threaten the sustainability of CA area through the discharge rate of CA after the improvement of food security but this effect is surpassed by increase of CA trust through the higher CA yield ratio and lower reduction in CA trust.

3. Increase in crop price from 900 ZMK/kg to 1150 ZMK/kg

There will be a slight decrease in the number of CA area because of increase in crop price. The increment of crop price leads to the contrary of what happens in the decrease of crop price. In this condition, higher crop price leads to higher profit which enables farmers to invest more on tools that generates higher decrease in CA trust and lower CA effectiveness. Lower CA effectiveness produces less yield productivity which brings lower increase in CA trust. Those together bring lower CA trust and lower yield, which means lower comparative attractiveness, and causes lower adoption rate.

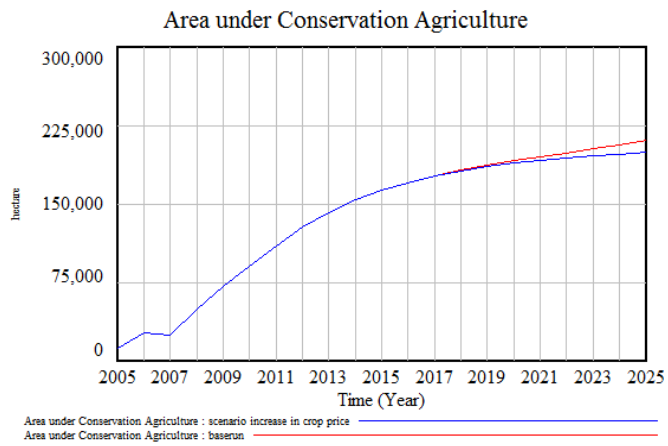

Figure 5.23. Forecast with Increase in Crop Price Condition

4. Decrease in rainfall intensity from 878.83 mm/year to 778.83 mm/year
   As researchers foresee the decrease of rainfall in Zambia should increase CA adoption among farmers. The rainfall scarcity makes farmers need to utilize all possibilities to maximize maize production. In the model, that condition is shown by lower discharge rate by food security condition as the state of food security worsened. Lower rainfall also increase CA yield ratio, as has been predicted by CA researcher in Zambia, which generates higher increase in CA trust thus increase CA adoption.

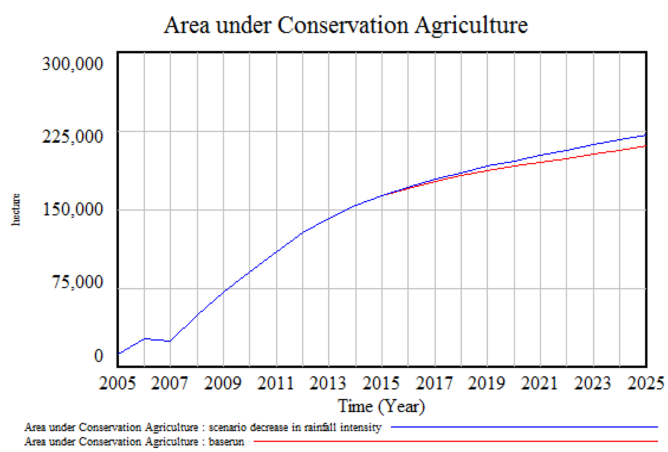

Figure 5.24. Forecast with Decrease in Rainfall Intensity Condition

5. Increase in rainfall intensity from 878.83 mm/year to 1000 mm/year
   As predicted, higher rainfall intensity leads to lower CA adoption. In the condition of abundant rainfall farmers tend to ignore the benefit of early land preparation and early planting from CA practice and that occurrence is shown in this scenario. The relation is shown by higher discharge rate by the improvement of food security. The plentiful of rainfall condition makes maize production increases therefore ensure food supply for the farmers.

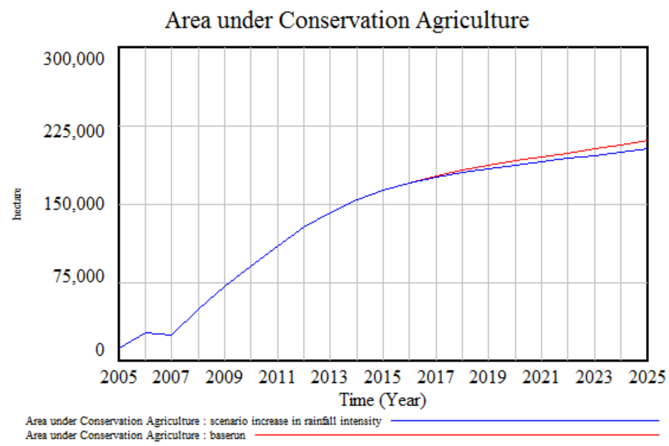

Figure 5.25. Forecast with Increase in Rainfall Intensity Condition

6. Decrease in input price of 30%

   As input price plays prominent role in CA adoption, lower input cost affects the adoption of CA practice as that means input package is not seen as attractive anymore since all the price is cheaper. This scenario proves that if input price is decreased in the future, there will be a lot of discharge in CA adoption. In the model, the discharge is explained by lower adoption rate as farmers see CA as less attractive that CV when all the prices is lower.

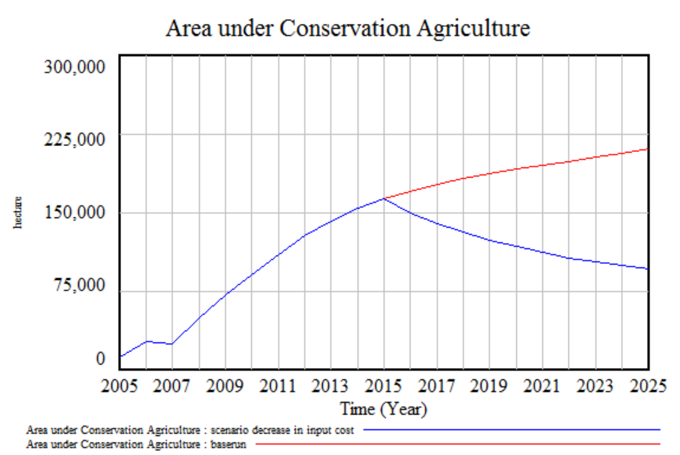

Figure 5.26. Forecast with Decrease in Input Cost

7. Increase in input price of 30%

   As we can see in Figure 5.26, there is a huge decrease in the area under CA without input package support, yet even with the increase of it, there is only a small increase of CA area (Figure 5.27). This effect is explained in the model through comparative attractiveness that governs adoption rates. Low increase of adoption may happen as cost is not seen as the most important aspect of farmer thus lower cost does not significantly increase comparative attractiveness.

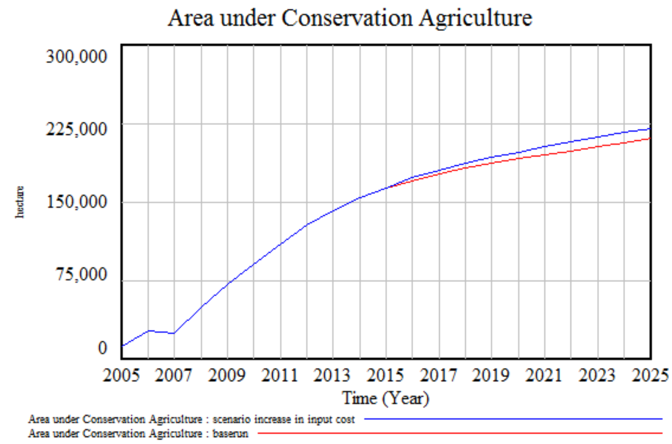

Figure 5.27. Forecast with Increase in Input Cost

8. Discontinuation of the project

   In Figure 5.28 one can see there is a significant decrease of adoption if the project is discontinued. Although this is undesirable, this occurrence is reasonable as input package and training are what makes CA practice different to CV practice and govern the adoption. In this condition, input package for CA is made similar for input package for CV which is 27%

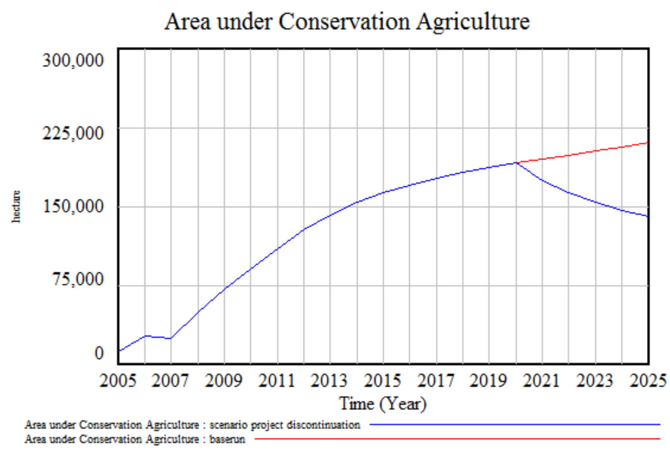

Figure 5.28. Forecast with Project Discontinuation

Based on 7 scenarios beside base run, there are two distinctive scenario results: an insignificant change (decrease or increase) in the behavior and an obvious decrease in the behavior. The significant changes are shown in decrease and increase in crop price, decrease and increase of rainfall intensity, and increase in input cost while apparent decreases are shown in decrease in input cost and project discontinuation.

In the model structure, crop price affects investment in equipment which finally affects yield productivity. Similar with rainfall intensity, this variable also affects yield productivity. Related to adoption rate, yield productivity affects the increase of CA trust which has low value in 2015 (slightly lower that 0.2). The effect from any decrease or increase of CA yield productivity to the increase of CA trust is low as well (lower that 0.1) and that does not give significant effect to CA trust. As currently trust does not give significant effect to adoption rate compared to comparative attractiveness, any change in CA trust will only lead to small change in the behavior.

Different with decrease in input cost condition and project discontinuation. The similarity between those scenarios is both target the single-moment yet significant determinant of conservation agriculture. Project discontinuation means input package is no longer available thus create a much higher input cost. Input cost affects attractiveness of each farming practices and also affect the comparative attractiveness which currently has big impact on adoption process. The increase of input price does not result to apparent change in the behavior as decrease in input cost or discontinuation of project because in the increase of input cost, both farming practices' input cost get higher and CA still provides higher input support than CV which makes CA is still quite attractive for farmers. In the event of lower CA price, farmers do not see additional input package (discount) as attractive anymore. From model structure's perspective, any change that targets single-moment determinant in this model (cost, hired labor, and yield) will result to obvious change in the behavior; different with any change that target long-term determinant of adoption, those changes will result to small and gradual shift in behavior.

Based on all scenario result, all but three scenario results to higher CA adoption than the base run condition, the conditions that result to decrease in the adoption are increase in crop price, increase in rainfall, and decrease in input price. For the other scenario, even though they have achieved higher adoption without doing anything, higher adoption is still desirable. Therefore policies are explored in next sub-chapter to find out which policy will work under any condition.

5.3.2 POLICY OPTIONS

The goal for policy is set to increase area under conservation agriculture using possible policy. The policies being taken are not analyzed from financial perspective as each of the cost used to promote CA in Zambia was not for public's knowledge.

There are four leverage points used as policy in the model, which are average farmers' training per year, input package, consideration of CA as climate change adaptation, and provision of equipment by market price control or supplying new ripper to the farmers. Those variables are seen as possible policy option to increase CA adoption among farmers in Zambia. The policies are explained based on each scenario.

Due to boundary limitation of the study, several policies are shown without any additional structure. Those policies are average training/year, discount for input package, and also change in ripper price and addition of ripper. Further discussion of those policies is conducted outside system dynamics model related.

Without any complete information about current promotion cost and different situation that, making policy that resembles reality is difficult. Therefore this policy section's sub-chapter focuses on comparing most effective policy for each scenario. All similar policies are applied in the different conditions; the goal is to create higher adoption than the condition when no policy is implemented. Applied policies use the same number for each scenario and the best two scenarios are combined to see the result. The policies are:

Table 5.7. Policy Variables

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training/year	2.59	4	5
Average training for CA consideration as climate change adoption/year	0	0.85	5
Input package (percentage)	0.4745	0.7	5
Input package (percentage)	0.4745	1	2
Ripper Price (ZMK/tool)	400,000	550,000	5
New Ripper (tool/year)	0	1000	5

The policy options are made based on possibilities to be implemented to CA promotion in reality. All of those policies are implemented starting in 2015 until the length of policy duration.

1. *Base run*

Policies taken in the base run condition are listed in Table 5.7 and added with policy in Table 5.8.

Table 5.8. Additional Policy Variable on Base Run Condition

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training for CA consideration & input package	0 & 0.4745	0.85 & 0.7	5

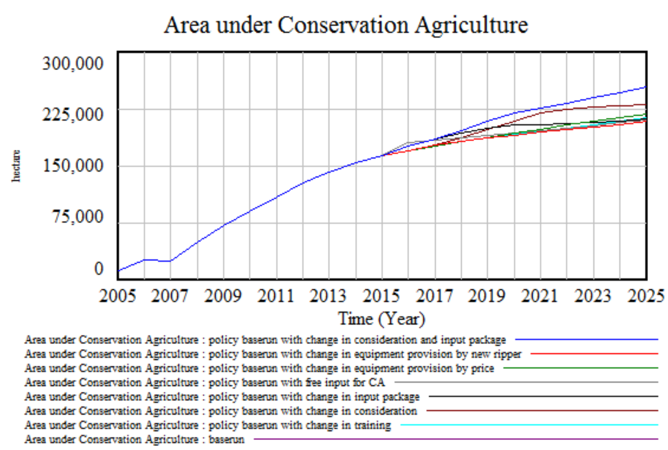

Figure 5.29. Base Run and Policies

The result of policies in base run scenario is shown in Figure 5.29. Based on Figure 5.29, one can see that the best single policy for base run condition is the increase of CA consideration as climate change adaptation. This is conducted by making additional training about how CA can tackle the effect of climate change.

Based on the simulation this policy can get larger area under CA practice compared to other single policies excluding the combination of this policy and input package. What makes the advantage of this policy is because this targets the increase of trust which creates sustainable adoption instead of input package that targets single-moment comparative attractiveness to generate adoption rate. Besides the two mentioned policies, other experimented policies do not produce significant change in the area under CA practice.

2. Decrease in crop price from 900 ZMK/kg to 650 ZMK/kg

Policies taken in the base run condition are listed in Table 5.7 and added with policy in Table 5.9.

Table 5.9. Additional Policy Variable on Decrease in Crop Price

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training for CA consideration & input package	0 & 0.4745	0.85 & 0.7	5

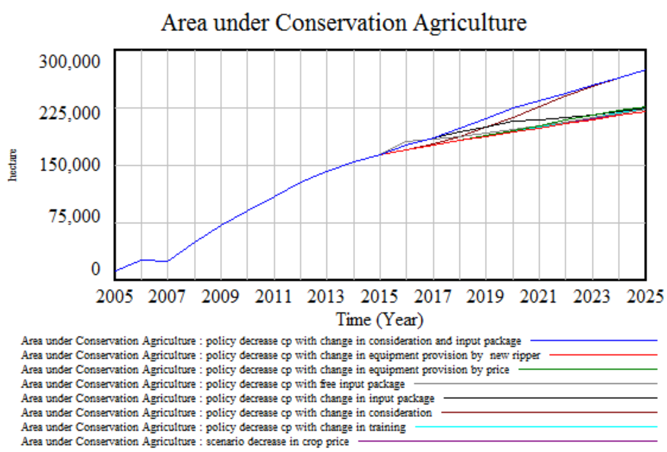

Figure 5.30. Decrease in Crop Price and Policies

The result of policy runs is captured in Figure 5.30. Similar with policies in base run's result, policy that results higher CA adoption is the one that targets consideration of CA as climate change adaptation. If this policy is combined with input package, there is a slightly higher adoption in the beginning of the simulation period. This is important point in promoting CA adoption in Zambia since when input package is used there is higher adoption but when the input package is reduced the adopters start to discharge the adoption or create lower adoption rate.

3. Increase in crop price from 900 ZMK/kg to 1150 ZMK/kg

Policies taken in the base run condition are listed in Table 5.7 and added with policy in Table 5.10.

Table 5.10. Additional Policy Variable on Increase in Crop Price

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training for CA consideration & input package	0 & 0.4745	0.85 & 0.7	5

One can see the policies result in Figure 5.31. Similar with previous two results, change in consideration and input package create higher adoption compared to another policy options therefore those two policies is joined to find out whether they together can achieve broader area under CA. Despite the combination of two policies reach bigger area under CA right after 2015 until 2022, in the end of simulation period (2025) it achieves the same area under CA as change in consideration alone. On the other hand, higher CA area means better food security condition, so higher CA area after 2015 means higher percentage of farmers' household under food security condition and that condition is desirable. Nevertheless that condition is achieved with bigger effort and cost.

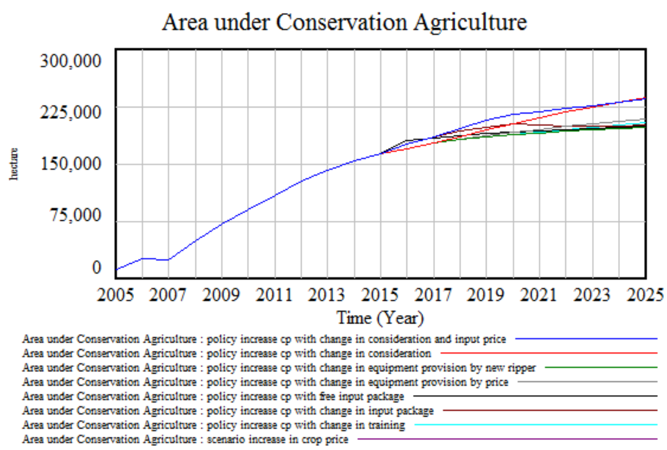

Figure 5.31. Increase in Crop Price and Policies

4. Decrease in rainfall intensity from 878.83 mm/year to 778.83 mm/year

   Policies taken in the base run condition are listed in Table 5.7 and added with policy in Table 5.11.

Table 5.11. Additional Policy Variable on Decrease in Rainfall Intensity

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training for CA consideration & input package	0 & 0.4745	0.85 & 0.7	5

Figure 5.32 shows policy simulation result for decrease in rainfall intensity condition. Similar with previous policy simulations result, in this condition change in consideration and input package produce highest CA adoption compared to another policies for this condition. Those two policies are combined for running new policy and that creates the same condition as previous condition: higher adoption in the beginning yet same level in the end of simulation period.

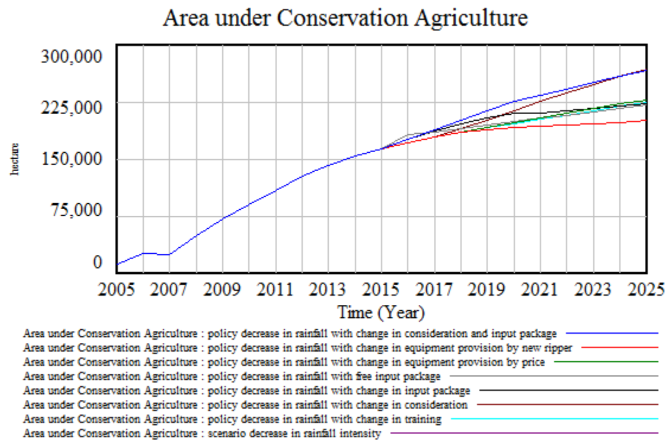

Figure 5.32. Decrease in Rainfall Intensity and Policies

5. Increase in rainfall intensity from 878.83 mm/year to 1000 mm/year

   Policies taken in the base run condition are listed in Table 5.7 and added with policy in Table 5.12.

Table 5.12. Additional Policy Variable on Increase in Rainfall Intensity

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training for CA consideration & input package	0 & 0.4745	0.85 & 0.7	5

Figure 5.33 shows policies simulation result for increase of rainfall intensity. The distinctive result is clearly seen on implementation of change in consideration and the second policy that creates distinctive result is input package. Those together are joined and create highest adoption in the beginning of policy implementation and same level of adoption in the end of simulation period. Different with the simulation result in the beginning of the period (2005-2012), the adoption is mostly governed by comparative attractiveness as the effect of input packages and in this simulation during policy implementation trust, as the effect of increase in consideration, mostly governs adoption process.

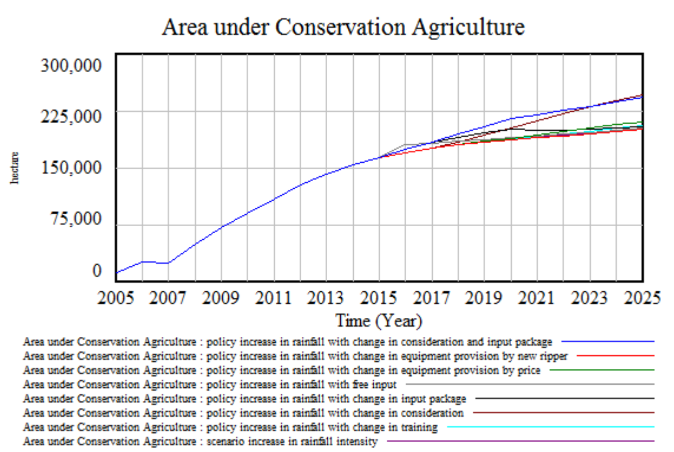

Figure 5.33. Increase in Rainfall Intensity and Policies

6. Decrease in input price of 30%

   Policies taken in the base run condition are listed in Table 5.7 and added with policy in Table 5.13.

Table 5.13. Additional Policy Variable on Decrease in Input Price

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training for CA consideration & input package	0 & 0.4745	0.85 & 0.7	5

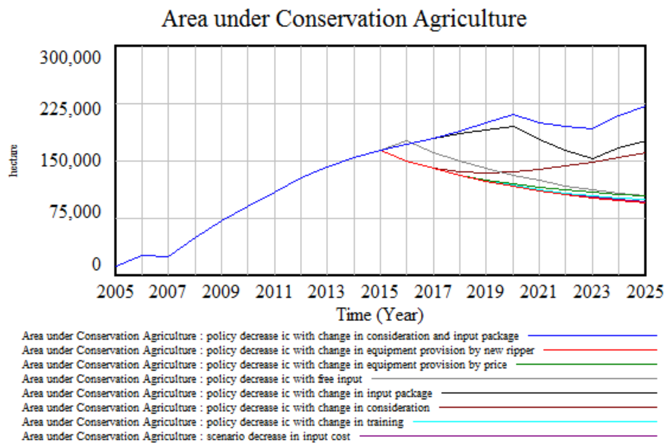

Figure 5.34. Decrease in Input Price and Policies

Figure 5.34 shows the condition where there is a significant decrease in CA adoption as result of decrease of input price. In the current condition, farmers do not pay attention on farming cost and decrease in input price makes farmers are even more careless to consider input price when choosing farming practice. The policies simulation result in this condition shows slightly different result as simulation in the previous conditions. In this condition, change in input package achieves highest adoption compared to the others, yet that resulted adoption level is slightly lower than simulation's result before the decrease in input price happens. This policy combined with training to increase awareness can successfully increase the adoption even though with a slight decrease of adoption in the middle.

7. Increase in input price of 30%

   Policies taken in the base run condition are listed in Table 5.7 and added with policy in Table 5.14.

Table 5.14. Additional Policy Variable on Increase in Input Price

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training for CA consideration & input package	0 & 0.4745	0.85 & 0.7	5

Figure 5.35 shows similar policy simulation result as previous condition where the best single policy is increasing consideration and the second best is input package. The combination of

those policies creates higher adoption in the beginning of policy implementation but reaches similar level as policy of increasing consideration alone.

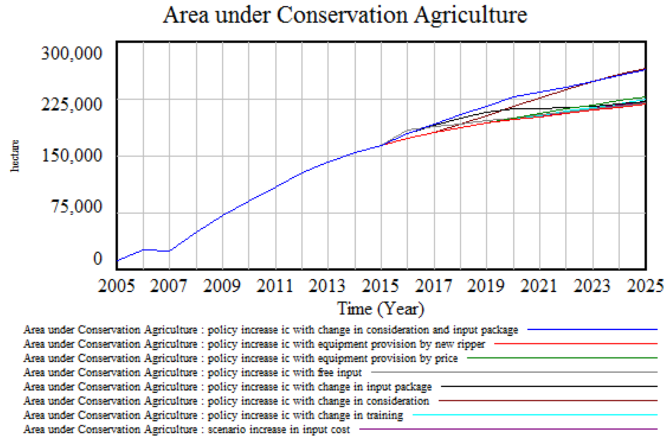

Figure 5.35. Increase in Input Price and Policies

8. Discontinuation of the project

In this part, several policies is tested and seen which policy result to sustainable adoption of CA. The policies is assumed that the termination of the project in 2020 is known beforehand so alternative action can be determined to encounter the effect of project termination.

As one can see in Figure 5.36, none of the policy can maintain CA adoption after project termination, including the extreme policies. The policies used in this condition are policies listed in Table 5.7 and Table 5.15.

Table 5.15. Additional Policy Variable on Project Discontinuation

Policy Variable	Initial Value	Policy Value	Duration (yrs)
Average training for CA consideration & input package	0 & 0.4745	0.85 & 0.7	5
Average training for CA consideration, training, & input package	0, 2.57 & 0.4745	1, 4 & 0.7	5

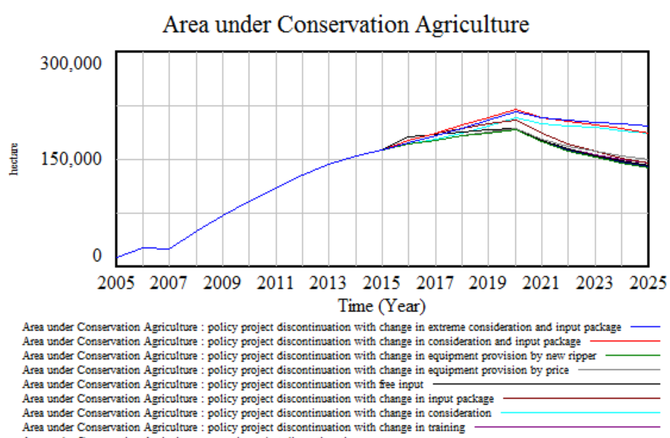

Figure 5.36. Project Discontinuation and Policies

This result implies that to maintain CA adoption among farmers, longer project period is needed until the dependency to single-moment determinant (input package) is seen as no longer important and long-term factor (trust) is big enough to significantly affect adoption process.

5.3.3 Policy Sensitivity Test

In this sub-chapter the sensitivity of CA adoption from any change in each of the policies taken is tested. The sensitivity test is conducted on base run condition.

1. Average training policy/year

   The result of sensitivity test for average training/year variable can be seen in Figure 5.37. This result shows any attempt to increase or even maximizing farmers' participation in training will not produce significant effect on CA adoption. The knowledge together with potential knowledge from farmers' share in CA forms knowledge for CA practice that determines CA yield productivity. This happens as the remaining knowledge to be transferred through training is not much left so the addition to knowledge for CA practice is not much added.

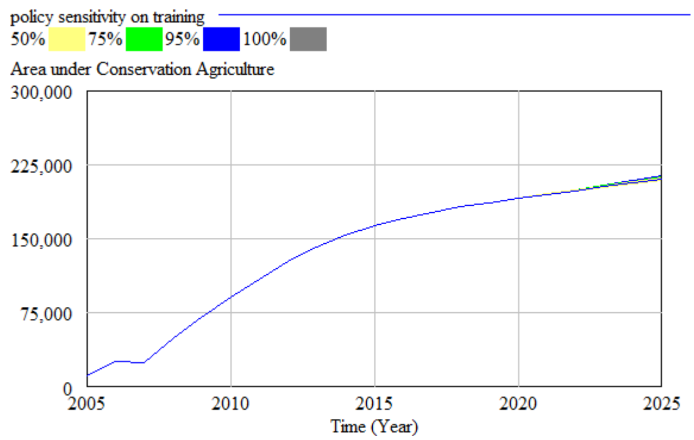

Figure 5.37.Sensitivity Test Result on Training Policy

2. Average additional training/year

   Figure 5.38 shows sensitivity test result of additional training variable. This test uses 0 and 1 as minimum and maximum value of additional training/year. This variable shows the average attendance of additional training for increasing climate change awareness and consideration of CA as climate change adaptation. Additional training variable is related to farmers' consideration of adopting CA for minimizing climate change effect to agriculture production.

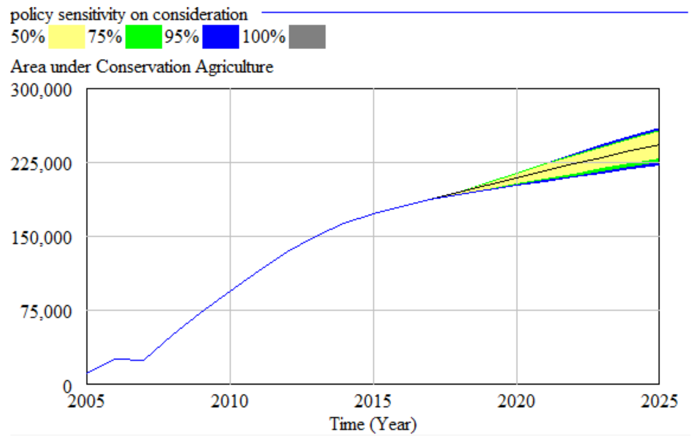

Figure 5.38. Sensitivity Test Result on Additional Training Policy

This result shows that change in additional training which leads to changing in consideration has significant effect on CA adoption. This result is also proven from policy simulation result that additional training can improve CA adoption compared to another policies. As can be seen also in Figure 5.38, the sensitivity of area under CA increases from 2018 until 2025 so it is safe to assume that it still increases after 2025 meaning the area under CA is more sensitive to the change in additional training. The result also shows time lag since the policy is implemented (2015) until it affects area under CA practice in 2017.

3. Input packages/year

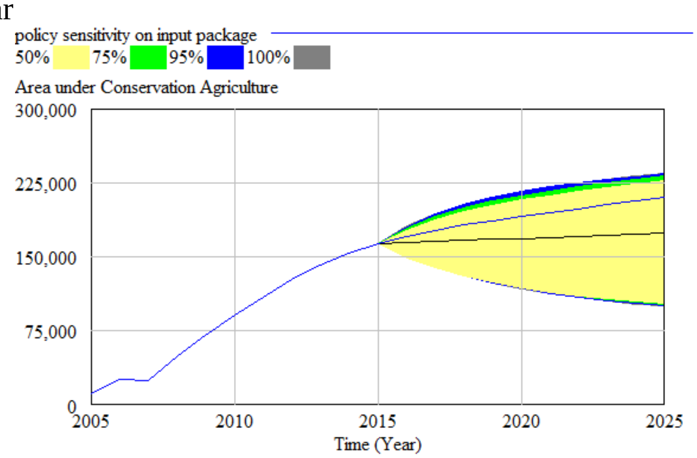

Figure 5.39. Sensitivity Test Result on Input Package Policy

Figure 5.39 shows sensitivity test result for input package policy. This test uses 0 and 1 as the minimum and maximum range of input package. This test shows that CA adoption still highly depend on input package. Even if it is compared to area under CA's sensitivity from additional training policy, area under CA is still more sensitive to change in input package. This is undesirable yet proves the real system condition that adoption is highly affected by input package. Different as previous policy, this policy gives instant effect to CA adoption yet this is a single-moment effect, when input package is discontinued the adopters will instantly discharge the practice.

4. Ripper price/tool

Figure 5.40 shows sensitivity test on equipment provision by changing ripper's market price. This test uses 0 as price's minimum value and 1,000,000 as the maximum value. The test results shows that change in ripper's price also produce quite big impact on CA adoption especially near the end of simulation period. Even though the policy is started on 2015, the sensitivity range is shown in 2019, which means there is a time lag until this policy gives effect to CA adoption

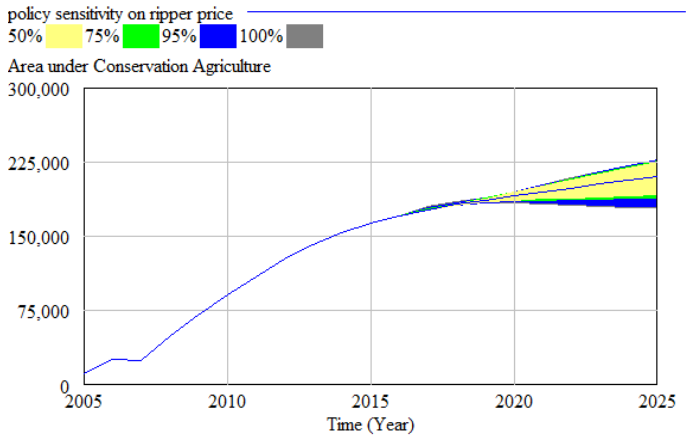

Figure 5.40. Sensitivity Test Result on Ripper's Price Provision

5. Number of new ripper/year

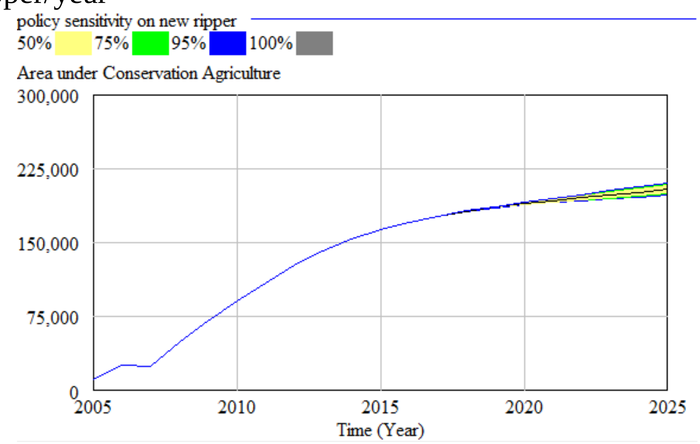

Figure 5.41. Sensitivity Test Result on New Ripper Provision

Figure 5.41 shows the last sensitivity test for policy options of this study. This sensitivity test uses 0 as minimum value and 5000 as maximum value. Apparently, this policy does not give significant effect to the increase of area under CA. This is shown by only small range of possible area under CA is produced under the change in new ripper policy. This implies more ripper must be distributed if this policy will be implemented. This policy also shows the long time lag between it is started to implement until the effect takes place.

CHAPTER 6
SUMMARY OF THE THESIS

6.1 POLICY RECOMMENDATION

There are several policy options for increasing CA adoption. All policy has been simulated to assure each of them gives positive impact to CA adoption. The policies are:

1. Increasing number of training

   The increase in number of training can be achieved by changing the way training is held (e.g., smaller area/ training thus decrease the limitation caused by distance).

2. Additional training to increase consideration of CA as climate change adaptation method

   This policy can be implemented by creating special module that explains about climate change, its effect on agriculture production, available solutions to tackle the effect on production system and how CA can encounter the effect of climate change. This module can be given as additional training alongside current trainings.

3. Increase in input package

   Since this is not a new policy, its implementation does not need to be explained.

4. Equipment provision by controlling ripper's price or distribute more ripper among farmers

   This policy can be conducted by controlling ripper's market price or ensuring ripper's availability among farmer. Ensuring ripper's availability can be organized by distributing ripper directly to selected farmers or creating a ripper rent point in several areas.

Based on policies simulation, there is no significant CA adoption as the result of another policy implementation besides additional training to increase consideration and increasing input package. Increasing distribution of input package is not desirable because that maintains farmers' dependency to input package which means farmers are likely to discharge adoption when input package is not available.

From system analysis in Chapter 4 there is indication that the advantage of CA as climate change adaptation method is not well known among farmers and based on policy simulation in Chapter 5 the additional policy to promote CA as climate change adaptation method can increase the adoption of CA among farmers. This policy specifically targets farmers' awareness of climate change adaptation method since the awareness affects trust in CA, an adoption factor whose value is influence over time. This policy is different with input package, which targets a one-time influence factor (comparative attractiveness) and makes the advantage of CA over CV depends all the time to input package.

This policy can be implemented by creating a specific module that explains the event of climate change, how it will affect agriculture production and how conservation agriculture can minimize the effect of climate change in farm.

6.2 CONCLUSION

This sub-chapter answers research questions stated in sub-Chapter 1.2.

1. There is less adoption rate compared to previous years in CAP project. Although the area under CAP project still increases but the increase is not as high as previous years. The adoption of conservation agriculture in this study is captured by area under conservation agriculture. Current condition of area under CA is characterized by small implementation in farm area. CA is not seen as substitution of CV instead it is only seen as complement of CV.
2. There are two influence factors of CA diffusion in Zambia: trust in CA practice and comparative attractiveness. Those two factors simultaneously govern adoption rate as CA is new practice therefore consideration of adopting the practice is not fully affected by trust factor. Trust shows farmers' reliance to CA that CA can produce higher yield compared to conventional agriculture while comparative attractiveness shows farmers' assessment of advantage between CA and CV. The comparative assessment consists of three variables: cost, hired labor, and yield.
3. During CAP project several activities to promote CA adoption is made. The main activities are training and distribution of input package. There is also equipment provision by distributing ripper to farmers but that does not give significant addition to the number of rippers. Training mostly consists of instruction of implementing CA in the farm and gives example between the implementation of CA and without CA between two farms. There are also field days to show the real CA implementation in the farm. Distribution of input package consists of several types yet the main purpose is to give lower input cost to farmers. This policy targets farmers' short analysis about advantage between two farming practice. Until recently, this policy is what mostly governed adoption rate of CA practice among farmers under CAP.
4. In the base run, most of the possible policy can increase the adoption; the different is in significance of increase using different policy. The highest adoption is performed by implementing additional training to make farmers understand why CA is necessary to implement in their farm.
5. Policy that will maintain CA adoption is those which targets trust in CA. Current policy is mostly concentrated on single-time consideration of adopting certain practice (comparative assessment) and less focused on long-term consideration for adopting certain practice (trust

in CA). Bases on policy simulation, policy that targets increase of CA consideration for climate change adaptation can significantly increase CA adoption.

CA diffusion based on the cultivated area shows significant increases compared to the condition before CAP project is implemented; yet there is still a lot of possible increase in the adoption of CA. CA adoption process is affected by one single-moment and one long term determinant that explains current adopters' behavior. The single-moment factor is comparative attractiveness which consists of cost, hired-labor and yield productivity while long term effect on adoption is determined by trust level. Currently, the CA promotion project concentrates on the single-moment factor by giving input package and does not maintain the long term factor. That leads to quick discharge of CA practice when farmers do not receive input package anymore. Policy that would achieve successful conservation agriculture diffusion is one that focuses on long-term determinant.

6.3 LIMITATION AND FURTHER RESEARCH

There are several limitation used in his study:

1. Population is limited to farmers under CAP project.
2. Process captured in agriculture system is limited to agriculture practice.
3. Data sources for constructing the model are limited in the period between 2006/2007-2009/2010.

From those limitations, there are several improvements that can be used for further research:

1. Related to point 1 and 2 of limitations of the study, if population is enlarged to all people in the surveyed area and distribution process is captured, more comprehensive perspective can be gained thus more comprehensive analysis of food security condition can be gained. Better perspective of the effect of CA diffusion to country's food security condition can also be obtained by extend the study area to country level.
2. More accurate assessment of the system can be obtained by using longer period of data. Current issue related with data is unavailability of CAP project data during implementation project.
3. More detail analysis about farmers' preference between farming practices can be conducted to obtain more accurate utility elasticity variables.
4. Broader perspective of system's condition can also be obtained when agri-family subsystem being studied is expanded to agri-family system level that analyzes the lifestyle and human development of farming system. Therefore the activity besides farming practice that relates to the state of food security and conservation agriculture diffusion can also be captured in the study.

REFERENCE

Aagaard, P. (2007) Conservation Farming & Conservation Agriculture Handbook. *Handbook for HOE Farmers in Agro Ecological Regions I & IIa - Flat Culture*. Lusaka: Conservation Farming Unit.

Aagaard, P. J., & CFU. (2011). The practice of Conventional and Conservation Agriculture in east and Southern Africa. Zambia: Conservation Farming Unit.

Arslan, A., McCarthy, N., Lipper, L., Aswaf, S., & Cattaneo, A. (2013). Adoption and Intensity of Adoption of Conservation Farming Practice in Zambia: Indaba Agricultural Policy Research Institute (IAPRI).

Aune, J. B., Nyanga, P. H., & Johnsen, F. H. (2012). A Monitoring and Evaluation Report of the Conservation Agriculture Project 1 (CAP1) in Zambia: Noragric.

Bain, L. E., Awah, P. K., Geraldine, N., Kindong, N. P., Sigal, Y., Bernard, N., & Tanjeko, A. T. (2013). Malnutrition in Sub-Saharan Africa: burden, cause, and prospect. *The Pan African Medical Journal, 15*, 120.

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review, 12*(3), 183-210.

Baudron, F., Mwanza, H. M., Triomphe, B., & Bwalya, M. (2007). Conservation agriculture in Zambia: a case study of Southern Province. Nairobi: African Conservation Tillage Network, Centre de Cooperation Internationale de Recherche Agronomique pour le Developpement, Food and Agriculture Organizzation of the United Nations.

Berger, T. (2001). Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. *Agricultural economics, 25*(2-3), 245-260.

Bolliger, A., Magid, J., Amado, J. C. T., Skóra Neto, F., Ribeiro, M. d. F. d. S., Calegari, A., . . . de Neergaard, A. (2006). Taking Stock of the Brazilian "Zero-Till Revolution": A Review of Landmark Research and Farmers' Practice. *Advances in agronomy, 91*, 47-110.

Brown, L. R. (2004). *Outgrowing the earth: the food security challenge in an age of falling water tables and rising temperatures*: WW Norton & Company.

CFU. (2007). Conservation Farming & Conservation Agriculture Handbook for HOE Farmers in Agro-Ecological Regions I & IIa-Flat Culture. *CF Handbook, Lusaka, Zambia*.

CFU. (2012). The Promotion and adoption of CF/CA in Zambia, Experience Gained and Future Perspectives. Zambia: Conservation Farming Unit.

Chomba, G. N. (2004). *Factors Affecting Smallholder Farmers' Adoption of Soil and Water Conservation Practices in Zambia.* (Master), Michigan state University.

CIA. (2014). The World Factbook. *Zambia.* 2014, from https://www.cia.gov/library/publications/the-world-factbook/geos/za.html

Coughenour, C. M., & Chamala, S. (2000). *Conservation Tillage and Cropping Innovation. Constructing the New Culture of Agriculture*. Ames, Iowa: Iowa State University Press.

Critchley, W., Siegert, K., & Chapman, C. (1991). A manual for the design and construction of water harvesting schemes for plant production. *Rome, IT: FAO.*

CRU. (2014). Average Monthly Temperature and rainfall for Zambia from 1990-2009: Climate Research Unit of University of East Anglia.

D'Souza, G., Cyphers, D., & Phipps, T. (1993). Factors affecting the adoption of sustainable agricultural practices. *Agricultural and Resource Economics Review, 22*(2), 159-165.

Dejong-Hughes, J., Moncrief, J., Voorhees, W. B., & Swan, J. B. (2001). Soil Compaction: causes, effects, and control. Retrieved 12th May, 2014, from http://www.extension.umn.edu/agriculture/Tillage/soil-compaction/index.html#consequences

Dixon, J. A., Gibbon, D. P., & Gulliver, A. (2001). *Farming systems and poverty: improving farmers' livelihoods in a changing world* (M. Hall Ed.): Food & Agriculture Org.

FAO. (1996). World Food Summit 1996 *Plan of Action* (Vol. 7). Rome: FAO.

FAO. (2009). Declaration of the World Summit on Food Security *Plan of Action* (pp. 7). Rome: FAO.

FAO. (2012). *FAO Statistical Yearbook 2012*. Accra: FAO Regional Office for Africa.

FAO. (2013a). *AQUASTAT database*.

FAO. (2013b). FAOSTAT. Retrieved April 2014, from FAO http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E

FAO. (2013c). Food Security Indicators. from Food and Agriculture Organization of the United Nations (FAO)

FAO. (2013d). *The State of Food and Agriculture*. Rome: FAO.

FAO. (2014). Agri-Environmental Indicators. *FAOSTAT.* Retrieved April, 2014, from http://faostat3.fao.org/faostat-gateway/go/to/download/E/*/E

FAO, IFAD, & WFP. (2013). The State of Food Insecurity in the World 2013 *The Multiple Dimensions of Food Security*. Rome: FAO.

Forrester, J. W., & Senge, P. M. (1978). *Tests for building confidence in system dynamics models*: System Dynamics Group, Sloan School of Management, Massachusetts Institute of Technology Cambridge.

Gerber, A. (2014). *Food security as an outcome of food systems. A system dynamics approach*. Paper presented at the 32nd International Conference of the System Dynamics Society, Delft, The Netherlands.

Gowing, J., & Palmer, M. (2008). Sustainable agricultural development in sub-Saharan Africa: the case for a paradigm shift in land husbandry. *Soil use and management, 24*(1), 92-99.

Gruhn, P., Goletti, F., & Yudelman, M. (2000). *Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges*: Intl Food Policy Res Inst.

Haggblade, S., & Tembo, G. (2003a). *Conservation farming in Zambia*: Intl Food Policy Res Inst.

Haggblade, S., & Tembo, G. (2003b). *Early Evidence on Conservation Farming in Zambia*. Paper presented at the International Workshop on "Reconciling Rural Poverty and Resource Conservation: Identifying and Remedies", New York.

Hobbs, P. R. (2007). Conservation agriculture: what is it and why is it important for future sustainable food production? *JOURNAL OF AGRICULTURAL SCIENCE-CAMBRIDGE-, 145*(2), 127.

IFAD. (2011). Smallholder Conservation Agriculture: International Fund for Agricultural Development (IFAD).

IFAD, WFP, & FAO. (2013). The State of Food Insecurity in the World 2013 *The multiple dimensions of food security*. Rome.

Jones, P. G., & Thornton, P. K. (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change, 13*(1), 51-59.

Kabwe, G. (2010). *Uptake of agroforestry technologies among smallholder farmers in Zambia.* Lincoln University.

Kabwe, S., & Donovan, C. (2005). The Magoye Ripper: Preliminary Findings on Adoption, Benefits, and Constraints *Food Security Research Project*. Zambia: USAID.

Kassam, A., Friedrich, T., Shaxson, F., & Pretty, J. (2009). The spread of conservation agriculture: justification, sustainability and uptake. *International journal of agricultural sustainability, 7*(4), 292-320.

Kingsley, G., Bozeman, B., & Coker, K. (1996). Technology transfer and absorption: an 'R & D value-mapping'approach to evaluation. *Research Policy, 25*(6), 967-995.

Knowler, D., & Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food policy, 32*(1), 25-48.

Kopainsky, B., & Derwisch, S. (2009). *Model-based exploration of strategies for fostering adoption of improved seed in West Africa.* Paper presented at the Proceedings 27th international conference of the system dynamics society, Albuquerque.

Kopainsky, B., Tröger, K., Derwisch, S., & Ulli-Beer, S. (2012). Designing Sustainable Food Security Policies in Sub-Saharan African Countries: How Social Dynamics Over-Ride Utility Evaluations for Good and Bad. *Systems Research and Behavioral Science, 29*(6), 575-589.

Kotrlik, J. W. K. J. W., & Higgins, C. (2001). Organizational research: Determining appropriate sample size in survey research appropriate sample size in survey research. *Information technology, learning, and performance journal, 19*(1), 43.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science, 319*(5863), 607-610.

MFA. (2011). ZAM 3037 ZAM 09/014 Conservation Agriculture Programme phase II (CAP II) (pp. 12). Zambia: Norwegian Ministry of Foreign Affairs (MFA).

Microsoft. (2010). Microsoft Office Professional Plus: Microsoft Corporation.

Mortimore, M., & Harris, F. (2005). Do small farmers' achievements contradict the nutrient depletion scenarios for Africa? *Land Use Policy, 22*(1), 43-56.

Munodawafa, A. (2012). The Effect of Rainfall Characteristics and Tillage on Sheet Erosion and Maize Grain Yield in Semiarid Conditions and Granitic Sandy Soils of Zimbabwe. *Applied and Environmental Soil Science, 2012*.

Nyanga, P. H. (2012a). *Conservation agriculture among smallholder farmers in Zambia: Attitudes and socio-economic impacts.* (Doctoral), Norwegian University of Life Sciences, Ås. (2012:39)

Nyanga, P. H. (2012b). Factors Influencing Adoption and Area under Conservation Agriculture: A Mixed Methods Approach. *Sustainable Agriculture Research, 1*(2).

Nyanga, P. H. (2012c). Food Security, Conservation Agriculture and Pulses: Evidence from Smallholder Farmers in Zambia. *Journal of Food Research, 1*(2), 19.

Nyanga, P. H. (2014). Current Implementation of Conservation Agriculture in Zambia. In D. F. Amelia (Ed.), *Thesis Interview*.

Nyanga, P. H., & Johnsen, F. H. (2010). 2009/2010 Monitoring and Evaluation Draft Report: Noragric.

Nyanga, P. H., Johnsen, F. H., Aune, J. B., & Kalinda, T. H. (2011). Smallholder Farmers' Perceptions of Climate Change and Conservation Agriculture: Evidence from Zambia. *Journal of Sustainable Development, 4*(4).

Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change, 14*(1), 53-67.

Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A., Temesgen, M., Mawenya, L., . . . Damgaard-Larsen, S. (2009). Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. *Soil and Tillage Research, 103*(1), 23-32.

Rogers, E. (2003). *The Diffusion of Innovations*. New York: The Free Press.

Saldarriaga, M., Kopainsky, B., & Alessi, S. M. (2013). *Knowledge analysis in coupled social-ecological systems. What do stakeholders in sub Saharan Africa know about the dynamic complexity of climate change, agriculture and food security?* . Paper presented at the 31st International Conference of the System Dynamics Society, Cambridge, MA.

Saldarriaga, M., Nyanga, P. H., & Kopainsky, B. (2014). *Dynamic decision making in coupled social-ecological systems. Smallholder farmers' goals, resources and constraints in improving food security and adapting to climate change in Zambia*. Paper presented at the 32nd International Conference of the System Dynamics Society, Delft, The Netherlands.

Siegel, P. (2008). Profile of Zambian Smallholders: Where and Who are the potential beneficiaries of Agricultural Commercialization: Africa Region Working Paper Series.

Sitko, N. J., Chapoto, A., Kabwe, S., Tembo, S., Hichaambwa, M., Lubinda, R., . . . Nthani, D. (2011). Technical Compendium: Descriptive Agricultural Statistics and Analysis for Zambia in Support of the USAID Mission's Feed the Future Strategic Review: Michigan State University, Department of Agricultural, Food, and Resource Economics.

Smit, B., & Skinner, M. W. (2002). Adaptation options in agriculture to climate change: a typology. *Mitigation and adaptation strategies for global change, 7*(1), 85-114.

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*: McGraw-Hill Higher Education.

Thierfelder, C., Chisui, J. L., Gama, M., Cheesman, S., Jere, Z. D., Trent Bunderson, W., . . . Rusinamhodzi, L. (2013). Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity. *Field Crops Research, 142*, 47-57.

Thierfelder, C., & Wall, P. C. Manual and Animal Traction Seeding Systems in Conservation Agriculture. In B. a. I. CIMMYTs (Ed.). Zimbabwe: CIMMYT (International Maize and wheat Imprvement Center) Zimbabwe Office.

Twomlow, S., Urolov, J., Jenrich, M., & Oldrieve, B. (2008). Lessons from the field–Zimbabwe's conservation agriculture task force. *Journal of SAT Agricultural Research, 6*(1), 1-11.

Umar, B. B. (2013). A critical review and re-assessment of theories of smallholder decision-making: a case of conservation agriculture households, Zambia. *Renewable Agriculture and Food Systems*, 1-14.

Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in Conservation and Conventional Agriculture Systems. *Journal of Sustainable Agriculture, 36*(8), 908-929.

Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, O. (2011). Options for Improving Smallholder Conservation Agriculture in Zambia. *Journal of Agricultural Science (1916-9752), 3*(3).

Umar, B. B., & Nyanga, P. H. (2011). *Conservation Agriculture as an innovation forincreasing food security and environmental management: Empirical evidence from Zambia's smallholder farming sector*. Paper presented at the Increasing Agricultural Productivity and Enhancing Food Security in Africa, Addis Ababa, Ethiopia.

The Universal Declaration of Human Rights, 25 (1948).

UN. (2004). Zambia Administrative Map *PDF*: Department of peacekeeping Operations, Cartographic Section.

UN. (2013). Millennium Development Goals and Beyond 2015. 2.

Ventana System, I. (2013). Vensim (Version DSS): The Ventana Simulation Environment.

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. (2012). Climate change and food systems. *Annual Review of Environment and Resources, 37*(1), 195.

WB. (2003). Zambia: The Challenge of Competitiveness and Diversification. Washington, DC: World Bank.

WB. (2005). World Development Indicators: The World Bank.

WB. (2011). World Development Indicator: The World Bank.

WB. (2014a). Arable land (% of land area). 2014, from http://data.worldbank.org/indicator/AG.LND.ARBL.ZS

WB. (2014b). Poverty headcount ratio at national poverty line (% of population). from World Bank http://data.worldbank.org/indicator/SI.POV.NAHC/countries/ZM?display=graph

WB. (2014c). World Development Indicator: The World Bank.

APPENDIX A. INTERVIEW QUESTIONS AND ANSWERS

About Condition before Conservation Agriculture

1	a	*How was the agriculture condition in terms of sustainability before conservation agriculture implementation in Zambia?*
		1. Indigenous farming: some aspect sustainable, some not sustainable a. Slash & burn, part of Zambian culture, mostly in the northern part, is still being practice. Difficult to use this nowadays because of the increase of population. Before the population increase, the same people could come back to the same land after 15-20 years but now it is difficult because the need of land increase but the supply (availability of land) is stagnant. No longer an option for agriculture development in Zambia b. Direct sowing (of seed plant): no need to cultivate the soil, just need to open soil (make hole) for putting the seed without tilling & plowing or another soil disturbance; the closest way with conservation agriculture-the no tilling practice. 2. Conventional farming (product of green revolution) uses chemical fertilizer, plow-turn the soil (100% soil disturbance): not sustainable
	b	*How was the agriculture condition in terms of productivity before conservation agriculture implementation in Zambia?*
		1. Indigenous farming: lowest result Direct sowing: productivity is not as high as conventional nor conservation farming practices because the unit area was not high. The reason of why this system does produce yield as high as the other farming practice is because this system does not use hybrid seed and use organic fertilizer. 2. Conventional Farming: used to have the highest yield before conservation agriculture practice was implemented
2		*Were there any farming management method options besides conservation agriculture?*
		1. Indigenous farming management Currently this method has the lowest yield production. This method is mostly used in northern part of Zambia. Principles: a) Slash & ban (unsustainable for environment) – in northern part of Zambia Open forest are for farming, use the area for several harvest period and then shift to

		another forest area. This practice is not sustainable especially in the phase of population increase population. The population become important aspect in sustainable; in the past period, people can go back to the same area after 15-20 years but now because of the population increase they cannot do that b) Direct sowing/no till (sustainable for environment, the idea is similar with one of the principles of conservation) 2. Conventional farming management system (resulted drom green revolution) This method is the result of green resolution. Currently this is the second highest method in terms of productivity compares to another two methods. Plowing (using tractor & animal); hand hoe digging all over the space; making ridges using hand hoe then plant onto the ridges; making ridges using animal or plow. Plowing makes this practice does not really pay attention on the growth of weeds. Principles: a. Chemical fertilization b. Soil disturbance (usage of hand hoe, animal, plow, tractor) create ridges

About Diffusion process

3		*How do you know about conservation agriculture implementation in Zambia in the first place?*
		In document
4		*How is conservation agriculture promoted in Zambia?*
		Conservation Farming Unit is the key institution that promotes conservation agriculture in Zambia. The promotion of CA in Zambia is highly dependent on donor agencies while NGO in rural area develop the system to promote conservation agriculture. International NGO & international development agencies take component of CA promotion in their project. CFU is the number one promoter of CA in Zambia. Faith-based organization (church) also takes roles to promote CA. CA is promoted through field days (see the real implementation of conservation farming in the field own by farmer), media (television, radio, and newspaper) and also through personal visit by field officer & lead farmers. The farmer are selected through extension workers, the extension workers go to fields & villages to talk with farmers within the area they are given. The extension worker’s duty is to promote CA to farmers. They choose

		farmers by discussion and identify whether they are capable to work or not. The selected farmers become lead farmer and the lead farmer will search for another people. The promotion activity can also undergo through village headman. If village headman accepts, then CA can be promoted in the village. In the beginning CFU works in 12 districts out of 72 districts, now they expanded to almost 30 districts. There are several district that is not rural (no agriculture happening-so CA is not promoted everywhere), some district may only implement fishing instead of crop growing. CFU only works in area where it has high concentration of farming activities. CFU is not the only unit who promote CA, to avoid overlapping with another NGO they have to work in different district. CFU has the largest coverage area.
5	a	*What do you think the success factor(s) of conservation agriculture diffusion in Zambia are?*
		Currently the promotion of CA is still heavily funded therefore the availability of international donor funding (the funding is given based on project, and historically the amount of funding increased project by project). The funding is obtained from Norwegian and also other donor funding. Ministry of Agriculture of Zambia also receives the funding. Many of the national budgets depend on donor aid. Donor funding is given on project term (usually in 3-5 years). *Inputs which is fully supported by donor funding.*
	b	*How do those factors affect conservation agriculture diffusion in Zambia?*
		The funding is used to conduct the training of the farmers (minimum of 4 training/years), motorbikes, and salary of the workers to make sure the farmers are visited and also conducted the field days. Some of the donor funding also go to the promoting by incentives to farmers
	c	*How are those factors important in conservation agriculture diffusion in Zambia?*
		At first, incentives are used as condition to practice conservation farming. The incentives are given in the form of direct material ex: free cassava seed. In food security condition, NGO may use that condition to ask someone practicing conservation farming, by subsidizing food security parts ex: seed, fertilizer. Those are given easier compare to without help. The incentives are used just to make farmers are interested in the practice. And finally some of them upscale the area under conservation farming. Most farmers have seen that productivity in CA is higher, some farmers even does not use the incentive anymore because they've seen the productivity increase. The incentives are given heavily in the early

		years, nowadays the use of incentives decrease. Nowadays they are just given groundnut and they have to payback for the groundnut. CFU is shifting from incentive-based promotion to the increase of benefit (higher production) awareness. The time famers finally realize the benefit of CA is taken at least almost 20 years. There are some areas where CFU introduced CA for 10 years and there is also increase in the implementation. CFU become formal organization in late 90's, it is possible before the formalization the process has been happening.
6	a	*What do you think the factor(s) that inhibit conservation agriculture diffusion in Zambia are?*
		1. Weeds: this occurs because there is no plowing in CA. In conventional farming there are minimal weeds because there is plowing. In CA, farmers can find a lot of weed between the basin & rip lines and the weed starts to germinate easily after rain even faster that the main crop. Plowing is method in controlling weed. In CA, weed control, if not using herbicides, uses workforce which uses many labor. 2. Access to technology (ripper). For making the rip lines they need ripper and animal. Farmers usually have animal but ripper is not really familiar for them. The commercialization of ripper is not really high therefore the recognition of ripper among farmer is limited. 3. Basins: digging of basins is labor intensive that is why it is discouraged the implementation of CA and this is mostly done by women. 4. Promotion of herbicides usage to remove the weed from field (difficult and toxic material though may not disturb mineral but maybe disturb microorganism, the idea of farmers that herbicides is nonselective). The use of herbicide by farmers makes the idea of implement CA is unacceptable among farmers. To use herbicides, farmers need knowledge and some farmers do not want to disturb the field with toxic material. The idea is if herbicide is capable to kill weed so herbicide is capable to kill the micro organism also and decrease the health of the soil. Herbicide will not have effect on mineral content but they will give effect on living things-microorganism. Some farmers said some herbicides are non-selective meaning that herbicide kills everything except the one that is selected. In the indigenous farming system, in field farmers may have 3-4 different crops. In selective herbicide of maize, for example all crops will die except of maize. In indigenous farming system there are lots of intercropping, that is why the use of herbicide is unacceptable for farmers. Farmers also question about what will happen to livestock that eat the crop residue which die because of herbicide.

		5. Cultural factor: certain communities identify themselves with certain farming practices so they will not adopt conservation farming (as a new farming practice). A specific farming practice becomes part of the cultural factor of that community. Major reason that inhibit CA diffusion: because of labour digging basins + weeds Feels that farmers have what they need, they produce enough and don't feel to change, human behaviour of resistant to change
	b	*How do those factors affect conservation agriculture diffusion in Zambia?*
		1. Weeds hinder the implementation of conservation agriculture because that needs lots of labor. Weeds makes the area under CA are often small (eg 0.25 ha under conservation agriculture vs 20ha under conventional agriculture). **2.** The making of basins is also labor intensive which leads to more labor needed in preparation period
	c	*How are those factors important in conservation agriculture diffusion in Zambia?*
		Basins and ripper are the variant of CA therefore those two practices cannot be avoided in CA practice while weeds cannot be avoided if the use of herbicide & cover crops is limited by the farmers.
7	a	*What are the reason(s) farmers adopt conservation agriculture on their farm?*
		1. The availability of incentives or other means of help in providing input (seeds or fertilizer) 2. Farmers expect to get higher production from the field 3. Farmers hope to get rid from food insecurity
	b	*What is the attractiveness of adopting conservation agriculture for a farmer?*
		1. Higher **productivity** (amount of production per area eg: some farmer can produce almost 7000kg/ha and the average productivity of conservation agriculture is 5000kg/ha). Notes: Productivity is amount of yield per unit area Production is total productivity in the whole area Production=total area x productivity Conventional agriculture can produce :3000-3500kg/ha The issue is that farmers usually plant the are bigger with conventional agriculture than conservation agriculture. 2. Food security, the key management practice that farmers can plan earlier and that cannot be done in conventional agriculture because plowing needs to wait until rain

		comes. In conservation agriculture, planting can be started as soon as rain comes but in conventional agriculture the land preparation will just started 3. Time saving: Tractor in conventional agriculture needs to plow all the field (tilling all of the area without space left untilled) but in conservation farming only lines that need to be made use more fuel than conservation
	c	*What are the supports that farmers get if they adopt conservation agriculture on their farm?*
		Incentives from farmer association: high likelihood to get free inputs
8	a	*Who do you think are stakeholder in conservation agriculture diffusion in Zambia? (stakeholders can be those who affect the process directly or indirectly)*
		1. farmers 2. donor community (norad, fao, finida, usaid, eu,) 3. governments 4. civil society (cfu, other ngo) 5. research institution (universities, agriculture research centre) 6. agrochemical dealers (herbicide, hybrid seed seller company)
	b	*What is each of their roles in conservation agriculture diffusion in Zambia?*
		1. Program Practitioner 2. Program Supporter 3. Policy maker 4. Trainer 5. Researcher 6. Dealers
	c	*Can you please explain each of their roles?*
		1. Implement directly the practice; sometimes give feedback to conservation agriculture community (another stakeholders; for example in the meeting). Membership of farmers is based on project and so is the input that they receive, If a farmer join a project which is held by an organization so they will receive input but not necessary a member of the organization 2. Give support to CA implementation (check Norwegian embassy Zambia to know how much the support is) and get report. 3. Provide conducive environment to operate (platform: guideline to participate, ex Norad can't give support without government; facilitate operation of FA,EU-they have right to accept and reject the donor), create policy guideline for implementation for agriculture policy in Zambia (policy objective for agriculture

		sector, how is public funding, budget), they also have unit that support implementation, biggest buyer of maize (from farmer most of the product goes to government, some goes to private company; farmer-government-company/market) 4. Implement various activity of conservation farming, accept aid directly from donor community, lobby government, suggest policy in certain issues (ex: lobbying on behalf of the farmers) 5. Answer certain question regarding some issues; conduct research of farmer implementation on CA; on farm research (on farm-to farmers) & on station research (in lab). The finding is shared between donor community and civil society and some of the research is shared with other stakeholder. 6. On the marketing of agriculture equipment, seed, chemical, herbicide. The price is controlled by agrochemical dealers. Inputs are tied to the project.
9		*What do you think about each of their current involvement in conservation agriculture diffusion in Zambia? (are each of the stakeholder useful?)*
		1. active involve, associated (CFU has chosen to be trained in CA-associated with the project) vs non-associated (some of them implement but all of them not associated with the project 2. donor community: active involve in support 3. active 4. active 5. active 6. limited in the supply, is not related directly in promotion program
10		*Why are those stakeholders important in conservation agriculture diffusion in Zambia?*
		Five first stakeholders are actively involved in the program, missing one stakeholder will affect the whole promotion program
11		*How is current condition of conservation agriculture adaptation in Zambia? (how is the farmer adoption condition? is it easier to start spreading CA among farmer?)*
		More NGO promote CA, it’s spread throughout rural area (which is located in Southern and Eastern Zambia)
12		*What are the success indicators of conservation agriculture diffusion in Zambia?*
		inputs

About Implementation Process

13		*What are the distinctions for farmers who implement conservation agriculture on his farm? (ex: technical assistance, subsidize)*
		Since farmer is associated with project, those who participate in the project will accept input subsidize or input loan and technical assistance about how to conduct the practice. In Progress Nyanga's dissertation there are two groups of farmers: associated & non-associated farmers. Yet there is no distinction between associated and non associated; 300 associated 300 non associated
14	a	*What do you think the success factor(s) of conservation agriculture implementation in Zambia are?*
		Short term benefit that is offered by the practice comes from 1 principle of CA which is early planting, if farmers plant early, even in first year in short rain season the crop of this farmer will be higher. Basin in the case drought will save the seed. Long term benefit: soil organic matter.
	b	*How do those factors affect conservation agriculture implementation in Zambia?*
		By realizing the advantages of early land preparation which leads to early planting, CA is more interesting for farmers
	c	*How are those factors important in conservation agriculture implementation in Zambia?*
		Early planting leads to capture more rain in rain season compares to conventional farming (which just start land preparation when the rain season starts)
15	a	*What do you think the factor(s) that inhibit conservation agriculture implementation in Zambia are?*
		Have only one instant benefit yet farmers need to change their value of farming practice (of no tilling farming practice).
	b	*How do those factors inhibit conservation agriculture implementation in Zambia?*
		The long term benefit can't be obtained instantly yet farmers need profit to fulfill their needs yearly without need to wait until the long term benefit occurs
	c	*How are those factors important in conservation agriculture implementation in Zambia?*
		Profit is the most important factor of farmers for doing farming
16	a	*What are the reason(s) farmers implement conservation agriculture in their farm?*
		Farmers got access to financial resource. There is one farmer who implements 12 years of ideal CA, he is well-educated and for him farming is not main financial source (he's a teacher retiree)

	b	*What do you think the reason farmers implement all aspects of conservation agriculture in their farm?*
		They understand the long term impact of CA to their farm, other than that farmers realize that the early planting leads to higher yield
	c	*What is the attractiveness of implementing conservation agriculture for a farmer?*
		Same as success factor - Short term benefit that is offered by the practice comes from 1 principle of CA which is early planting, if farmers plant early, even in first year in short rain season the crop of this farmer will be higher. Basin in the case drought will save the seed. Long term benefit: soil organic matter.
	d	*What are the supports that farmers get if they implement conservation agriculture on their farm?*
		Inputs (hybrid seed, fertilizer, and herbicide) and also financial loan
17	a	*Who do you think are stakeholder in conservation agriculture implementation in Zambia? (stakeholders can be those who affect the process directly or indirectly)*
		1. Farmers 2. Civil society 3. Government 4. Research institution
	b	*What is each of their roles in conservation agriculture implementation in Zambia?*
		1. Practitioner 2. Trainer 3. Crop buyer 4. Farming Practice developer
	c	*Can you please explain each of their roles?*
		(read stakeholder in conservation agriculture implementation's role)
18		*What do you think about each of their current involvement in conservation agriculture implementation in Zambia?*
		(read stakeholder in conservation agriculture implementation's involvement)

About Condition after Conservation Agriculture

19	a	*How was the agriculture condition in terms of sustainability after conservation agriculture implementation in Zambia?*
		Reduction in the benign of crop residue, left some for livestock
	b	*How was the agriculture condition in terms of productivity after conservation agriculture*

		implementation in Zambia?
		Increase in productivity (yield/ha)
20	a	*What is current method that dominates farming management practice?*
		Conventional,
	b	*What are the other method's advantages compare to conservation agriculture?*
		(previously mentioned)-less herbicide
	c	*What are the other method's disadvantages compare to conservation agriculture?*
		Unsustainable for environment

APPENDIX B. MODEL EQUATION

"target of CA knowledge & skills"=
(potential knowledge acquired from CA share
+potential knowledge acquired from training)/2
~ dmnl
~ |

"change in knowledge & skills in CA practice"=
IF THEN ELSE("target of CA knowledge & skills">="Knowledge & Skills in CA practice",\
("target of CA knowledge & skills"-"Knowledge & Skills in CA practice")/adjustment time to acquire knowledge\
, 0)
~ dmnl/Year
~ |

potential consideration of CA as climate change adaptation=
Potential Consideration for CA as Climate Change Adaptation
~ dmnl
~ |

change in potential consideration=
IF THEN ELSE(Switch Policy Consideration=0, 0, (target of additional training-Potential Consideration for CA as Climate Change Adaptation\
)/adjustment time to acquire potential consideration)
~ dmnl/Year
~ |

potential consideration from training= WITH LOOKUP (
average additional training per farmer per year/"total training for increasing CA potential consideration/year"\
,
([(0,0)-(1,1)],(0,0.25),(0.13,0.3),(0.25,0.4),(0.5,0.7),(0.75,0.9),(1,1)))
~ dmnl
~ |

"total training for increasing CA potential consideration/year"=
1
~ training/Year
~ |

target of additional training=
potential consideration from training
~ dmnl
~ |

Policy New Ripper=
0
~ tool/Year [0,?,1]
~ |

Switch Policy Additional Ripper= GAME (
0)
~ dmnl [0,1,1]

~ |

adjustment time to acquire potential consideration==
2
~ Year
~ |

policy average additional training per farmer per year=
0
~ training/Year [?,4]
~ |

new ripper rate=
(average CA investment per farmer*percentage investment for ripper/ripper price)+policy additional ripper
~ tool/farmer/Year
~ |

average additional training per farmer per year=
IF THEN ELSE(Time<2015, 0, IF THEN ELSE(Switch Policy Consideration=0,
0, policy average additional training per farmer per year))
~ training/Year
~ |

Potential Consideration for CA as Climate Change Adaptation= INTEG (
change in potential consideration,
0.11)
~ dmnl
~ |

policy additional ripper=
IF THEN ELSE(Time<2015, 0, IF THEN ELSE(Switch Policy Additional Ripper=0, 0, Policy New Ripper\
/Total Farmers under CAP))
~ tool/(Year*farmer)
~ |

Switch Policy Consideration= GAME (
0)
~ dmnl [0,1,1]
~ |

Switch Policy Ripper Price= GAME (
0)
~ dmnl [0,1,1]
~ |

Switch Policy Training= GAME (
0)
~ dmnl [0,1,1]
~ |

ripping input cost=
IF THEN ELSE(Time<2015, base ripping input cost, IF THEN ELSE(Switch Input Price=0\
, base ripping input cost, percentage input price scenario*base ripping input cost)\
)
~ ZMK/(Year*hectare)
~ |

"base hand-hoe input cost"==
665505
~ ZMK/(Year*hectare)
~ Source Table 7: Partial budget analysis for CA and CV systems of \
smallholder farmers. Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. \
O. (2012). Are Smallholder Zambian Farmers Economists? A Dual-Analysis of \
Farmers' Expenditure in Conservation and Conventional Agriculture \
Systems. Journal of Sustainable Agriculture, 36(8), 908-929.
|

plough input cost=
IF THEN ELSE(Time<2015, base plough input cost, IF THEN ELSE(Switch Input Price=0,\
base plough input cost, percentage input price scenario*base plough input cost))
~ ZMK/(Year*hectare)
~ Source Table 7: Partial budget analysis for CA and CV systems of \
smallholder farmers. Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. \
O. (2012). Are Smallholder Zambian Farmers Economists? A Dual-Analysis of \
Farmers' Expenditure in Conservation and Conventional Agriculture \
Systems. Journal of Sustainable Agriculture, 36(8), 908-929.
|

base ripping input cost==
1.45913e+006
~ ZMK/(Year*hectare)
~ Source Table 7: Partial budget analysis for CA and CV systems of \
smallholder farmers. Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. \
O. (2012). Are Smallholder Zambian Farmers Economists? A Dual-Analysis of \
Farmers' Expenditure in Conservation and Conventional Agriculture \
Systems. Journal of Sustainable Agriculture, 36(8), 908-929.
|

current ripper price==
400000
~ ZMK/tool
~ |

percentage input price scenario= GAME (
1)
~ dmnl [0,3]
~ |

ripper price=
IF THEN ELSE(Time<2015, current ripper price, IF THEN ELSE(Switch Policy Ripper Price\
=0, current ripper price, Policy Ripper Price))
~ ZMK/tool
~ |

Policy Ripper Price=
400000
~ ZMK/tool [0,?]
~ |

base basin input cost==
662336
~ ZMK/(Year*hectare)

~ Source Table 7: Partial budget analysis for CA and CV systems of \
smallholder farmers. Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. \
O. (2012). Are Smallholder Zambian Farmers Economists? A Dual-Analysis of \
Farmers' Expenditure in Conservation and Conventional Agriculture \
Systems. Journal of Sustainable Agriculture, 36(8), 908-929.
|

basin input cost=
IF THEN ELSE(Time<2015, base basin input cost, IF THEN ELSE(Switch Input Price=0, \
base basin input cost, percentage input price scenario*base basin input cost))
~ ZMK/(Year*hectare)
~ Source Table 7: Partial budget analysis for CA and CV systems of \
smallholder farmers. Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. \
O. (2012). Are Smallholder Zambian Farmers Economists? A Dual-Analysis of \
Farmers' Expenditure in Conservation and Conventional Agriculture \
Systems. Journal of Sustainable Agriculture, 36(8), 908-929.
|

base plough input cost==
1.31498e+006
~ ZMK/(Year*hectare)
~ |

"hand-hoe input cost"=
IF THEN ELSE(Time<2015, "base hand-hoe input cost", IF THEN ELSE(Switch Input Price\
=0, "base hand-hoe input cost", percentage input price scenario*"base hand-hoe input cost"\
))
~ ZMK/(Year*hectare)
~ |

average training per farmer per year=
IF THEN ELSE(Time<2015, historical average training per farmer per year, IF THEN ELSE\
(Switch Policy Training=0, historical average training per farmer per year, policy average training per farmer per year\
))
~ training/Year
~ |

Switch Input Price= GAME (
0)
~ dmnl [0,1,1]
~ |

potential effect on discharge from CV trust=
Trust in Conventional Agriculture*"weight of CA trust for adoption-discharge rate"
~ dmnl
~ |

rainfall intensity scenario= GAME (
878.83)
~ Milimeter/Year
~ |

crop price=
IF THEN ELSE(Time<2015, normal crop price, IF THEN ELSE(Switch Crop Price=0, normal crop price\
, crop price scenario))

```
	~	ZMK/kg
	~	Based on Table 7: Partial budget analysis for CA and CV systems of \
		smallholder farmers
	|

crop price scenario= GAME (
	900)
	~	ZMK/kg
	~		|

rainfall intensity=
	IF THEN ELSE(Time<2015, normal rainfall intensity, IF THEN ELSE( Switch Climate Change\
		=0, normal rainfall intensity
	, rainfall intensity scenario))
	~	Milimeter/Year
	~		|

Total Farmers under CAP= INTEG (
	addition in number of farmer,
		75000)
	~	farmer
	~		|

effectiveness of CV method==
	0.6
	~	dmnl
	~		|

CV yield productivity=
	((effect of rainfall intensity+effect of fertilizer used in CV farm-percent of yield decline as effect of delay
planting
	)*effectiveness of CV method)*potential yield productivity
	~	kg/(hectare*Year)
	~		|

adoption rate=
	(potential effect on adoption from comparative CA attractiveness+potential effect on adoption from CA
trust\
		)*Area under Conventional Agriculture
	/adjustment time to adopt
	~	hectare/Year
	~		|

CA input packages=
	IF THEN ELSE(Time<2015, input packages, IF THEN ELSE(Switch Input Package=0, input packages\
		,input packages policy))
	~	dmnl
	~		|

increase in CA trust=
	(potential effect on CA trust from CA adoption+effect of awareness of climate change to increase in trust
	)*potential effect on trust from yield ratio*Trust in Conventional Agriculture
	/adjustment time to increase CA trust
	~	dmnl/Year
	~		|
```

"potential effect on yield from Knowledge & Skills"=
(SMOOTH("Knowledge & Skills in CA practice", adjustment time to improve CA yield))*weight effect of Knowledge to CA yield productivity
~ dmnl
~ |

discharge rate=
(potential discharge from food security condition*potential effect on discharge from CV trust\
)*Area under Conservation Agriculture
/adjustment time to discharge
~ hectare/Year
~ |

normal crop price==
900
~ ZMK/kg
~ Source: Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). \
Are Smallholder Zambian Farmers Economists? A Dual-Analysis of Farmers' \
Expenditure in Conservation and Conventional Agriculture Systems. Journal \
of Sustainable Agriculture, 36(8), 908-929.
|

CA yield ratio=
CA yield productivity/CV yield productivity
~ dmnl
~ |

decrease in CA trust=
(potential effect on CV trust from CV adoption+potential effect on decrease of CA trust CA from tools ownership to\
)*Trust in Conservation Agriculture
/adjustment time to decrease CA trust
~ dmnl/Year
~ |

Switch Input Package= GAME (
0)
~ dmnl [0,1,1]
~ |

normal rainfall intensity==
878.83
~ Milimeter/Year
~ calculated based on Bridget Bwalya Umar et al. (2011)
|

Switch Crop Price= GAME (
0)
~ dmnl [0,1,1]
~ |

Switch Climate Change= GAME (
0)
~ dmnl [0,1,1]
~ |

```
weight effect of Knowledge to CA yield productivity==
	0.5
	~	dmnl
	~		|

Historical Area under CA= WITH LOOKUP (
	Time,
		([(2007,0)-(2010,90000)],(2007,30187.5),(2008,46183.5),(2009,76196.5),(2010,86814) \
		))
	~	hectare
	~		|

input packages policy=
	0.4745
	~	dmnl [0,1]
	~		|

average CV cost=
	hand hoeing cost-potential effect from CV tool availability*(hand hoeing cost-ploughing cost\
		)
	~	ZMK/(hectare*Year)
	~		|

general input packages=
	0.27
	~	dmnl
	~		|

Area under Conventional Agriculture= INTEG (
	additional area under CAP+discharge rate-adoption rate,
		initial CV)
	~	hectare
	~		|

ploughing cost=
	"plough hired-labor cost"+plough input cost*(1-general input packages)
	~	ZMK/(hectare*Year)
	~	Based on Table 8: total variable costs as reported by households in Umar, \
		B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
		Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
		Conservation and Conventional Agriculture Systems. Journal of Sustainable \
		Agriculture, 36(8), 908-929.
	|

Area under Conservation Agriculture= INTEG (
	adoption rate-discharge rate,
		initial CA)
	~	hectare
	~		|

hand hoeing cost=
	"hand-hoe hired-labor cost"+"hand-hoe input cost"*(1-general input packages)
	~	ZMK/(hectare*Year)
	~	Based on Table 8: total variable costs as reported by households in Umar, \
		B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
		Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
```

Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

weight of comparative attractiveness==
0.38
~ dmnl [0,2]
~ |

CA attractiveness=
EXP(average CA labor requirement*utility elasticity labor requirement+CA yield productivity\
*utility elasticity yield+average CA cost*utility elasticity cost)
~ dmnl
~ |

CV attractiveness=
EXP(average CV labor requirement*utility elasticity labor requirement+CV yield productivity\
*utility elasticity yield+average CV cost
*utility elasticity cost)
~ dmnl
~ |

ripping cost=
"ripping hired-labor cost"+ripping input cost*(1-CA input packages)
~ ZMK/(hectare*Year)
~ Based on Table 8: total variable costs as reported by households in Umar, \
B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

potential effect on adoption from comparative CA attractiveness=
IF THEN ELSE(comparative CA attractiveness<0.5, 0, comparative CA attractiveness*weight of comparative attractiveness\
)
~ dmnl
~ |

basin cost=
"basin hired-labor cost"+basin input cost*(1-CA input packages)
~ ZMK/(hectare*Year)
~ Based on Table 8: total variable costs as reported by households in Umar, \
B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

standard fertilizer used in CV==
200
~ kg/hectare
~ |

effect of fertilizer used in CV farm=

potential yield ratio without fertilizer+degree of fertilization in CA farm*(potential yield ratio with fertilizer\
-potential yield ratio without fertilizer)
~ dmnl
~ |

degree of fertilization in CA farm=
actual fertilizer used/standard fertilizer used in CV
~ dmnl
~ |

actual fertilizer used= WITH LOOKUP (
Time,
([(2005,0)-(2010,100)],(2007,32.3),(2008,39.99),(2009,37.39),(2010,63.1)))
~ kg/hectare
~ |

effectivenesss from CA methods=
effectiveness from basin-potential effect from CA tool availability*(effectiveness from basin\
-effectiveness from ripping)
~ dmnl
~ |

input packages= WITH LOOKUP (
Time,
([(2006,0.4)-(2009.1,0.6)],(2006,0.44),(2007,0.47),(2008,0.52),(2009.01,0.4745)))
~ dmnl [0,1]
~ |

"ripping hired-labor cost"==
99685
~ ZMK/(Year*hectare)
~ Calculated based on Table 2 & 3: Labour use on different phases of farming \
cycle and Table 8: Total variable costs as reported by household. Umar, B. \
B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

CA yield productivity=
potential yield productivity*("potential effect on yield from Knowledge & Skills"+(effect of rainfall intensity\
+effect of fertilizer used in CA farm)*effectivenesss from CA methods
)
~ kg/(hectare*Year)
~ |

degree of fertilization=
actual fertilizer used/standard fertilizer used
~ dmnl
~ |

standard fertilizer used==
220
~ kg/hectare

~ |

effectiveness from ripping==
0.5
~ dmnl
~ |

"hand-hoe hired-labor cost"==
158649
~ ZMK/(Year*hectare)
~ Calculated based on Table 2 & 3: Labour use on different phases of farming \
cycle and Table 8: Total variable costs as reported by household. Umar, B. \
B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

"plough hired-labor cost"==
153261
~ ZMK/(Year*hectare)
~ Calculated based on Table 2 & 3: Labour use on different phases of farming \
cycle and Table 8: Total variable costs as reported by household. Umar, B. \
B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

weight of CA tools ownership to decrease of CA trust=
0.1
~ dmnl
~ |

effectiveness from basin==
1
~ dmnl
~ |

potential effect on decrease of CA trust CA from tools ownership to=
tools for CA*weight of CA tools ownership to decrease of CA trust
~ dmnl
~ |

potential yield ratio with fertilizer==
1
~ dmnl
~ |

potential yield ratio without fertilizer==
0.25
~ dmnl
~ |

"basin hired-labor cost"==
279764

~ ZMK/(Year*hectare)
~ Calculated based on Table 2 & 3: Labour use on different phases of farming \
cycle and Table 8: Total variable costs as reported by household. Umar, B. \
B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

effect of fertilizer used in CA farm=
potential yield ratio without fertilizer+degree of fertilization*(potential yield ratio with fertilizer\
-potential yield ratio without fertilizer)
~ dmnl
~ |

potential effect on adoption from CA trust=
Trust in Conservation Agriculture*"weight of CA trust for adoption-discharge rate"
~ dmnl
~ |

"weight of CA trust for adoption-discharge rate"==
0.5
~ dmnl [0,?]
~ |

addition in number of farmer=
number of new farmer/adjustment time to add
~ farmer/Year
~ |

additional area under CAP=
new area/adjustment time to add
~ hectare/Year
~ |

additional target farmer==
6600
~ farmer
~ |

ideal awareness==
1
~ dmnl
~ |

adjustment time to change awareness=
20
~ Year
~ |

CA revenue=
crop price*CA yield productivity
~ ZMK/(hectare*Year)
~ |

new area=

number of new farmer*average farmer's area
~ hectare
~ |

new plough rate=
average CV investment per farmer*percentage plough investment/plough price
~ tool/farmer/Year
~ |

new trained oxen rate=
(average CA investment per farmer*(1-percentage investment for ripper)+average CV investment per farmer\
*(1-percentage plough investment
))/oxen price
~ tool/farmer/Year
~ |

"number of days/year"==
365
~ days/Year
~ |

available tools for CA=
MIN("average ripper/hectare", average trained oxen per hectare)
~ tools/hectare
~ |

available tools for CV=
MIN("average plough/hectare", average trained oxen per hectare)
~ tools/hectare
~ |

average availability for household consumption==
0.28
~ dmnl
~ |

average CA cost=
basin cost-potential effect from CA tool availability*(basin cost-ripping cost)
~ ZMK/(hectare*Year)
~ |

average CA investment per farmer=
average CA investment per hectare*Area under Conservation Agriculture/Total Farmers under CAP
~ ZMK/(Year*farmer)
~ |

average CA investment per hectare=
percentage for investment*CA profit
~ ZMK/(hectare*Year)
~ |

average CA labor requirement=
basin labor requirement-potential effect from CA tool availability*(basin labor requirement\
-ripping labor requirement)
~ persondays/hectare

~ |

average CV investment per farmer=
average CV investment per hectare*Area under Conventional Agriculture/Total Farmers under CAP
~ ZMK/farmer/Year
~ |

average CV investment per hectare=
percentage for investment*CV profit
~ ZMK/(hectare*Year)
~ |

average CV labor requirement=
hand hoeing labor requirement-potential effect from CV tool availability*(hand hoeing labor requirement\
-ploughing labor requirement)
~ persondays/hectare
~ |

average delay to start planting=
(3+14)/2
~ day
~ Hand hoe is 3 days late and ploughing is 14 days late. Source:Table 16. \
Average dates started planting maize under various tillage methods in \
2009/2010 season. Nyanga, P. H., & Johnsen, F. H. (2010). 2009/2010 \
Monitoring and Evaluation Draft Report: Noragric.
|

ploughing labor requirement==
45.9
~ persondays/hectare
~ Calculated based on Table 2: Labour use on different phases of farming \
cycle for hand based tillage system and Table 3:Labour use in different \
phases of farming cycle for animal powered tillage systems. Umar, B. B., \
Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

average household size= WITH LOOKUP (
Time,
([(0,0)-(3000,10)],(2005,7.51),(2006,7.53),(2007,7.54),(2008,7.58),(2009,7.79)))
~ people/farmer
~ |

"Average Plough/ farmer"= INTEG (
new plough rate-plough depreciation rate,
0.6)
~ tool/farmer
~ |

"average plough/hectare"=
"Average Plough/ farmer"/average farmer's area
~ tool/hectare
~ |

```
"Average Ripper/ Farmer"= INTEG (
	new ripper rate-ripper depreciation rate,
		0.03)
	~	tool/farmer
	~		|

"average ripper/hectare"=
	"Average Ripper/ Farmer"/average farmer's area
	~	tools/hectare
	~		|

average trained oxen per hectare=
	"Average Trained Oxen/ Farmer"/average farmer's area
	~	tools/hectare
	~		|

"Average Trained Oxen/ Farmer"= INTEG (
	new trained oxen rate-decrease of trained oxen,
		0.9)
	~	tools/farmer
	~		|

hand hoeing labor requirement==
	98.09
	~	persondays/hectare
	~	Calculated based on Table 2: Labour use on different phases of farming \
		cycle for hand based tillage system and Table 3:Labour use in different \
		phases of farming cycle for animal powered tillage systems. Umar, B. B., \
		Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
		Zambian Farmers Economists? A Dual-Analysis of Farmers’ Expenditure in \
		Conservation and Conventional Agriculture Systems. Journal of Sustainable \
		Agriculture, 36(8), 908-929.
	|

basin labor requirement==
	88.71
	~	persondays/hectare
	~	Calculated based on Table 2: Labour use on different phases of farming \
		cycle for hand based tillage system and Table 3:Labour use in different \
		phases of farming cycle for animal powered tillage systems. Umar, B. B., \
		Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
		Zambian Farmers Economists? A Dual-Analysis of Farmers’ Expenditure in \
		Conservation and Conventional Agriculture Systems. Journal of Sustainable \
		Agriculture, 36(8), 908-929.
	|

CA profit=
	CA revenue-average CA cost
	~	ZMK/(hectare*Year)
	~		|

depreciation time of plough=
	10
	~	Year
	~		|
```

production available for human consumption=
average availability for household consumption*total maize production
~ kg/Year
~ |

"dietary need/person/day of maize"==
1670
~ kcal/day/people
~ FAO Food Security Indicator
|

ripper depreciation rate=
"Average Ripper/ Farmer"/depreciation time of ripper
~ tool/farmer/Year
~ |

change in perceived awareness=
(ideal awareness-Perceived awareness of climate change)/adjustment time to change awareness
~ dmnl/Year
~ |

comparative CA attractiveness=
CA attractiveness/(CA attractiveness+CV attractiveness)
~ dmnl
~ |

crop to food conversion factor==
0.9
~ dmnl
~ |

CV profit=
CV revenue-average CV cost
~ ZMK/(hectare*Year)
~ |

CV revenue=
crop price*CV yield productivity
~ ZMK/hectare/Year
~ |

percentage for investment=
0.25
~ dmnl
~ |

percentage of farm with maize==
0.82
~ dmnl
~ Calculated based on Table 23. Area under non-legume crops in hectares. \
Nyanga, P. H., & Johnsen, F. H. (2010). 2009/2010 Monitoring and \
Evaluation Draft Report: Noragric.
|

decrease of trained oxen=
"Average Trained Oxen/ Farmer"/period of oxen as drafter

~ tool/(Year*farmer)
~ |

period of oxen as drafter=
7
~ Year
~ |

depreciation time of ripper=
10
~ Year
~ |

plough price=
600000
~ ZMK/tool
~ |

effect of awareness of climate change to increase in trust=
Perceived awareness of climate change*potential consideration of CA as climate change adaptation
~ dmnl
~ |

effect of rainfall intensity= WITH LOOKUP (
rainfall intensity,
([(0,0)-(2000,1)],(0,0),(100,0),(200,0),(300,0.1),(400,0.2),(500,0.3),(581.04,0.412281\
),(660.55,0.517544),(733.945,0.666667),(805.2,0.8026),(896.9,0.802632),(1009.17,0.842105\
),(1135,0.635965),(1204.89,0.447368),(1272.17,0.27193)))
~ dmnl
~ Source Munodawafa, A. (2012). The Effect of Rainfall Characteristics and \
Tillage on Sheet Erosion and Maize Grain Yield in Semiarid Conditions and \
Granitic Sandy Soils of Zimbabwe. Applied and Environmental Soil Science, \
2012.
|

energy adequacy=
total energy availability/"dietary need/person/day of maize"
~ people
~ |

energy value==
3070
~ kcal/kg
~ |

utility elasticity yield=
0.000185
~ 1/(kg/hectare/Year) [-1,1]
~ |

food sufficiency=
energy adequacy/total population under CAP project
~ dmnl
~ |

percent of yield decline as effect of delay planting=

```
	average delay to start planting*yield loss per day delay
	~	dmnl
	~		|

"desired number of tools/hectare"==
	1
	~	tools/hectare
	~		|

percentage investment for ripper=
	0.05
	~	dmnl
	~		|

total energy availability=
	quantity staple food for human consumption*energy value/"number of days/year"
	~	kcal/day
	~		|

percentage plough investment=
	0.4
	~	dmnl
	~		|

total maize production=
	total production from CA+total production from CV
	~	kg/Year
	~		|

potential yield productivity==
	3000
	~	kg/hectare/Year
	~		|

total production from CA=
	percentage of farm with maize*Area under Conservation Agriculture*CA yield productivity
	~	kg/Year
	~		|

quantity staple food for human consumption=
	crop to food conversion factor*production available for human consumption
	~	kg/Year
	~	Zambian food balance sheet
	|

number of new farmer=
	IF THEN ELSE( Time<2011, new farmer, additional target farmer)
	~	farmer
	~		|

potential effect from CV tool availability=
	IF THEN ELSE(0.508*LN(tools for CV)+1.4845>1, MIN(1, 0.508*LN(tools for CV)+1.4845),\
		 MAX(0, 0.508*LN(tools for CV)+1.4845))
	~	dmnl
	~		|
```

oxen price=
900000
~ ZMK/tool
~ |

Perceived awareness of climate change= INTEG (
change in perceived awareness,
0.7)
~ dmnl
~ |

tools for CV=
available tools for CV/"desired number of tools/hectare"
~ dmnl
~ |

ripping labor requirement==
57.18
~ persondays/hectare
~ Calculated based on Table 2: Labour use on different phases of farming \
cycle for hand based tillage system and Table 3:Labour use in different \
phases of farming cycle for animal powered tillage systems. Umar, B. B., \
Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are Smallholder \
Zambian Farmers Economists? A Dual-Analysis of Farmers' Expenditure in \
Conservation and Conventional Agriculture Systems. Journal of Sustainable \
Agriculture, 36(8), 908-929.
|

potential discharge from food security condition=
food sufficiency
~ dmnl
~ |

potential effect from CA tool availability=
IF THEN ELSE((0.2014*LN(tools for CA))+0.9731>1, MIN(1, (0.2014*LN(tools for CA))+0.9731\
), MAX(0, (0.2014*LN(tools for CA))+0.9731))
~ dmnl
~ |

utility elasticity labor requirement=
-0.032
~ 1/(persondays/hectare) [-1,1]
~ |

plough depreciation rate=
"Average Plough/ farmer"/depreciation time of plough
~ tool/farmer/Year
~ |

yield loss per day delay==
0.015
~ dmnl/day
~ |

tools for CA=
available tools for CA/"desired number of tools/hectare"

~ dmnl
~ |

total population under CAP project=
average household size*Total Farmers under CAP
~ people
~ |

utility elasticity cost=
-2.2e-006
~ 1/(ZMK/hectare/Year) [-0.001,0,1e-005]
~ |

total production from CV=
Area under Conventional Agriculture*CV yield productivity*percentage of farm with maize
~ kg/Year
~ |

historical average training per farmer per year= WITH LOOKUP (
Time,
([(2005,0)-(2016,5)],(2005,0),(2006,1.15),(2007,2.67),(2008,2.37),(2009,2.59)))
~ training/Year
~ Source:Table 12. Average number of CFU training sessions attended. Nyanga, \
P. H., & Johnsen, F. H. (2010). 2009/2010 Monitoring and Evaluation Draft \
Report: Noragric.
|

adjustment time to acquire knowledge==
2
~ Year
~ |

CA share=
Area under Conservation Agriculture/Total area
~ dmnl
~ |

adjustment time to decrease CA trust==
2
~ Year [0,?]
~ |

"Knowledge & Skills in CA practice"= INTEG (
"change in knowledge & skills in CA practice",
0.05)
~ dmnl
~ |

adjustment time to improve CA yield==
15
~ Year
~ |

adjustment time to increase CA trust==
3
~ Year [0,?]

~ |

potential effect on CV trust from CV adoption=
CV share
~ dmnl
~ |

potential effect on trust from yield ratio= WITH LOOKUP (
CA yield ratio,
([(1,0)-(2,1)],(1.00917,0.0614035),(1.2263,0.135965),(1.42202,0.254386),(1.5474,0.640351\
),(1.737,0.75),(1.98165,0.820175)))
~ dmnl
~ |

potential knowledge acquired from CA share=
CA share
~ dmnl
~ |

CV share=
Area under Conventional Agriculture/Total area
~ dmnl
~ |

total training per year=
4
~ training/Year
~ |

policy average training per farmer per year=
2.59
~ training/Year [?,4]
~ |

potential knowledge acquired from training= WITH LOOKUP (
average training per farmer per year/total training per year,
([(0,0)-(1,1)],(0,0.25),(0.13,0.3),(0.25,0.4),(0.5,0.7),(0.75,0.9),(1,1)))
~ dmnl
~ |

Trust in Conventional Agriculture= INTEG (
decrease in CA trust-increase in CA trust,
1-Trust in Conservation Agriculture)
~ dmnl
~ |

Trust in Conservation Agriculture= INTEG (
increase in CA trust-decrease in CA trust,
0.05)
~ dmnl
~ |

potential effect on CA trust from CA adoption=
CA share
~ dmnl
~ |

```
adjustment time to add=
	IF THEN ELSE(Time<2011, 1, 5)
	~	Year
	~		|

adjustment time to adopt==
	2
	~	Year [0,?]
	~		|

adjustment time to discharge==
	2
	~	Year [0,?]
	~		|

new farmer= WITH LOOKUP (
	Time,
		([(2005,0)-(2010,50000)],(2005,0),(2006,45000),(2007,13000),(2008,13000),(2009,13000\
		),(2010,12000)))
	~	farmer
	~	Estimated based on Haggblade, S., & Tembo, G. (2003a). Conservation \
		farming in Zambia: Intl Food Policy Res Inst. and MFA. (2011). ZAM 3037 \
		ZAM 09/014 Conservation Agriculture Programme phase II (CAP II) (pp. 12). \
		Zambia: Norwegian Ministry of Foreign Affairs (MFA).
	|

average farmer's area==
	2.1
	~	hectare/farmer
	~	Source: Nyanga, P. H., & Johnsen, F. H. (2010). 2009/2010 Monitoring and \
		Evaluation Draft Report: Noragric (tabulated)
	|

Total area=
	Area under Conservation Agriculture+Area under Conventional Agriculture
	~	hectare
	~		|

initial CA==
	12000
	~	hectare [0,30000,500]
	~		|

initial CV= INITIAL(
	75000*2.1-initial CA)
	~	hectare
	~		|
```