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Exploratory model of conservation agriculture adoption and diffusion in Zambia: A dynamic perspective

Dea Fitri Amelia[1], Birgit Kopainsky[2], Progress H. Nyanga[3]
[1] e-mail: dea.amelia@student.ru.nl
+ e-mail: maria.saldarriaga@geog.uib.no
2 System Dynamics Group, Department of Geography, University of Bergen, P.O. Box 7800, 5020 Bergen, Norway
e-mail: birgit.kopainsky@geog.uib.no; phone: +47 55 58 30 92; fax: +47 55 58 30 99
[2] Geography and Environmental Studies Department, School of Natural Sciences, University of Zambia, P.O. Box 32379, Lusaka, Zambia, 10101

ABSTRACT

Population growth and constant arable land in Zambia continuously increase the scarcity of decreases the availability soil for agricultural purposes and thus the risk of food insecurity. The importance of soil as a vital resource in the agricultural production system increases with the expected impacts of climate change.

Conservation agriculture is highly promoted in Zambia as a sustainable agricultural practice. Conservation agriculture protects the sustainability of minerals in the soil, which leads to higher and more stable yields. However, conservation agriculture in Zambia is only conducted as part of farmers' farming practice, which means that farmers still use other practices or mix some practices from conservation agriculture with conventional agriculture practices.

Previous studies have identified important determinants of conservation agriculture adoption as an innovation in agricultural practice in sub-Saharan Africa. However, none of those capture the dynamics of adoption and diffusion process. This study uses a system dynamics model to study adoption and diffusion patterns of conservation agriculture. The model structure is based on economic and social determinants identified in previous adoption studies and reports and it is calibrated using a combination of quantitative and qualitative data collection methods. Policy analyses identify coherent policy options to increase the implementation of conservation agriculture.

INTRODUCTION

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, 2013b). Poverty (Bain et al., 2013; FAO, 2013c; Vermeulen, Campbell, & Ingram, 2012), gendered access to productive resource (FAO, 2012) and other factors considerably affect the state of food security in sub-Saharan Africa. Climate change (Bain et al., 2013; Brown, 2004; Lobell et al., 2008; 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 (FAO, IFAD, and WFP, 2013).

Maize, the main staple food in most of sub-Saharan Africa countries, is projected to be affected negatively by climate change (Jones & Thornton, 2003; Lobell et al., 2008). A wide range in adaptation options to counter the impacts of climate change on agriculture production have been promoted, such as technological developments, governments programs and insurance schemes, farm production practices, and farm financial management (Smit & Skinner, 2002).

Population growth in Zambia has been about 300.000 people annually or 2.7% on average in the last 11 years (FAO, 2013b). The Zambian population has grown from 10.4 million in 2001 to 13.9 million in 2012 (FAO, 2013b) while the total of arable land could not increase considerably and currently is still around 2.900.000 hectares (FAO, 2013b). The ratio between a growing population and constant arable land makes the availability of soil become even more important. Soil is a renewable resource that needs to be conserved for it to fulfill the manifold functions it has. Soil in Zambia, however, is damaged as the result of indigenous[1] and conventional farming practices[2].

The limited availability of arable land and also the impacts of climate change such as increase in temperature and variability of rainfall in sub-Saharan Africa make soils become a crucial resource for farming systems. Therefore, it is essential that their sustainability be maintained. Conservation agriculture is an agricultural production practice that is currently highly promoted in sub-Saharan Africa. The principles of conservation agriculture 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 make soil retain minerals better than conventional agriculture practices, reduce soil

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

[2] Conventional agriculture is tilling-based agricultural practice

erosion, increase water absorption and generate higher and more stable yields (Kassam, Friedrich, Shaxson, & Pretty, 2009).

Zambia has the highest percentage of conservation agriculture area on total cultivated area among sub-Saharan African countries (FAO, 2013a) and it is reported to have reduced the intensity of food shortages during peak hunger periods because of early green harvests from conservation agriculture practice (Nyanga, 2012b). In spite of increases in productivity from conservation agriculture practices (Haggblade & Tembo, 2003), conservation agriculture in Zambia is only partially adopted by Zambian smallholder farmers, that is, they only implement the farming principles on parts of their farm (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 (2012b)). However, those evaluations do not capture the dynamics of the diffusion of conservation agriculture. 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.

Conservation agriculture was introduced to Zambian farmers in the mid 1990s. It can thus be regarded as an innovation or innovative agricultural practice. Adoption and diffusion are the processes governing the utilization of innovations (Kopainsky, Tröger, Derwisch, & Ulli-Beer, 2012). This paper aims at explaining the economic and social determinants of conservation agriculture adoption from a dynamic perspective. This involves developing a structural explanation of the behavior patterns observed in the past. By understanding the root causes of the observed dynamic behavior, we can analyze the implications over time of plausible interventions to foster implementation of conservation agriculture in Zambia and thus the preconditions for enhancing diffusion of conservation agriculture in Zambia.

BACKGROUND

Conservation Agriculture – Conservation agriculture is a farming concept that aims to gain acceptable profit through high and sustained production levels by conserving the key resources of soil and water (Coughenour & Chamala, 2000; Kassam et al., 2009). In conservation agriculture, productivity results from protecting the environment and the processes that happens in it. The basic principles of conservation agriculture are to apply crop rotation, to retain soil coverage and minimum soil disturbance (Baudron et al., 2007; Coughenour & Chamala, 2000; Hobbs, 2007; Kassam et al., 2009; Twomlow et al., 2008). Some of the idea of conservation agriculture is different to conventional agriculture practice, which tills the soil to prevent weed to grow and does not apply soil coverage

Conservation agriculture was started as a new agriculture practice to counter the effect of conventional tilling farming practice. In Zambia, conservation agriculture practices were introduced as a solution for damaged soil resulting from indigenous and conventional farming practices. Currently, the Ministry of Agriculture and Livestock (MAL) embraces conservation agriculture as an official policy of the Zambian government. Consequently, the government has established conservation agriculture in the National Agricultural Policy (MAL, 2013).

Table 1. List of stakeholders in conservation agriculture in Zambia

No	Stakeholder Group	Institution	Description
1	User	Individual Farmer	Stakeholder who has direct involvement on daily farming practice
2	Farming Advisory	- Zambian National Farmer's Union (ZNFU) - Conservation Farming Unit (CFU) - The Golden Valley Agricultural Research Trust (GART) - Dunavant (also become donor agencies) - Agriculture Support Programme of MAL	Stakeholder who gives assistance about better farming practice. Besides giving counseling to the farmers, farming advisors also act as supplier of subsidized input packages (high-yielding-variety seeds; fertilizer, and herbicide) for farmers
3	Donor Agencies	- Food and Agriculture Organization (FAO) - Norwegian Agency for Development Cooperation (NORAD) - World Bank	Stakeholders who aids the promotion of conservation agriculture practice
4	Researcher	- Zambia Agriculture Research Institute of MAL - Institute of Agriculture and Environmental Engineering (works under the Agricultural Research Department (DLO) of the Ministry of Agriculture, Nature Management and Fisheries of The Netherlands)	Gives advisory to farming advisors for increasing adoption of conservation farming practices.
5	Ministry	Ministry of Agriculture and Livestock (MAL)	MAL acts as policy maker in agricultural system in Zambia.

Sources: (Baudron et al., 2007; Haggblade & Tembo, 2003)

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) (Table 1 and Figure 1). In Zambia, farming advisors and donor agencies together with researchers have an important position in promoting conservation agriculture among farmers (Haggblade & Tembo, 2003). The implementation of conservation agriculture in Zambia highly depends on aid from donor agencies that support the promotion of conservation agriculture practice among farmers. The promotion activities are mainly conducted by farming advisors from many non-governmental organizations (NGOs) in Zambia such as the Conservation Farming Unit (CFU), Zambia National Farmers Union (ZFNU), and Agriculture Support Programme (ASP). 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.

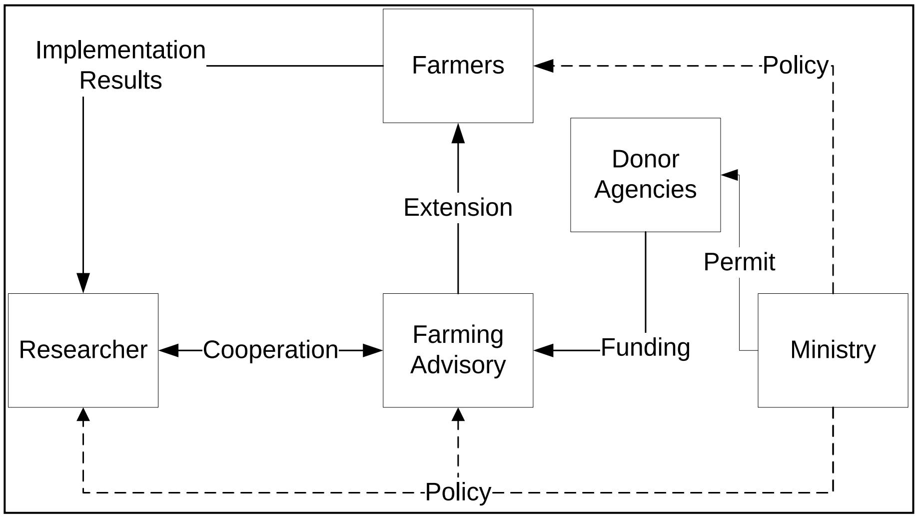

Figure 1. Relations between stakeholders

Innovation Adoption and Diffusion in Socio-economic systems – Diffusion is the process in which innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003). From the definition there are four important factors in diffusion process (1) innovation (2) communication through certain channels (3) over time (4) social system. Innovation is defined as idea, practice, or object perceived as new by an individual or other unit of adoption (Rogers, 2003). While diffusion explains the aggregate concept of a group of people implementing the new idea, adoption describes the individual decision to use the new idea. Rogers (2003) also mentioned that a crucial point in the innovation diffusion process is the communication of the innovation to potential adopters and how it will be evaluated for its different dimensions. Perceived attributes of innovations, the type of innovation-decision, communication channels, the nature of the social system, and the extent of agents' promotion efforts are variables determining the rate of adoption and have been found to explain about half of the variance in innovations' rate of adoption (Rogers, 2003).

Existing studies about the adoption of conservation agriculture in general and in Zambia in specific have identified the following determinants (Haggblade & Tembo, 2003; Nyanga, 2012b)

1. Absolute yield (harvest per unit area) and stability of yield under variable climatic conditions
2. Labor intensity (a factor that usually affects adoption of conservation agriculture negatively)
3. Availability of appropriate equipment
4. Cost of production inputs such as fertilizer
5. Incentives such as free seeds, fertilizer or diversifying products
6. Experience with and trust in the effectiveness of conservation agriculture
7. Cultural norms.

While the first five determinants describe utility aspects of conservation agriculture, the latter two are social constructs that might reinforce or compete with utility evaluations. Capturing the diffusion process of conservation agriculture and supporting it with adequate policy instruments requires a dynamic perspective. In this paper, we develop and calibrate a system dynamics model that represents utility evaluations and social dynamics for the case of conservation agriculture in Zambia. With our model, we analyze the dynamic impact of different policy options and derive conclusions for further research.

MODEL STRUCTURE

The structure of the simulation model is based on the diffusion of agricultural innovations framework described in Kopainsky et al. (2012). This framework includes an endogenous social norm-building process and was applied to the diffusion of new agricultural technology (improved maize seed varieties). Our model replicates a norm-building structure that addresses the phenomenon of a tipping point or a critical mass, 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.

Adoption and diffusion of conservation agriculture depends on how farmers evaluate the new practice and act on the evaluations. In its most basic form, these evaluations can be described as a simple adoption structure with a stock of non-adopters, a stock of adopters, an adoption rate linking the non-adopters to the adopters and a discard rate that turns adopters back to non-adopters (Figure 2). The "trust in conventional agriculture" and "trust in conservation agriculture" stocks in the figure represent the two different norms underlying the two farming practices.

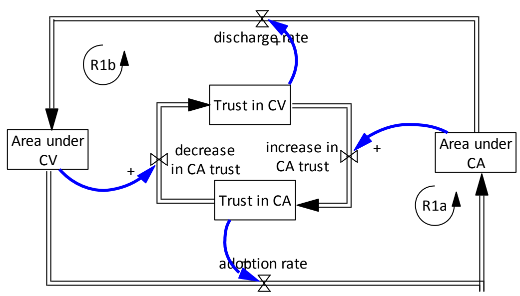

Figure 2. Core structure of the adoption and diffusion model

The trust structure in Figure 2 describes social processes such as farmers copying other farmers on the basis of prestige, regardless of that farmer's actual success with the innovation, and farmers adopting an innovation when and because many others have adopted it. The link between the adopter stock and the trust building process forms a reinforcing loop (*R1a*, "social learning") that enhances adoption and diffusion of conservation agriculture.

Similar to the R1a loop, the discharge rate is determined by a reinforcing feedback loop (*R1b*; "back to conventional agriculture"), where the stock of trust in conventional agriculture depends nonlinearly on the share of non-adopters (Figure 2)

The adoption rate in Figure 3 is determined by evaluations of the relative attractiveness of conservation agriculture and trust in conservation agriculture. The relative attractiveness of conservation agriculture depends on the attractiveness of conservation agriculture (CA) compared to the attractiveness of conventional agriculture (CV). Attractiveness is determined by attributes such as input costs (seeds and fertilizer), yield, and labor requirements.

An additional learning process influences innovation adoption and diffusion. In the course of this process, farmers develop the skills needed for fully exploiting the potential of conservation agriculture. Individual learning improves the farmers' ability to realize the yield potential of conservation agriculture. As in the case of social learning, individual learning forms a reinforcing loop (*R3*) that might lock the system into a conventional agriculture trajectory or reinforce the adoption of conservation agriculture. Besides the social learning that leads to adoption, yield potential of conservation agriculture also increases trust in conservation agriculture which also forms reinforcing feedback loop (*R2*).

Realizing the yield potential of conservation agriculture enables farmers to increase their farm revenue, which, in turn, enables them to invest in the equipment (hoe and ripper) necessary for the proper implementation of conservation agriculture. This reinforcing process is described in the *R4* loop.

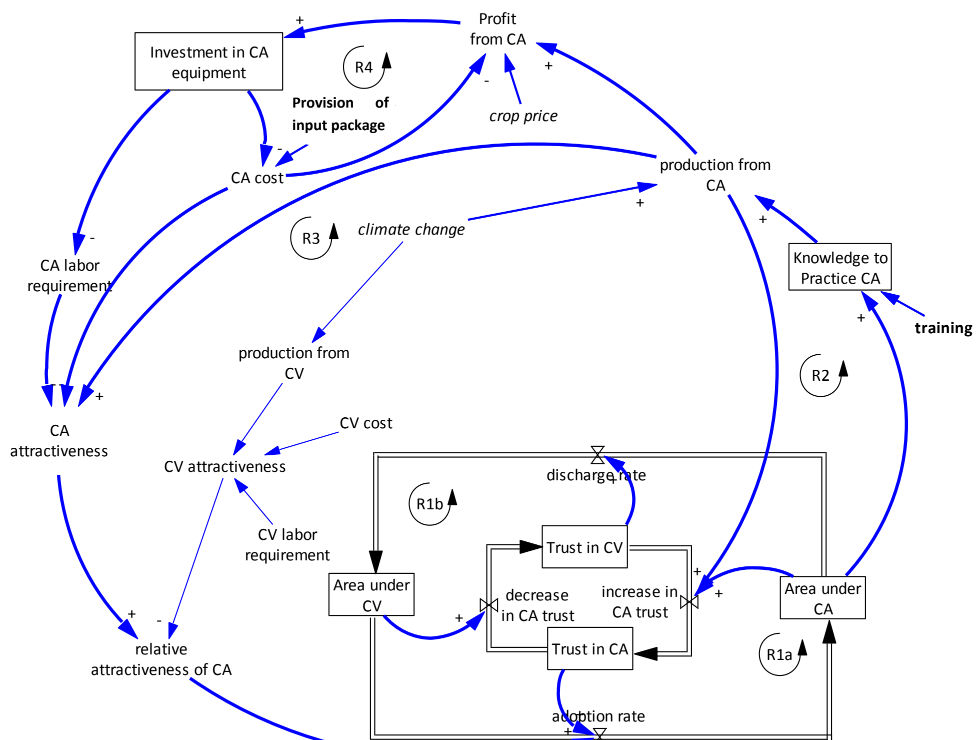

Figure 3. Loops enhancing adoption and diffusion

The strength of R1b loop is also regulated by the intensity of food insecurity (*B1*). If food insecurity is low (represented by a high value for the "production adequacy" variable), farmers have little pressure to switch to a farming practice that has proven beneficial impacts on yield but tends to be seen as a practice for poor farmers and not in line with proper farm management (Nyanga, 2012b). In turn, when food insecurity is high, farmers cannot afford the luxury of complying with this norm. Food adequacy thus closes a balancing loop that limits continuous adoption of conservation agriculture.

In addition to the food adequacy balancing loop, another mechanism limits adoption of conservation agriculture. The more revenue is generated by conservation agriculture, the more money can be invested in CA labour saving equipment such as hoes and rippers. The usage of these tools (this CA equipment) shifts conservation agriculture practice away from the construction of basins, which would allow for higher yields (but implies higher labour requirements). This lowers the yields from conservation agriculture and thus production from CA. Less production results in lower profit (B2). The use of equipment also has another side effect to adoption process as it results to less production, CA will be seen as less attractive to be implemented when it has lower productivity which will result to lower CA adoption rate among farmer.

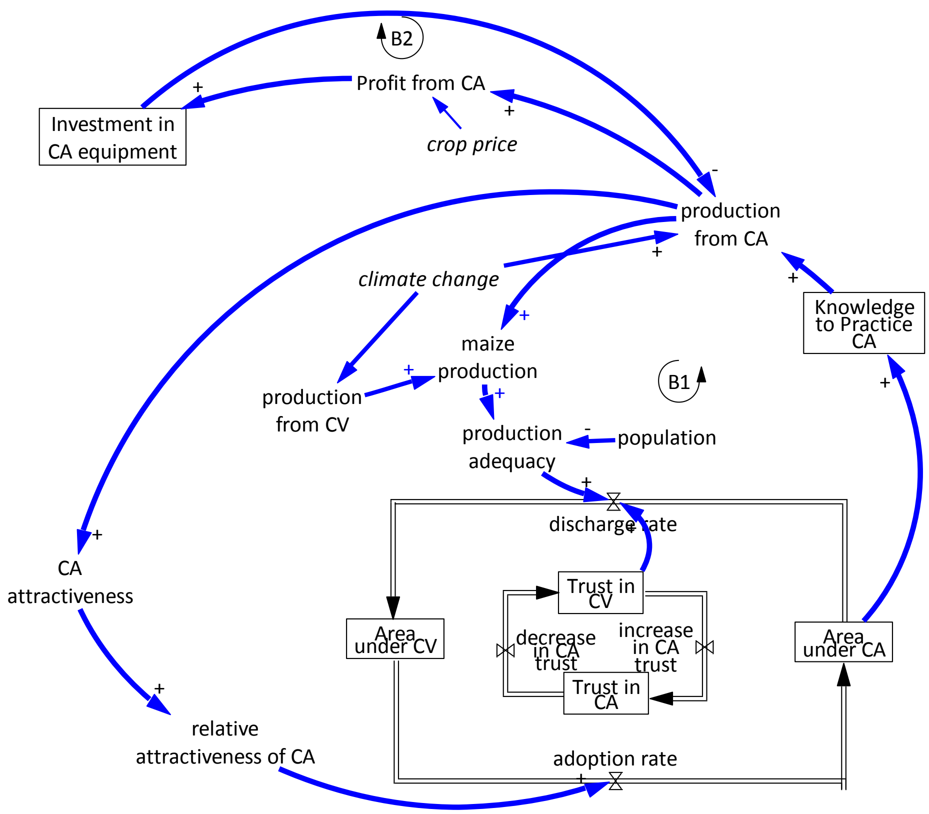

Figure 4. Loops enhancing discharge and return to conventional agriculture

Figure 5 summarizes the considerations made so far and provides an overview of the main feedback loops represented in the simulation model. The figure also summarizes issues that are excluded from the model and exogenous variables that are either important policy or scenario variables.

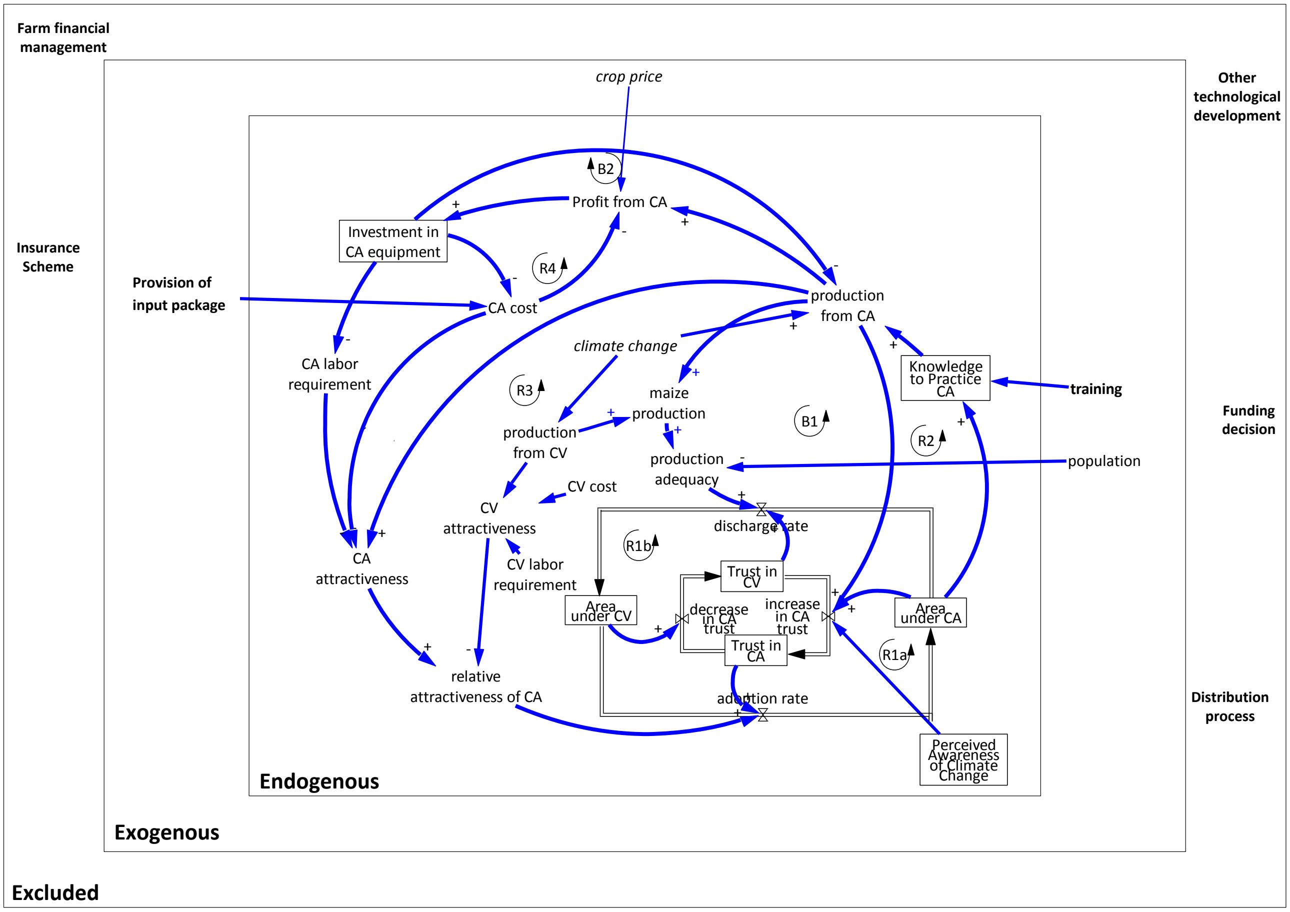

Figure 5. Summary of the main feedback loops in the simulation model

Model Calibration

Statistical data from Monitoring and Evaluation Reports from 2006/2007 until 2009/2010 in Nyanga and Johnsen (2010) is used to construct the reference mode of conservation agriculture adoption in Zambia under the CAP project and for the specification of initial values in the simulation model. An extensive multi-year household survey with adopters and non-adopters of conservation agriculture (e.g., Aune, Nyanga, and Johnsen (2012), Nyanga (2012b), and Nyanga and Johnsen (2010)) provides the information necessary for estimating weights and parameter values in the model. In-depth qualitative interviews with a sub-sample of these farmers ((Saldarriaga, Kopainsky, & Alessi, 2013)) helps specifying relationships and parameter values in areas where the household survey did not go into detail.

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 (2003); MFA (2011); Nyanga (2012a); Nyanga and Johnsen (2010)

Variable	Definition	Unit	Value	Source
New farmer	Number of new farmers 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 (2012a); Nyanga and Johnsen (2010)
Average area/farmer	Average cultivated area per farmer	Hectare/ farmer	2.1	Calculated based on Nyanga and Johnsen (2010)
Rainfall Intensity	Current average rainfall intensity in surveyed area	Mm/year	878.83	Calculated based on B. B. Umar, Aune, Johnsen, and Lungu (2011)
Effect of rainfall on maize yield	Percentage of maximum 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 tools ownership on adoption	Change in adoption due to changes in tools ownership			Calculated based on Nyanga and Johnsen (2010)
Average days to start planting	Average days to start 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 B. B Umar, Aune, Johnsen, and Lungu (2012)
Input cost for hand hoe, ploughing, basin, and ripping	Input price for hand-hoe practice	ZMK/year/ hectare	665,505; 1,314,980; 662,336; 1,459,130	Calculated based on B. B Umar et al. (2012)
Crop Price	Current crop price in the market	ZMK/kg	900	B. B Umar et al. (2012)

The model runs from 2007 until 2025. The first CAP I implementation years, i.e., the period between 2006/2007 until 2009/2010, are used as reference mode for model construction. CAP is a CA promotion project that was initiated by the Norwegian Development Agency. This project, so far, has the biggest area under CA implementation and encompasses 16 districts out of 73 districts in Zambia. The long time horizon into the future is necessary for studying the long-term behavior of CA adoption. I

SIMULATION RESULTS

Base Run

Figure 6 compares the model's base run ("base run"; green line) with statistical data ("CA area"; grey line). The model captures the increase in the area under conservation agriculture shown in the data but fails to reproduce the slight changes in the flows that affect area under CA.

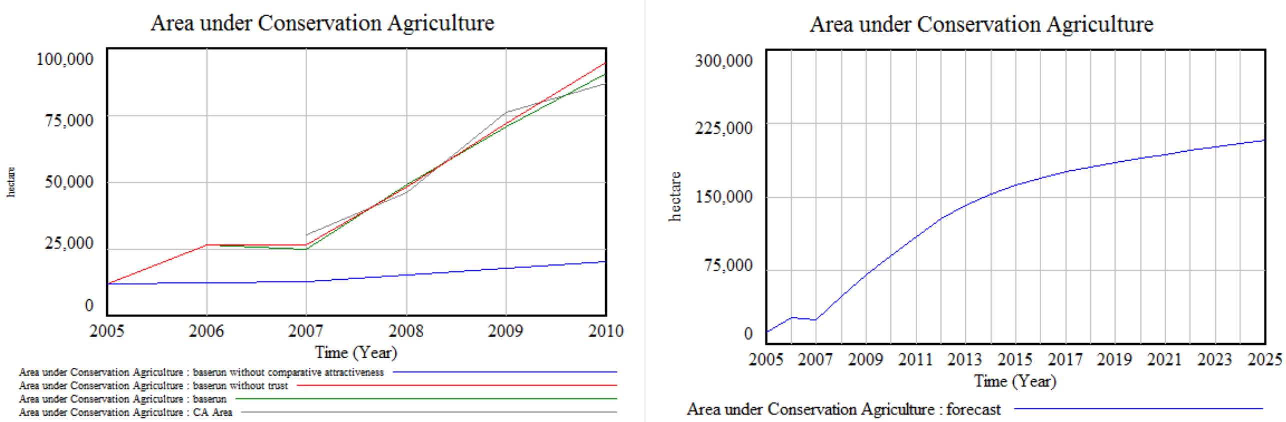

Figure 6. Model behavior for the historical time period (left hand side) and the future time period (right hand side)

Figure 6 on the left hand side shows two additional simulation runs for the historical time period. The red line ("base run without trust") studies CA adoption assuming that trust in CA did not influence adoption. The blue line ("base run without comparative attractiveness") studies CA adoption assuming that the attractiveness of CA, that is, the utility of CA compared to conventional agriculture, did not influence adoption. A comparison of these two simulation runs with the base run reveals that the trust mechanism did not affect CA adoption in the CAP project area much during the historical time period. The relative attractiveness of CA, on the other hand, was the decisive process for explaining adoption.

The right hand side of Figure 6 displays simulation result projects CA adoption under CAP until 2025. It shows that CA adoption under CAP 15 slows down considerably. This is due to a combination of factors. On the one hand, the number of new farmers in CAP each year remains constant (compared to an increase during the historical time period). This limits the potential for new CA adopters. On the other hand, the powerful balancing feedback loops restricting continuous adoption and diffusion of conservation agriculture become more and more influential. The first balancing feedback loop (B1) limits adoption through the cultural norm that labels CA as a practice for poor farmers. The second balancing feedback loop (B2) limits adoption through a shift towards the use of more tools that, at the same time, reduce the success of conservation agriculture.

Policies and Scenarios

Table 2 summarizes possible policies and scenarios for analyzing adoption and diffusion of conservation agriculture in the future. The scenario variables describe changes in the ecological and socio-economic environment of conservation agriculture. Policy variables represent entry points for different policies to enhance adoption and diffusion of conservation agriculture. Policies can have different characteristics in terms of dynamic complexity:

- They can affect the inflows to stocks and thus build resources necessary for further adoption and diffusion of conservation agriculture (e.g., building knowledge and skills through training; building trust through participatory monitoring and evaluation).
- They can change parameter values as in the case of incentives (such as subsidies for fertilizer and seed, provision of cassava cuttings).

As can be seen from Table 2, no policy can directly affect trust in conventional agriculture and the regulating impact of the "CA is for poor farmers" loop. Model simulations in the subsequent chapter will have to investigate under which conditions (timing and calibration of interventions) the impact of these processes can be controlled or even overridden.

Table 2. Entry points of policies and scenarios

	Variable	**Affected variables**	**Explanation**
Scenarios	Rainfall intensity	Yield conservation agriculture Yield conventional agriculture	The importance of CA increases as rainfall gets scarce. Rainfall intensity affects the importance of water for farmers. Any change in rainfall intensity will affect yield, which influences food adequacy.
	Input cost	Input costs conservation agriculture Input costs conventional agriculture	The relative attractiveness of CA increases with increases in fertilizer costs. Fertilizer costs affect both conservation and conventional agriculture. However, the need for fertilizer is lower in CA as fertilizers, at least in basin CA, can be used more efficiently.
	Crop price	Farm revenue	Crop prices determine farmers' revenues. In this model, revenue is used for buying new tools. Tools will affect the result of any farming practice.
	Project discontinuation	Provision of CA input packages	Current adoption rates are highly governed by input costs. Termination of CA input packages provision will likely decrease CA adoption. The provision of CA input packages depends to a large extent on the availability of donor funding, which may change fundamentally in the future.
Policies	Training in CA	Knowledge and skills	
	Training for increasing consideration	Perceived awareness of climate change	
	Monitoring & Evaluation of CA	Trust in conservation agriculture	
	Provision of equipment	CA equipment	
	Provision of incentives	Input costs conservation agriculture	

Figure 7 shows the dynamic implications of the different scenarios for the area under conservation agriculture. It reveals that the project discontinuation and decrease in input cost scenarios considerably decrease the area under CA. Both scenarios affect input prices, albeit in different ways. In the “input cost” scenarios, input costs such as costs for seed and fertilizer, change both in conservation and in conventional agriculture. As conservation agriculture uses inputs more efficiently, its relative attractiveness increases with an overall increase of input costs and decreases with an overall decrease of input costs. In the “project discontinuation” scenario, on the other hand, only inputs in conservation agriculture are affected. This scenario reduces the provision of input packages for CA, which has supported CA adoption for several years.

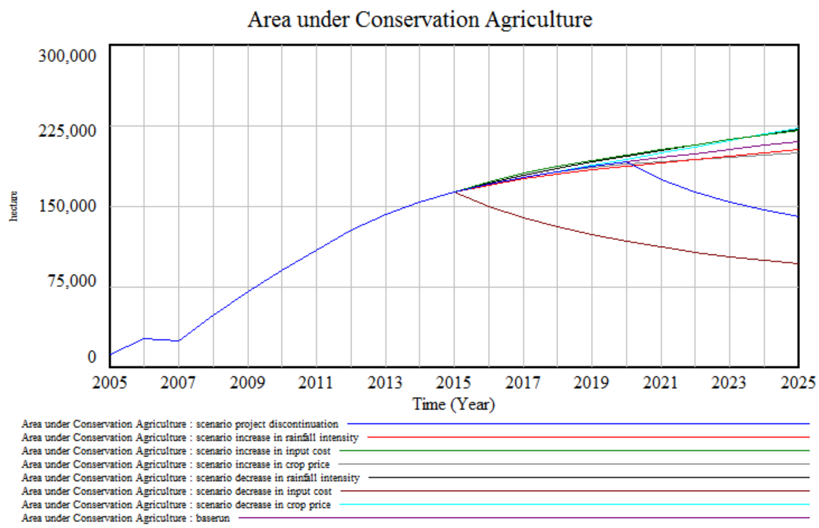

Figure 7. Scenario analysis

Due to the considerable impact on CA area, subsequent model analysis will focus on the project discontinuation and decrease in input cost scenarios. Figure 8 captures two scenarios that give significant decrease in CA area and also policies that try to encounter those effects.

Figure 8 on the left hand side displays the dynamic behavior generated by a variety of policies to counter the impact of decreasing input costs while the right hand side of the figure analyzes policies countering the impact of a project discontinuation. The graphs show that all the tested policies increase the area under conservation agriculture compared to the respective scenario without any policy.

Although all proposed policies to counter the impact of decreasing input prices are effective, only three of them result in overall increases in the area under conservation agriculture:

1. Change in input package: This policy implies that input costs of conservation farmers are supported more than input costs of conventional farmers.
2. Change in consideration: This policy implies that CAP and other projects supporting CA build deep understanding with farmers on the practices and benefits of CA instead of CV, especially regarding the potential of CA for adaptation to climate change.
3. A combination of the two previous policies.

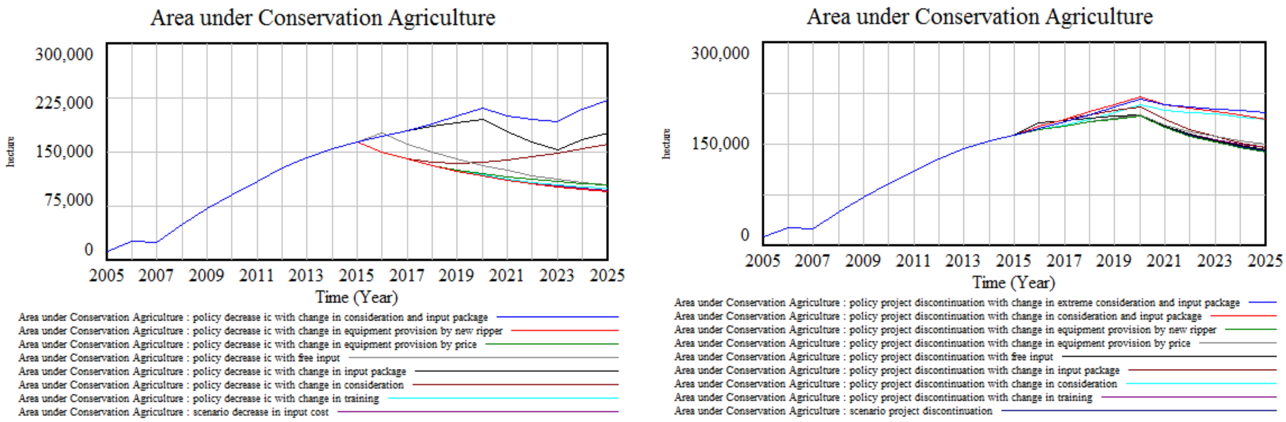

Figure 8. Policy analysis for the two most critical scenarios

Figure 8 on the right hand side shows that no policy, not even extreme ones is able to sustain or even increase adoption in the case of a CAP project discontinuation. This is an important insight as the model simulations indicate that CA adoption cannot be sustained without the support from CAP. CAP and most CA promotion projects in Zambia depend on donor funding, the stability of which cannot be guaranteed.

DISCUSSION

Policy analysis for the scenarios that reduce adoption of conservation agriculture considerably, revealed a critical dependency of conservation agriculture adoption and diffusion on donor funding. Donor funding directly affects the availability of input packages that provide a decisive incentive for CA adoption. Any strategy for promotion conservation agriculture thus needs to focus on reducing farmers' dependency on input packages.

The provision of input packages is very effective in facilitating adoption as it can be implemented easier and more quickly than strategies that affect other determinants of CA attractiveness such as strategies affecting the availability and costs of hired labor and strategies affecting yield from CA. However, the relative input costs of CA is a single moment variable. Contrary to skills or equipment, input cost is not a stock that continuously accumulates progress over the years. As soon as input costs change, the relative attractiveness of CA changes. If, on the other hand, training changes, the skill level of CA farmers remains fairly constant and does not instantly reduce CA attractiveness.

It is thus important for CA promotion to target processes that create long-term impacts, such as processes that build trust or increase skills. Such strategies are not effective instantly and require continued effort over several years. However, they are more sustainable over time. For example, farmers' awareness of CA's potential for adapting agricultural production to climate change, proved to be an important determinant of increasing trust in CA and thus adoption and diffusion of CA over continued periods of time.

CONCLUSIONS

This paper developed a dynamic framework that aimed to improve understanding of the transformation from conventional to conservation agriculture and to test policies supporting this transformation. The simulation model formalized the adoption determinants and processes described in the literature and confirmed by empirical analyses. The most important determinants were the relative attractiveness of conventional as well as conservation agriculture, trust in conservation agriculture, compatibility with a cultural norm favouring conventional agriculture, and skills for implementing conservation agriculture. The dynamic processes of trust building and skills development coupled with utility evaluations determine the adoption and discard rates that explain the diffusion of conservation agriculture.

Model calibration drew from statistical data, an extensive survey covering adopters and non-adopters of conservation agriculture as well as in-depth qualitative interviews with a sub-sample of these farmers. The model includes an interaction of two feedback processes that clearly have a major influence on observed adoption and diffusion patterns but that have so far not been explicitly described in the literature. The reinforcing loop responsible for keeping trust in conventional agriculture high can be overridden in situations of high food insecurity. As soon as conservation agriculture realizes some of its documented benefits in terms of increased yield, however, the attractiveness of conservation agriculture decreases again because the cultural norm of conservation agriculture being for poor farmers can gain in dominance. Additional feedback processes balance the initial increases in revenue from conservation agriculture and compete with other, reinforcing processes.

The model illustrated the critical dependence of CA adoption and diffusion on the provision of input packages and thus the importance of shifting promotion of CA towards strategies that build long-term resources for continued CA adoption. The explicit representation of accumulation processes in the simulation model highlighted the need for combining strategies that increase CA adoption in the short run with strategies that target these accumulation processes and thus provide long-term sustainability.

The simulation model and the processes represented therein not only proved to be valuable for the analysis and design of effective policies for enhancing adoption and diffusion of conservation agriculture. Instead, it also contributes to the further development of the diffusion of agricultural innovations framework.

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