Paper presented at the 27th International Conference of the System Dynamics Society

July 26-30, 2009

Model-based exploration of strategies for fostering adoption of improved seed in West Africa

Birgit Kopainsky[1], Sebastian Derwisch[1, 2]

[1] System Dynamics Group, Department of Geography, University of Bergen, Postbox 7800, 5020 Bergen, Norway

[2] Central Advisory Service on Intellectual Property (CAS-IP) of the Consultative Group on International Agricultural Research, Via dei Tre Denari 472, 00057 Maccarese, Rome, Italy

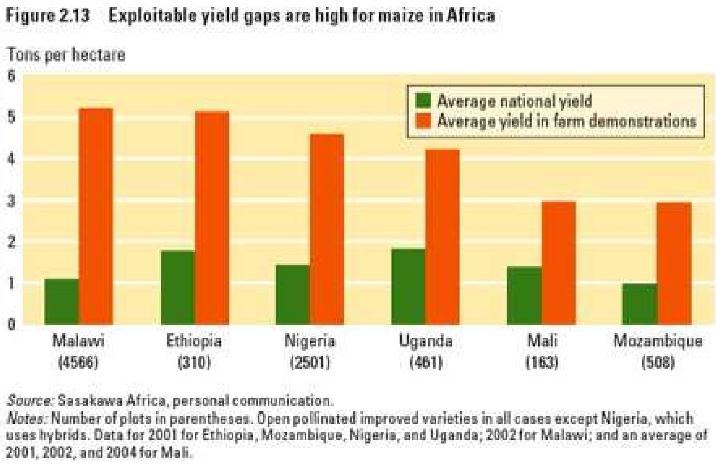
Abstract

Seed of improved varieties and other inputs are imperative to the transformation of the agricultural sector from subsistence farming to small-scale commercial agriculture in developing countries. This paper analyzes the adoption and diffusion process of improved seed by farmers in West Africa. The literature about farmers' adoption of new agricultural technology is abundant, yet it gives no integrated, process-oriented policy perspective that helps designing effective strategies for fostering the adoption of improved seed in West Africa. This paper develops a system dynamics model that integrates the findings from existing studies into a coherent framework. The model analyses the behavior patterns that are generated by such structure. With this approach we are able to identify parameter constellations that cause observed behavior patterns for different crops in different countries or regions. On this basis we can derive policy implications for supporting adoption for commercial and food crops in West Africa.

1 Introduction

West African economies depend heavily on agriculture. Agricultural earnings accounted for almost 41% of GDP in 2006 in Ghana (Alhassan & Bissi 2006). At the same time, the majority of West African agriculture is at a subsistence level, and most of the land is cultivated by smallholder farmers who are particularly vulnerable to production risks caused by climatic variability, pest plagues, environmental degradation, and other factors (Lobell et al 2008, Brown & Funk 2008). Poor transportation infrastructure and limited availability of agricultural inputs such as seed of high-yielding varieties and fertilizer contribute to low production levels. In the case of maize around 30% of the maximum achievable output is generated in Africa (Figure 1). Among other factors, this can be explained by the fact that most maize seed is obtained from informal sources (on-farm saved seed or seed exchange with neighbors). Informal seed supply tends to be inconsistent in terms of quality and such seed is vulnerable to new pests and diseases.

Figure 1: Yield gaps for maize in Africa (source: The World Bank 2007: 87).



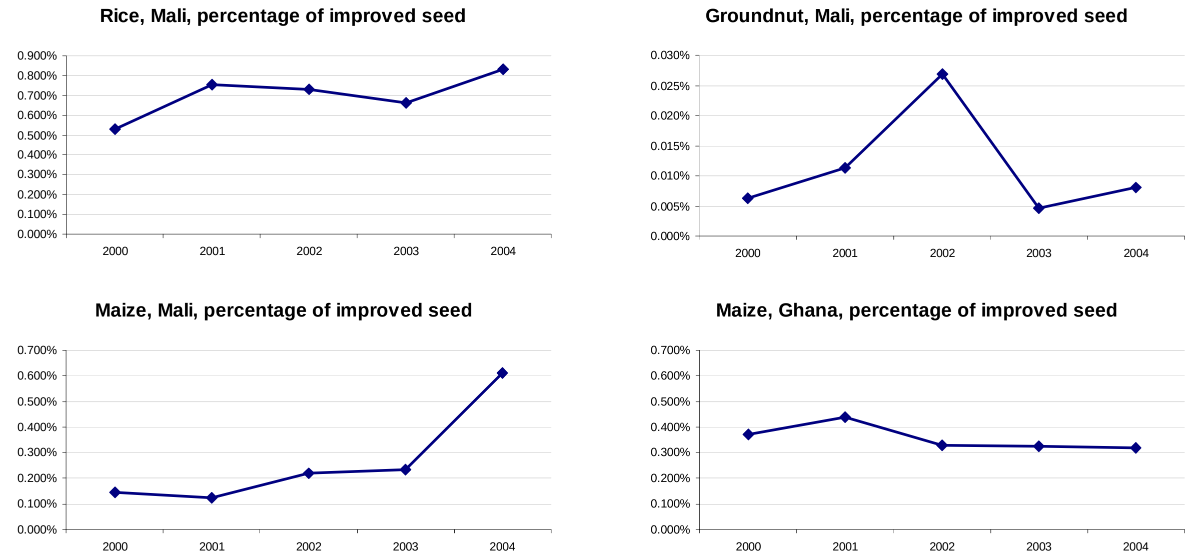
Seed of improved varieties and other inputs (fertilizer and crop protection products) are imperative to the transformation of the agricultural sector from subsistence farming to small-scale commercial agriculture. Quality seed can play a critical role in increasing agricultural productivity and thus food security as well as farmer incomes. It determines the upper limit of crop yields and the productivity of all other agricultural inputs into the farming system (Maredia et al 1999; Morris et al 1999). The development of new crop varieties is also a key factor to shape the future severity of climate change impacts on food production (Lobell et al 2008).

Improved seed varieties developed by the national and international agricultural research centers very often fail to be adopted by the smallholder farmer (Morris et al 1999). Although the public crop research institutes have breeding programs, the subsequent, private sector stages of the seed value chain such as foundation seed production, seed production and extension or agro-dealer networks are underdeveloped. A well functioning seed supply chain that generates improved varieties through research, produces them, and delivers them to farmers needs push and pull forces to develop. This paper looks at the determinants of farmers' adoption of improved seed as the major pull force in the seed supply chain. We specifically focus on improved seed for food crops such as maize, rice or Sorghum and on the transformation process from subsistence agriculture to small-scale commercial agriculture.

Data about the adoption of improved seed in West Africa is generally scarce. Figure 2 shows some development patterns for the adoption of improved seed in Mali and Ghana. The available data highlight a few characteristics of the adoption process of improved seed in West Africa:

- The use of improved seed is at very low levels
- There is no uniform adoption picture, neither for different crops in the same country (Mali) nor for the same crop in different countries (Maize in Mali and Ghana)

Figure 2: Adoption time series for food crops in West Africa



Sources for Ghana data: Plant Protection and Regulatory Services Directorate 2006 in: Alhassan & Bissi 2006; FAOSTAT | © FAO Statistics Division 2009

Sources for Mali data: National Seed Service in: Touré & Sanogo 2006; FAOSTAT | © FAO Statistics Division 2009

This paper develops a system dynamics simulation model that captures the basic processes affecting adoption. The model is used to design effective strategies for fostering adoption and diffusion of improved seed in West Africa. These strategies will differ depending on the characteristics of a specific crop and on the framework conditions in a specific country.

The structure of the simulation model is based on an extensive review of the literature on adoption and diffusion of new agricultural technologies. The literature about adoption of new agricultural technologies is abundant (for recent reviews see e.g. Sunding & Zilberman 2001; Stone 2007 from an anthropological point of view or Marra et al 2003 from an economic perspective). However, the existing literature gives no integrated, process-oriented policy perspective that helps designing effective strategies for fostering the adoption of improved seed for different crops in different countries in West Africa. This is due to mainly three reasons:

- Adoption studies have developed conceptual frameworks of adoption of an agricultural innovation (e.g. Abadi Ghadim & Pannell 1999, Marra et al 2003). The policy implications for specific crops and countries of such frameworks are, however, limited.
- Adoption studies focus on individual determinants of adoption such as the role of information or risk and uncertainty (e.g. Gerber 2004; Tsur et al 1990) or the focus on individual stages in the adoption process (early adopters vs. late adopters).
- Adoption studies very often consist in localized, country- and crop-specific empirical studies that provide partially conflicting or contradictory findings and conclusions (see Doss 2006).

Our system dynamics model synthesizes the adoption determinants and their relationships as found in the literature. The model is based on the hypothesis that the conflicting or contradictory findings and conclusions from existing empirical work are not due to the fact that farmers apply different decision rules for different crops and in different countries. Instead, the conflicting or contradictory findings are the result of the same fundamental decision process under different framework conditions, i.e. the specific characteristics of a crop and a region or country assign different weights to the same fundamental factors that influence farmers' adoption decisions.

The simulation model analyses the behavior patterns that are generated by such structure. With this approach we are able to identify parameter constellations that cause observed behavior patterns for different crops in different countries and we can derive conclusions for the design of effective adoption stimulation policies.

2 Theory

Improved seed varieties are new agricultural technologies or agricultural innovations. Usually, there is a significant interval between the time an innovation is developed and available in the market, and the time it is widely used by farmers. Adoption and diffusion are the processes governing the utilization of innovations. Adoption studies analyze factors that affect if and when a farmer will begin using an innovation (as measured e.g. in whether or not a farmer uses improved seed or how much of their land they cultivate with improved seed). Diffusion, on the other hand, can be interpreted as aggregate adoption. Diffusion studies analyze how an innovation penetrates its potential market (as measured e.g. in the share of farmers who use improved seed or in the share of land in total agricultural land that is cultivated with improved seed) (Fernandez-Cornejo & McBride 2002; Sunding & Zilberman 2001).

The first empirical studies about the adoption of new agricultural technologies (all about the diffusion of hybrid corn in Iowa) established that diffusion is an S-shaped function of time (Griliches 1957, Rogers 1962, Ryan & Gross 1943). The determinants of adoption and diffusion of new technology can be grouped into four major categories (Table 1; Eaton & Wiersinga 2008; Morris et al 1999). In the remainder of the theory section these determinants will be arranged into an operational framework that captures the process of adoption and diffusion. The table also illustrates that the characteristics of a specific crop and/or a specific region/country will affect the adoption and diffusion of improved seed. We will further investigate this aspect in the results section where we calibrate the simulation model for specific crops and regions/countries and identify the implication of such parameter constellation on the formulation of effective strategies to foster adoption and diffusion.

Table 1: Determinants of adoption and diffusion of new agricultural technologies

Category	**Determinant**
Varietal characteristics	E.g. yield (or expected gross margin, respectively) E.g. input prices E.g. uncertainty associated with the variety E.g. riskiness of the variety
Farm-level characteristics	E.g. climatic and agro-ecological suitability of the location for the variety E.g. quality of the land
Farmer characteristics	E.g. agronomic expertise & skills E.g. knowledge about variety E.g. risk aversion E.g. capital availability, access to credit
Institutional characteristics	E.g. consumer and market demand for improved varieties

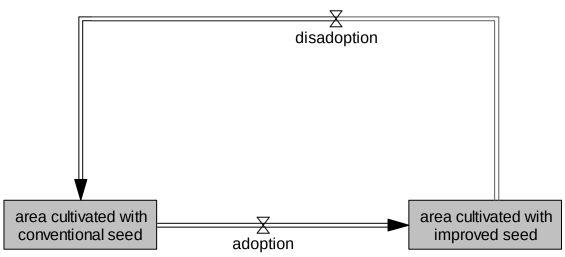
2.1 Core structure

Adoption and diffusion studies focus on how farmers evaluate the new seeds and act on the evaluations. This evaluation happens in several stages (e.g. Rogers 2003; Ryan & Gross 1943):

- Initial knowledge: Farmer learns of the innovation
- Persuasion: Farmer forms an attitude towards the innovation
- Decision: Farmer evaluates the relative advantages of the innovation
- Implementation: Farmer adopts innovation
- Confirmation. Farmer evaluates the performance of the innovation

Figure 3 displays the backbone of these stages in the form of a two stock model with a discard rate where farmers may decide to abandon the innovation in the confirmation stage. In the remainder of the theory section of this paper we gradually develop the structure influencing the adoption and discard flow. The list of evaluation stages shows that innovation diffusion research is also concerned with the social component of adoption which is most visible in the initial knowledge and persuasion stage.

Figure 3: Core structure of the innovation adoption and diffusion model

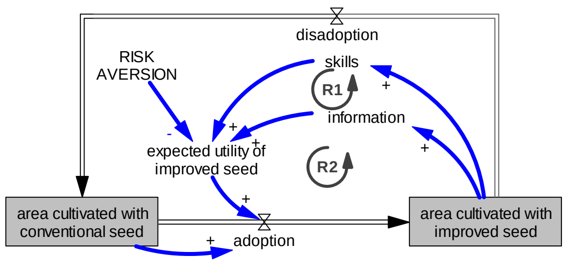


2.2 Decision and implementation stage: learning

The decision and implementation stages are characterized by evaluations of the relative profitability of a new technology (improved seed) relative to the profitability of the old technology (conventional seed). The decision and implementation stages are characterized by three core elements (Marra et al 2003). Figure 4 provides an operational description of the logic behind these elements.

- Skills development: Individual learning improves the farmer's ability to implement the new technology. Individual learning also allows the farmer to make better decisions about the new technology. By conducting their own trials or accessing information on trials by others, farmers develop the skills that are required for using the new technology. With adequate skills the revenue potential of the new technology can better be exploited (see also Abadi Ghadim & Pannell 1999; Foster & Rosenzweig 1995).
- Perceptions of the farmer about the uncertainty of the profitability of the new technology: By conducting own trials or accessing information on trials by others, farmers also receive information about the performance of the new technology. Information, in turn, is crucial for reducing uncertainty (see also Adesina & Baidu-Forson 1995;).
- Option value from delaying the adoption decision and implementation when there are fixed costs of adoption. In these situations attitudes towards risk such as risk aversion influence the farmer's perception of the profitability of the new technology Risk (see also Tsur et al 1990).

Figure 4: The dynamics of decision and implementation



R1: Individual learning and skills development

R2: Individual learning and reduction of uncertainty

2.3 Initial knowledge and persuasion stage: social dynamics

Social processes might override or replace empirical evaluations of the relative utility of improved seed. Diffusion research has documented numerous cases in which local cultural practices and beliefs determine which innovations are adopted (for a review see Stone 2007). From a more anthropological perspective, the processes described so far can be termed individual learning where individuals evaluate the payoffs from old and new technology. Social dynamics affecting innovation adoption, on the other hand, describe processes of social learning (Munshi 2004), in which adoption decisions are based on teaching and imitation(Henrich 2001):

- Farmers copy other farmers on the basis of prestige, regardless of that farmer's actual success with the innovation (reinforcing word of mouth from adopters loop).
- Farmers also adopt an innovation when and because it has been adopted by many others (reinforcing word of mouth from non adopters loop).

These social processes are described by the trust structure in the lower part of Figure 5. Trust in improved seed is built when farmers are exposed to improved seed. Farmers can be exposed to improved seed

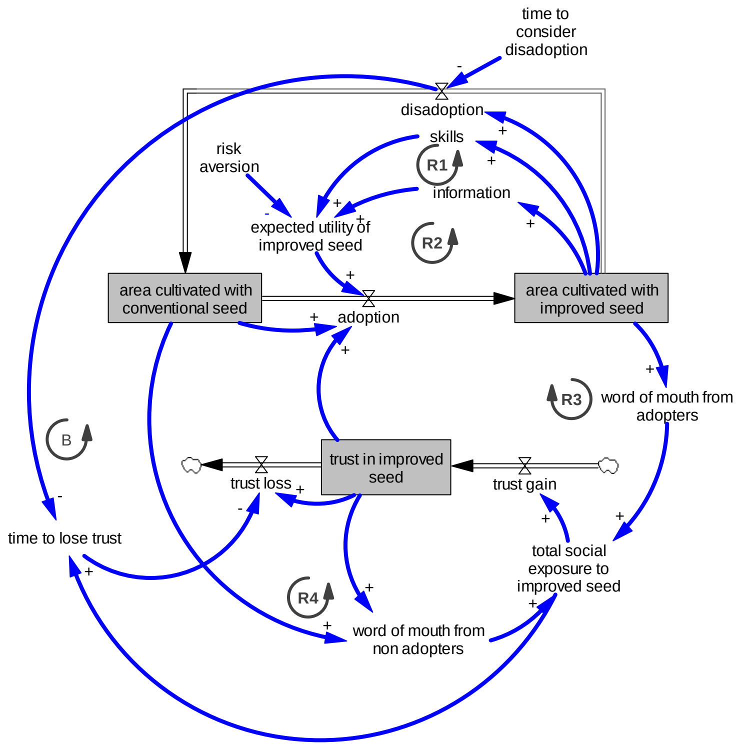
- either through farmers who have already adopted the seed or
- through non adopters who nevertheless talk about the innovation.

Social learning may spread maladaptive beliefs and practices when beliefs and practices have little grounding in individual learning. Especially when uncertainty is very high social learning may rely largely on biases and other factors that are weakly connected to actual profitability evaluations (Stone 2007).

The relative strength of the experiential and social learning loops will eventually determine the extent of adoption. Adoption is a multiplication of utility with trust where trust can override or replace an empirical evaluation of the utility of improved seed.

The speed with which trust can be lost is an important factor for the success of improved seed. Even in cases with high levels of trust, trust can depreciate quite quickly. This happens when a high share of adopters decide to stop using improved seed, for example because improved seed cannot be supplied reliably by retailers. In this case it becomes socially less acceptable to cultivate improved seed, trust depreciates quickly and adoption decreases (balancing social acceptability loop).

Figure 5: The dynamics of initial knowledge and persuasion



R3: social learning: word of mouth from adopters

R4: social learning: word of mouth from non adopters

B: social acceptability of improved seed

2.4 Policies to stimulate adoption of improved seed

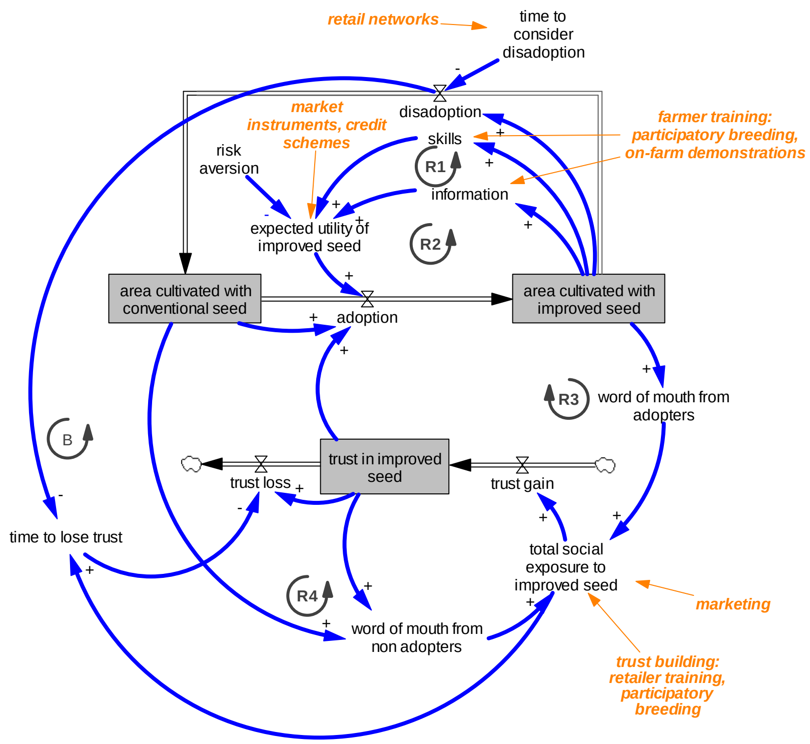
Policies to stimulate adoption can affect different determinants of adoption. Their position in the model structure is illustrated in Figure 6 with the variables shown in *italics*. Typical examples of policies to stimulate adoption and diffusion are:

- Marketing schemes: Seed companies can effectively market their seed by either advertising it through different media or by distributing free seed to key farmers in a region. If the seed performs well on these farms seed companies can organize field demonstrations for a large number of farmers (see Stone 2007). Farmers therefore become exposed to the new seed.
- Market instruments (e.g. Sunding & Zilberman 2001): input subsidies and price supports tend to increase the new technology's relative profitability and thus the relative utility of improved seed.
- Microcredits: Microcredits are likely to affect capital availability and thus increase the utility of improved seed.
- On-farm demonstrations (e.g. Jones et al 2001). On-farm demonstrations provide information about the performance of the seed and basic training about the necessary farming practices to achieve the revenue potential of the seed (farmer training component).

- Retail networks (e.g. Matuschke & Qaim 2008): The retail network strategy consists of increasing the density of agrodealers and of increasing their training. The policy therefore affects the availability of improved seed (the major factor influencing dis-adoption) and the exposure of farmers to improved seed (trust building component).
- Participatory breeding (e.g. Witcombe et al 1999): Participatory plant breeding is a long-term process and involves farmers in the entire breeding process so that farmers from the earliest stages have information about the characteristics of the varieties under development and on their potential profitability. Farmers can determine which traits should be pursued in the development of a new variety. Participator plant breeding, however, not only reduces uncertainty (farmer training component). Instead, it is also very likely to increase trust in improved seed because farmers are involved in the definition of the characteristics that new varieties need to have (trust building component).

The implementation costs of these policies vary considerably and they also affect different actors. The above list of policies is approximately in the order of their implementation costs.

Figure 6: Entry points of policies to stimulate adoption



3 Model

In this section the theoretical framework developed above is translated into a computer simulation model. The formal model allows the detailed analysis of the dynamic behaviors created by the structures common to the relevant theory. Thus, the principal contributions of this paper do not stem from proposing an entirely new framework or significant new extensions to an existing framework. Instead, the analysis highlights and clarifies the complex interactions between the elements common to the existing frameworks.

3.1 Model specification

As a baseline we initialize the model with parameter values typical for a food crop in West Africa (low initial values for adoption, trust, information and skills; Table 2). Expert interviews and field trip data provide us with background knowledge on the case of maize (a food crop) and cacao (a commercial crop) in Ghana (Derwisch et al 2008). As far as possible we use relative values for the model variables, i.e. the area cultivated with conventional and improved seed are not measured in e.g. hectares but in percentages of the total area. The two areas together always add up to a value of 100. Model simulations are run over a time horizon of 50 years. Such time horizon allows studying the potential long-term dynamics (better-before-worse and worse-before-better behavior) of a societal change process such as the adoption process.

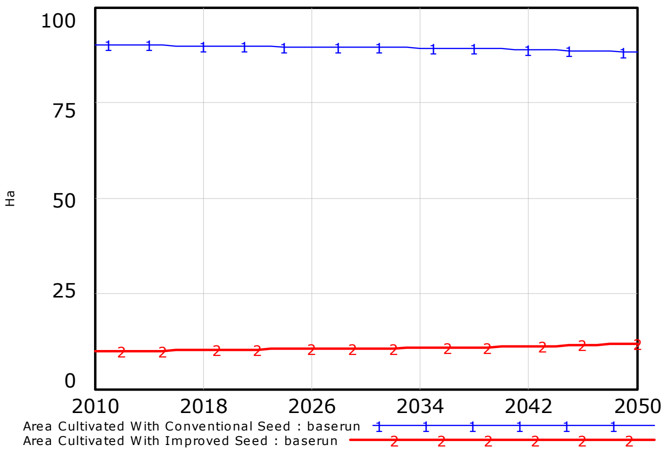
Table 2: Initial and parameter values under baseline conditions

Variable name	Value	Comment
Initial area cultivated with conventional seed	90	The two area stocks always add up to 100 which represents 100% of the total cultivated area
Initial area cultivated with improved seed	10	
Initial trust in improved seed	0.2	This variable represents the percentage of farmers who are willing to consider adopting improved seed. The maximal value of this variable is 1.
Initial skills	0.1	
Initial information	0.1	
Yearly contacts per adopter and non adopter	10	The yearly contacts per farmer represent the share of the total farming population that a farmer is able to contact per year
Effectiveness of contacts adopters	0.2	The effectiveness represents the percentage of the contacted farmers that will become willing to consider adopting improved seed.
Effectiveness of contacts non adopters	0.01	
Potential relative utility of improved seed	3	The potential relative utility of improved seed indicates the factor by which the gross margin of conventional seed could be multiplied, assuming the application of adequate cultivation practices.

Figure 7 illustrates that with low initial levels of adoption, trust, information and skills the area cultivated with improved seed increases only very slowly. Trust in improved seed increases gradually (not shown in the figure) but because the initial skills and information levels are very low and, in the absence of marketing, credit, extension and training schemes, only develop very slowly adoption nevertheless stagnates around low levels.

Model tests not shown in Figure 7 reveal that with different initial values the model allows reproducing the behavior patterns observed for different food crops and countries in West Africa (see Figure 2).

Figure 7: Base run with low initial levels of adoption

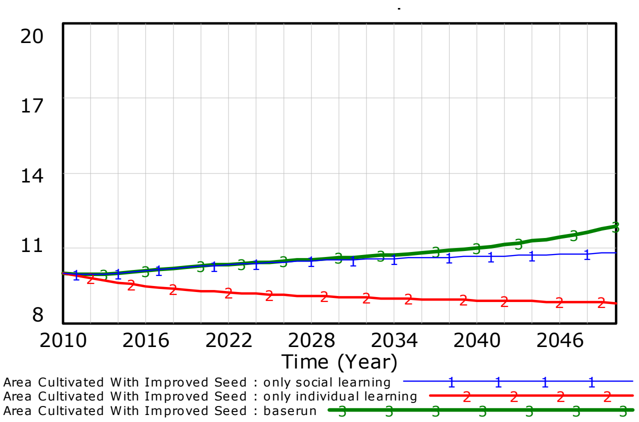


3.2 Behavior patterns generated by theory

Figure 8 shows the results of two simulation runs with the same base run parameter values (line 3) but with either the individual learning or the social learning structure deactivated. In the "only individual learning" run (line 2), adoption and diffusion of improved seed depend entirely on individual learning, i.e. on the skills developed and information acquired from conducting their own trials or accessing information on trials by others. In the "only social learning" run (line 1), the adoption and diffusion pattern is only determined by social dynamics and individual learning has no effect on the adoption potential of improved seed.

Figure 8 shows that individual learning alone is not sufficient for keeping adoption at a constant level, let alone for stimulating s-shaped growth. Social learning, on the other hand, is capable of stimulating adoption. However, it is only the interplay and combination of individual and social learning that reaches the base run values.

Figure 8: Base run with either only individual or only social learning



The model structure thus seems capable of reproducing the behavior patterns reported in the literature. This is not only true for the stagnation pattern that results from low initial levels of adoption (e.g. Morris et al 1999). The "only social learning" simulation run reproduces the behavior observed for the adoption of improved cotton varieties in India where Stone (2007) found that what he called cotton fads were entirely driven by social dynamics and not by more objective evaluations of the performance of improved varieties.

3.3 Policy-scenario space

After testing the fundamental behavior patterns generated by the model we now turn to using the model for the analysis of strategies to foster adoption and diffusion of improved seed in West Africa. For this purpose we distinguish between scenarios and policies. The scenarios refer to the specific characteristics of crops and countries or regions in West Africa. An aggregated classification of crops and countries/regions yields a crop and country portfolio as shown in Table 3.

Table 3: Policy-scenario space

		Scenarios				
		Crop type		Food crops		
		Commercial crop	Food crop	High farmer density	Openness towards innovations	Reluctance towards innovations
Policies	Market instruments					
	Retail networks					
	Participatory breeding					

The policies listed in the matrix are a selection of policies described in section 2.4. The model variables they affect are summarized in Table 4.

Table 4: Model variables affected by policies to stimulate adoption of improved seed

Policy	Affected variables	Duration of policy
Market instruments	Utility of improved seed	Entire simulation period
Retail networks	Availability and thus time to consider disadoption Total social exposure to improved seed	Entire simulation period 5 years
Participatory breeding	Skills Information Social exposure (higher intensity than for retail networks)	Two variety creation cycles, i.e. 10 years

The scenarios in the matrix analyze the sensitivity of the policies under a range of possible conditions. The variables that are affected by these conditions are summarized in Table 5. In a first step we differentiate between commercial crops and food crops. As we are mainly interested in food security and the transition from subsistence to small-scale commercial farming we then focus on food crops:

- Commercial crops versus food crops: A fundamental difference can be made between commercial crops that are cultivated for exports and non-commercial crops that are mainly cultivated for domestic food needs. In the case of commercial crops the input and output channels are well developed. Seed is delivered and the harvest is collected by private companies who have a crucial interest in farmers receiving the seed and delivering the harvest.

- Farmer density: The high farmer density scenario describes a region where farmers live relatively close to each other and thus have more contact with each other than in sparsely populated regions.
- The openness towards innovations tries to describe a form of innovation mentality that differs among regions.

Table 5: Model variables affected by scenarios

Scenario	**Affected variables**
Commercial crop vs. Food crop	initial number of adopters and non adopters initial skill and information level initial trust level time to consider disadoption (availability)
High farmer density	yearly contacts per farmer
Openness towards innovation	normal time to lose trust longer than in the other scenarios
Reluctance towards innovations	normal time to lose trust shorter than in the other scenarios

3.4 Results for the policy-scenario space

Commercial crops versus food crops

Figure 9 compares the effectiveness of selected adoption stimulation policies for commercial crops and food crops. Commercial crops are cultivated for exports and have well developed input and output channels. Seed is delivered and the harvest is collected by private companies who have a crucial interest in farmers receiving the seed and delivering the harvest. Food crops, on the other hand, are mainly cultivated for subsistence and domestic food needs. The seed supply chains and the output markets are usually much less developed than for commercial crops or hardly exist at all.

Figure 9: Effectiveness of adoption stimulation policies for commercial and food crops

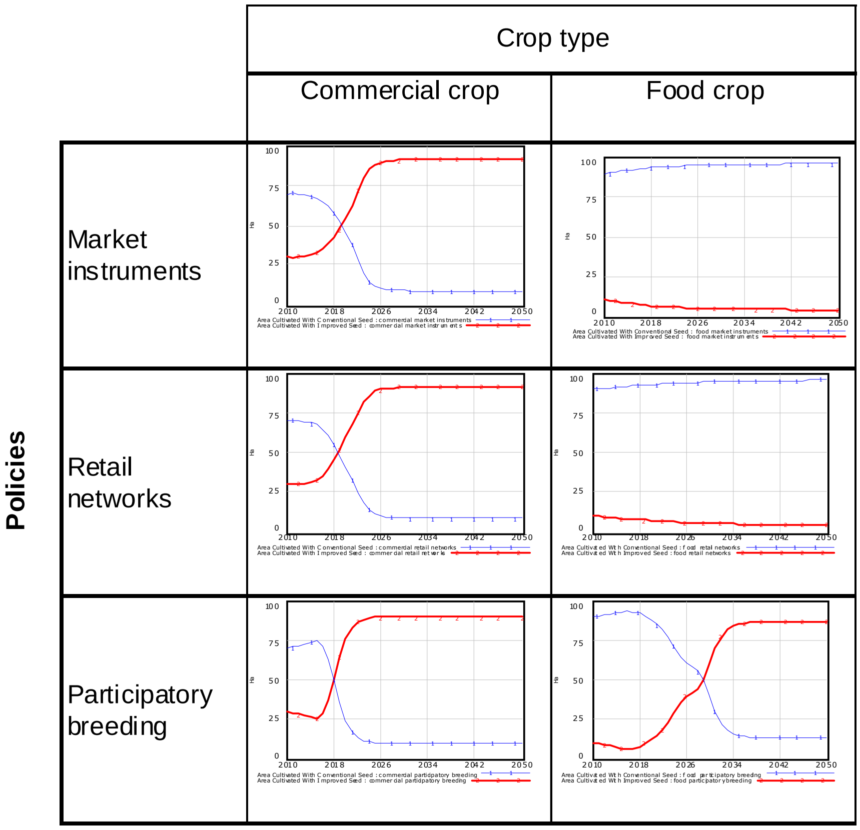
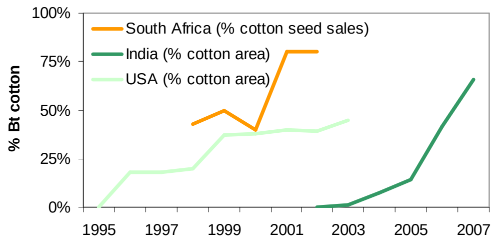


Figure 9 illustrates that commercial crops already react to the cheapest adoption stimulation policies (e.g. market instruments). Food crops, on the other hand, need both an intensive training and an intensive trust building component which can, for example, be offered by participatory breeding. The fast reaction of commercial crops to relatively easy and cheap policies can be explained by the fact that farmers already have adoption experience. As information and skills are already rather high it is more a question of trust in the improved seed that determines how fast new seed varieties are adopted. In the absence of market instruments trust can be built through social exposure to improved seed, e.g. through marketing campaigns, free distribution of seed to key farmers and ensuing demonstration days.

The fast reaction of commercial crops to relatively cheap interventions is confirmed by numerous empirical observations. One prominent example is the adoption of Bt cotton. Figure 10 shows time series data for the adoption of Bt cotton in such diverse countries as South Africa, India and the US. All three time series show the classical s-shaped growth pattern.

Figure 10: Adoption of Bt cotton in South Africa, India and the US

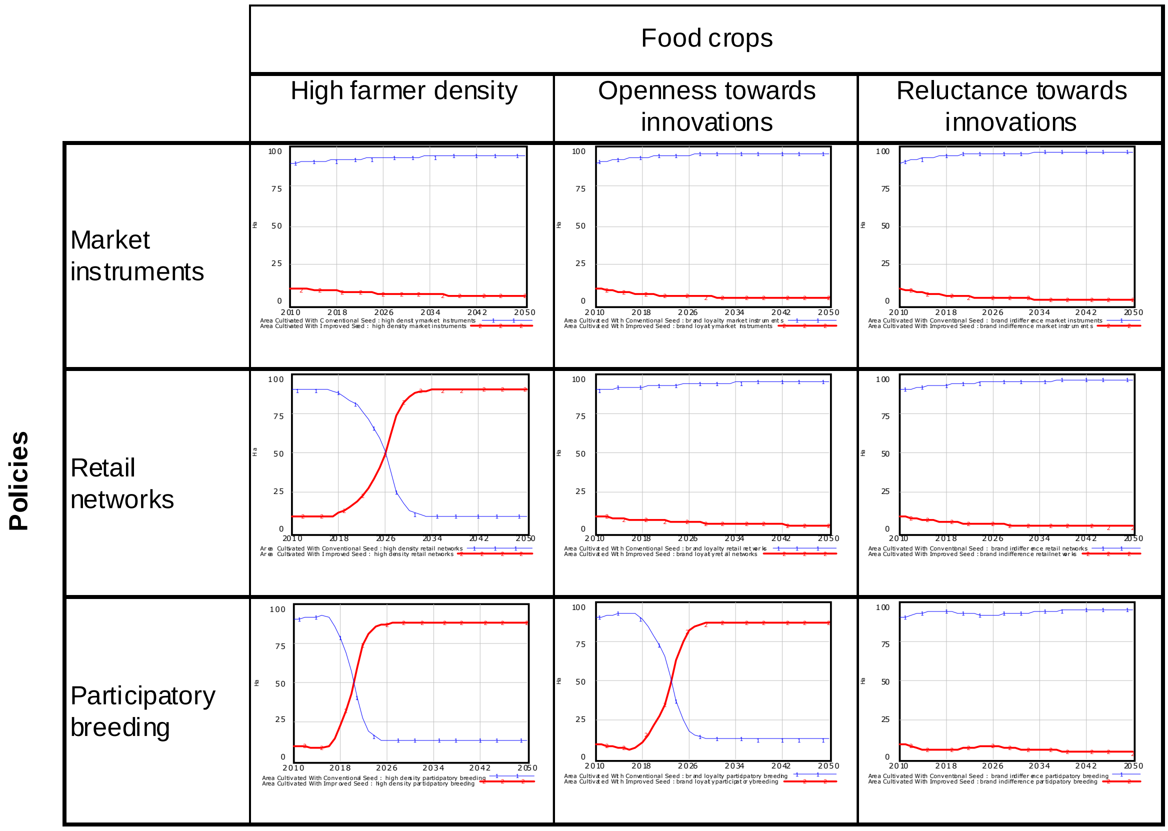


Data sources : Fernandez-Cornejo 2004 (USA); Manjunath 2009 (India); Kirsten & Gouse 2002 (South Africa)

Effectiveness of policies in the case of food crops

Figure 11 compares the effectiveness of selected adoption stimulation policies for food crops under a range of possible framework conditions (regional or country characteristics). The high farmer density scenario describes a region where farmers live relatively close to each other and thus have more contact with each other than in sparsely populated regions. The openness towards innovations tries to describe a form of innovation mentality that differs among regions (high in the openness towards innovations scenario, low in the reluctance towards innovations scenario).

Figure 11: Effectiveness of adoption stimulation policies for different food crop scenarios



The policy-scenario runs for food crops in Figure 11 give some insights about the effectiveness of policies for food crops. Market instruments, for example, are effective only for commercial crops. In the case of food crops market instruments alone are not able to initiate a successful adoption process.

The effectiveness of retail networks and participatory breeding depend on the characteristics of a region or a country. In the high farmer density scenario retail networks are sufficient to initiate a successful adoption process. As a consequence of the rather intensive exchange among farmers an adoption stimulation policy does not have to focus intensively on the social learning process as social learning already takes place through the exchange between farmers. Information on and training about the technical characteristics and cultivation needs of improved varieties are sufficient to stimulate adoption.

The reluctance towards innovations scenario, on the other hand, highlights that in regions with an innovation-reluctant mentality not even participatory breeding with its intensive training as well as trust building components is sufficient to stimulate adoption. Trust depreciates too quickly for social learning to support individual learning and thus adoption.

The results shown in Figure 11 do not contain combinations of policies. Instead, they analyze the effectiveness of individual policies and they identify sensitive parameters such as the farmer contact rate and the openness to innovation. The results should therefore not be interpreted in the sense that adoption and diffusion of improved seed cannot be realized for food crops in regions with an innovation-adverse mentality. In such regions, a combination of policies will be necessary for a successful adoption process.

The sensitive parameters can be supported in different ways. Farmer density, which denotes the share of farmers a particular farmer contacts per year, can be stimulated e.g. by organizing farmer field days or other occasions where farmers meet and exchange experiences. Reluctance towards innovation is more difficult and more expensive to overcome. One possibility is very strict seed certification and control which prevents fake seed from destroying the reputation of improved seed.

4 Discussion and outlook

The purpose of this paper was to develop an integrative framework about the determinants of farmer adoption of new technologies in developing countries. The framework was implemented as a system dynamics simulation model with which policies to stimulate adoption and diffusion can be tested for specific crops and countries or regions in West Africa. The existing literature about farmer adoption of new technologies addresses two main issues:

1. Determinants of profitability and objective evaluation of this profitability (individual learning processes).
2. Social dynamics that override or replace objective evaluations of a new technology's profitability (social learning processes).

This is in line with other innovation adoption and diffusion studies in the system dynamics field. Struben & Sterman (2008) and Ulli-Beer et al (2007), for example, include social norm concepts to more objective aspects in simulation models about the adoption and diffusion of environmentally friendly technologies.

Our simulation runs identified constellations in which the more objective parts of adoption prevail and constellations in which social dynamics override objective evaluations of improved seeds. Adoption decisions are driven more by objective evaluations in the early stages when the share of adopters on the total farmer population (measured in the cultivated agricultural land) is still low. When the number of adopter increases social dynamics tend to override objective evaluations. Effective policies to stimulate adoption and diffusion of improved seed thus depend on the relative dominance of the individual and social learning feedback loops. For the design of policies this implies that the specific characteristics of the corresponding crops as well as countries or regions have to be taken into account.

While the simulation model discussed in this paper was applied and calibrated to the issue of adoption of improved seed the results have implications beyond this specific issue. Adoption of new farming technology and farm management practices is very likely to also be a more dynamic process than the literature might suggest and support strategies will also have to be tailor-made to specific products and regions. Appropriate farming technologies (e.g. fertilizer) and farm management practices determine how much of the productivity potential of improved seed can actually be realized.

At the outset of this paper we emphasized that a well functioning seed supply chain generates improved varieties through research, produces them, and delivers them to farmers. Analyzing the effectiveness of different policies to stimulate the adoption and diffusion of improved seed on the farmer level also has implications for the research sector. From an intellectual property rights point of view, for example, intellectual property management strategies have to differentiate between crops. Participatory breeding involves complicated intellectual property issues. These can be avoided in the case of commercial crops where more conventional breeding and subsequent marketing strategies are sufficient to initiate s-shaped adoption and diffusion patterns.

Acknowledgements

We would like to thank the Dutch Ministry of Foreign Affairs for financial support of the CAS-IP system dynamics modeling work and the West African Seed Alliance for financial and logistic support in West Africa. The paper benefitted greatly from comments by and the general support through Dr. Victoria Henson-Apollonio.

References

Abadi Ghadim AK, Pannell DJ. 1999. A conceptual framework of adoption of an agricultural innovation. *Agricultural Economics* 21:145-54

Adesina AA, Baidu-Forson J. 1995. Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso. *Agricultural Economics* 13:1-9

Alhassan WS, Bissi P. 2006. Program for Africa's Seed Systems (PASS). Country report Ghana, Rockefeller Foundation

Brown ME, Funk CC. 2008. Food security under climate change. *Science* 319:580-1

Derwisch S, Kopainsky B, Pöhlmann S. 2008. Making the value chain work - analysing the impact of Intellectual Asset and Property Management for seed sector development in West Africa. *26th International Conference of the System Dynamics Society*. Athens

Doss CR. 2006. Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement. *Agricultural Economics* 34:207-19

Eaton D, Wiersinga R. 2008. Impact of improved vegetable farming technology on farmers' livelihoods in tropical Asia, LEI, Wageningen University and Research Center, Wageningen

Fernandez-Cornejo J. 2004. The seed industry in U.S. agriculture: An exploration of data and information on crop seed markets, regulation, industry structure, and research and development, U.S. Department of Agriculture, Resource Economics Division, Economic Research Sercive, Washington, DC

Fernandez-Cornejo J, McBride WD. 2002. Adoption of bioengineered crops, US Department of Agriculture, Washington, DC

Foster AD, Rosenzweig MR. 1995. Learning by doing and learning from others: Human capital and technological change in agriculture. *Journal of Political Economy* 103:1176-209

Gerber J. 2004. *The role of information acquisition in the adoption of dairy related technologies in Tanzania*. PhD thesis. ETH Zürich, Zürich

Griliches Z. 1957. Hybrid corn: An exploration in the economics of technological change. *Econometrica* 25:501-22

Henrich J. 2001. Cultural transmission and the diffusion of innovation: Adoption dynamics indicate that biased cultural transmission is the predominant force in behavioral change. *American Anthropologist* 103:992-1013

Jones RB, Audi PA, Tripp R. 2001. The role of informal seed systems in disseminating modern varieties. The example of pigeonpea from a semi-arid area of Kenya. *Experimental Agriculture* 37:539-48

Kirsten J, Gouse M. 2002. Bt cotton in South Africa: Adoption and impact on farm incomes amongs small- and large-scale farmers, Virginia Tech, Information Systems for Biotechnology, Blacksburg, VA

Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science* 319:607-10

Manjunath TM. 2009. *Bt cotton in India: Remarkable adoption and benefits*. http://fbae.org/2009/FBAE/website/our-position-bt-cotton.html

Maredia M, Howard J, Boughton D. 1999. *Increasing seed system efficiency in Africa: Concepts, strategies and issues*. East Lansing, Michigan: Department of Agricultural Economics, Department of Economics, Michigan State University

Marra M, Pannell DJ, Abadi Ghadim AK. 2003. The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural Systems* 75:215-34

Matuschke I, Qaim M. 2008. Seed Market Privatisation and Farmers' Access to Crop Technologies: The Case of Hybrid Pearl Millet Adoption in India. *Journal of Agricultural Economics* 59:498-515

Morris ML, Tripp R, Dankyi AA. 1999. *Adoption and impacts of improved maize production technology: A case study of the Ghana Grains Development Project*. Mexico, D.F.: CIMMYT. 38 pp.

Munshi K. 2004. Social learning in a heterogeneous population: technology diffusion in the Indian Green Revolution. *Journal of Development Economics* 73:185-213

Rogers E. 1962. *Diffusion of innovations*. New York: Free Press of Glencoe

Rogers E. 2003. *Diffusion of innovations*. New York: Free Press

Ryan B, Gross NC. 1943. The diffusion of hybrid seed corn in two Iowa communities. *Rural Sociology* 8:15-24

Stone GD. 2007. Agricultural deskilling and the spread of genetically modified cotton in Warangal. *Current Anthropology* 48:67-87

Struben J, Sterman JD. 2008. Transition challenges for alternative fuel vehicle and transportation systems. *Environment and Planning B: Planning and Design* 35:1070-97

Sunding D, Zilberman D. 2001. The agricultural innovation process: Research and technology adoption in a changing agricultural sector. In *Handbook of Agricultural and Resource Economics*, ed. BL Gardner, GC Rausser, pp. 207-61. Amsterdam: North Holland

The World Bank. 2007. *World development report 2008. Agriculture for development*. Washington, DC: The World Bank

Touré A, Sanogo O. 2006. Program for Africa's Seed Systems (PASS): Country report Mali, Institut d'Economie Rurale, Bamako

Tsur Y, Sternberg M, Hochman E. 1990. Dynamic modeling of innovation process adoption with risk aversion and learning. *Oxford Economic Papers* 42:336-55

Ulli-Beer S, Andersen DF, Richardson GP. 2007. Financing a competitive recycling initiative in Switzerland. *Ecological Economics* 62:727-39

Witcombe JR, Petre R, Jones S, Joshi A. 1999. Farmer participatory crop improvement. IV. The spread and impact of a rice variety identified by participatory varietal selection. *Experimental Agriculture* 35:471-87