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Developing Conservation Agriculture Production Systems: An Analysis of Local Networks

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Abstract

Conservation agriculture (CA) has been trumpeted as the solution for reducing soil degradation and increasing agricultural productivity around the world. Some farmland settings, such as in Brazil and the United States, have established substantial hectarage in conservation agriculture production systems (CAPS) establishment, while other locations, such as in Africa, have little permanent adoption of CA practices. A close review of the literature on adoption of CA technologies indicates that small-scale farmers are unlikely to adopt the practices that mechanized commercial farmers have so readily embraced. Smallholder farmers need additional support to overcome the risks and uncertainties involved in changing agricultural inputs, practices, and knowledge necessary to improve their production systems. This analysis of successful CAPS adaptation suggests that stakeholder networks play a critical role. Locally constructed networks can build a foundation for innovation, development, and diffusion of CA knowledge and practices among smallholders by providing access to resources for successful implementation of CAPS that increase the intensity of smallholder farming. This working paper introduces a model highlighting the main components of the generic CAPS to identify the main opportunities for and obstacles to successful transition to conservation agriculture.

Introduction

Conservation agriculture promises to revolutionize farming practices around the world. The theory of no-till farming first emerged (as an invention, if you like) with the publication of Faulkner's *Plowman's Folly* in 1943 (Coughenour and Chamala 2000). It wasn't until herbicides became readily available in the late 1950s and early 1960s that the era of no-till agriculture or conservation agriculture, as it came to be called in 2001, began (World Congress of Conservation Agriculture 2001; Garcia-Torres 2001).

It took farmers many years of field trials to discover the proper mix of herbicides, crop rotations, and seedbeds to produce increasing yields without tillage. It is important to point out that research scientists had little to do with the emergence of this innovation in the United States. A network of extension agents and farmers trying to improve their production processes while controlling erosion – with a frame of reference (Bijker 1995) derived from strip till and contour farming problems – slowly developed the innovation on Harry Young's western Kentucky farm (Coughenour 2003). Their laboratories were their own fields on which their livelihoods depended. Young set up his own experiments and took careful note of the results during the 1960s. Once he had perfected his no-till system, he was surprised to learn of the difficulties that other farmers had in subsequent attempts at adoption (Coughenour and Chamala 2000). Each farmer has to make adaptations within his or her own agroecology to be successful.

Harry Young's problem was framed within the context of mechanized agriculture where, despite strip tillage, erosion was still a problem when the soil was prepared for planting. Wet springs were particularly a problem, for they delayed tillage for crop establishment in otherwise good climatic conditions. Through multiple trials over several years, Young and his extension associate Phillips found that, with limited labor and the introduction of herbicides, a spring crop could be planted through a vegetative cover. Later, with increasing demand, a no-till planter was introduced by agro-industry (Allis-Chalmers) to suit the evolving local needs. With the increase in herbicide sales in the county, chemical companies began to take notice. CA innovations were quite profitable because they not only reduced input costs but created conditions to double crop soybeans following a grain crop (Coughenour and Chamala 2000). Thus the frame of reference shaping agricultural innovation (Bijker 1995; Spielman et al. 2009) shifted from erosion control to timeliness of the cropping system.

The First World Congress of Conservation Agriculture was held in 2001, and the term “conservation agriculture” for no-till farming practices was coined. The frame of reference also changed from targeting mechanized commercial farming operations to smallholder farms in developing countries (World Congress of Conservation Agriculture 2001). The fundamental principles of CA were then formalized:

- Minimal soil disturbance
- Permanent vegetative cover
- Crop rotations

For the past decade smallholder agriculture has been the target of CAPS promoters, in large part because African soils have become further degraded and climate change has encouraged more environmentally friendly production methods. Smallholders, however, have been reluctant to adopt CA practices without subsidy or other risk-minimizing support. We have learned a great deal about the conditions under which CA practices are adapted to local farming conditions. In particular, we have learned that adoption/adaptation is not solely based on field specific conditions. CA practices are implicated in a vast network of relationships that reinforce certain sets of knowledge, beliefs and behaviors. This working paper explores the history of those networks to unravel the confusion of hypothesis-driven research in search of the universal causal variable, as suggested by Knowler and Bradshaw (2006).

This working paper organizes the range of global experience with establishment of CAPS. The raw historical materials for this analysis can be found in the appendixes, while the paper itself synthesizes that material. Appendix 1 contains the case studies of CAPS development by continent, forming the basis for this analysis. Appendix 2 provides suggested material for reflection and individual hypotheses to explore. In the following section we describe the underlying methodology and conceptual model applied in these analyses. The next section deconstructs the conceptual model of conservation agriculture production systems to its constitutive components. Finally, we abstract lessons from these histories as meaningful interactions with local knowledge systems. But first, let’s briefly review some of the overt empirical differences in the two types of production systems into which CA practices have been introduced.

Conventional and risk-averse agriculture

Commercial and risk-averse smallholder farmers are distinguished primarily by their resource levels. The majority of the global case studies analyzed define smallholder farmers as those who farm about or less than 5 ha of land (Rockstrom et al. 2009; Mercado et al. 2001; Bwalya 2005; Baudron et al. 2007; Huggins and Reganold 2008). Small-scale farmers usually use human power or sometimes draft animal power, whereas commercial farmers employ mainly mechanized power. Because commercial and smallholder farmers use different types of power, they do not implement CA practices in the same manner. Largely developed in the United States and Brazil, CA techniques have been generally associated with mechanized power implements (Kienzle and Sims 2006). Thus, commercial farmers around the world have gained more knowledge and support for implementing CAPS because of similarities to previous implementers. Table 1 displays the sources of farm power for regions of the world recently attempting to implement CA practices. While no explicit comparison is given for American or Brazilian counterparts, the percentage of human muscle power in those countries is minimal given the larger farm sizes and dominance of mechanized farm power (Coughenour and Chamala 2000; Ekboir 2002).

Table 1. Sources of power for land preparation (% of total)

	Human muscle	Draft animal	Engine
Sub-Saharan Africa	65	25	10
East Asia	40	40	20
South Asia	30	30	40
Latin America and Caribbean	25	25	50

Source: Sims and Kienzle, FAO 2006

Based on the large disparities in farm power, methods of implementing CAPS will need to be adapted so that smallholder farmers can successfully utilize these practices. It has been postulated that smallholders need to intensify their farm power to successfully adopt CA practices. Increasing draft animal production or introducing machines could greatly increase a farm's efficiency (Sims and Kienzle 2006). Commercial farmers have had the resources to take risks and import products necessary for CA implementation. In contrast, risk-averse smallholders, habitually trying to make a livelihood, cannot risk waiting for long-term CA benefits to occur. Those commercial farmers, who have taken the risk of implementing CA practices, have come to play prominent roles in starting CAPS networks. Networks develop the capacity to promote CA implementation by cultivating strong supportive interactions between stakeholders and mobilizing local inputs (Bot and Benites 2001).

Methodology and conceptual framework

The case studies in this working paper come from a range of sources including Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), the United Nations' Food and Agriculture Organization (FAO), and the World Association of Soil and Water Conservation, as well as leads from the CA Community of Practice listserv and Google searches of keywords like "conservation agriculture," "conservation tillage," and "no-till agriculture." We also traced references and followed leads suggested by colleagues and the other sources. Our objective was to identify articles, chapters, and reports on actual uptake (i.e., sustainable adoption) or as close to that stage as possible. We have not given the same scrutiny to documents describing potential benefits without actual data on farmer adoption/adaptation.

The main case studies for each continent have been used to write the history of conservation agriculture development section (Appendix 1). By reviewing these historical narratives, identifying principal actors in the process, and examining historically and ecologically specific development problems and solutions, one can better understand the complex networks and their dynamic processes necessary to support adoptable CAPS innovation. The paper introduces a generic CAPS model of components vital to system behavior (Figure 1). Complete CAPS can be divided into four stages: inputs, delivery mechanisms, the symbiotic farm/farmer ensemble, and the benefit streams.

To better understand how this model has functioned historically, three specific country scenarios were developed to characterize CAPS network implementation in the United States, Brazil, and Ghana. These scenarios allow one to consider the farmer-defined problem, how the emerging CA network frames that problem, and the factors found relevant to the adoption of CA practices and CAPS establishment.

Knowledge networks

Networks are necessary for the distribution of physical and knowledge inputs, to provide moral support for coping with the challenges of CA implementation, and to raise yields for increasing profit margins. A combination of actors and relationships constitutes a social network (Knoke and Yang 2008). Actors may be individuals or collectivities such as informal groups or formal organizations. CA networks include multiple actors such as farmers, extension agents, researchers, supply companies, and government policymakers that share knowledge and resources toward implementing no-till practices. A relationship is generally defined as a specific kind of contact or connection between two actors for as long as both actors maintain their association (Knoke and Yang 2008). Relationships in CA networks generally deliver the necessary inputs to advance the local implementation of CAPS. While the CAPS model seems linear, with inputs creating outputs (Figure 1), the innovation process establishing the network involves complex interactions and feedbacks among system actors and the system's environment (Knowler and Bradshaw 2001; Spielman et al. 2009).

A major challenge for many developing networks is the lack of farmer involvement. Specifically, the lack of early local farmer involvement has hindered recent attempts at CAPS establishment. The network established to support CAPS in Ghana by the Sasakawa Global 2000 program regressed once project activities ceased. Indeed, farmers participated little in original network development and, when incorporated, were cast in the role of passive participants rather than full partners defining network priorities (Ekboir 2002). Successful networks have had early farmer participation and strong relationships among stakeholders and farmers, such as in the cases of the United States and Brazil (Coughenour and Chamala 2000; Ekboir 2002). Small farmers need to gain the capacity to solve CA implementation challenges and to innovate in the context of a supporting network (Giller et al. 2009).

Adaptive management

A main challenge hindering the implementation of CA practices is lack of a CA package adapted to local agroecological conditions (Ekboir 2002). The use of adaptive management overcomes this challenge by empowering farmers with the skills necessary to adaptively implement CA practices. Brazilian farmers in the *cerrado* region lacked a local CAPS package until farmer organizations adapted CA practices to their new environmental conditions (FAO 2001). When researchers tried to implement Brazilian CA knowledge in Zambia without adaptation, implementation experienced significant challenges due to differing conditions (Baudron et al. 2007). Local extension agents, farmer organizations, and entrepreneurs need to employ the process of adaptive management for themselves and local farmers' benefits when implementing CA techniques. Farmers in regions lacking an organized CAPS network may not have the support to gain the capacity required for successful adaptation and innovation.

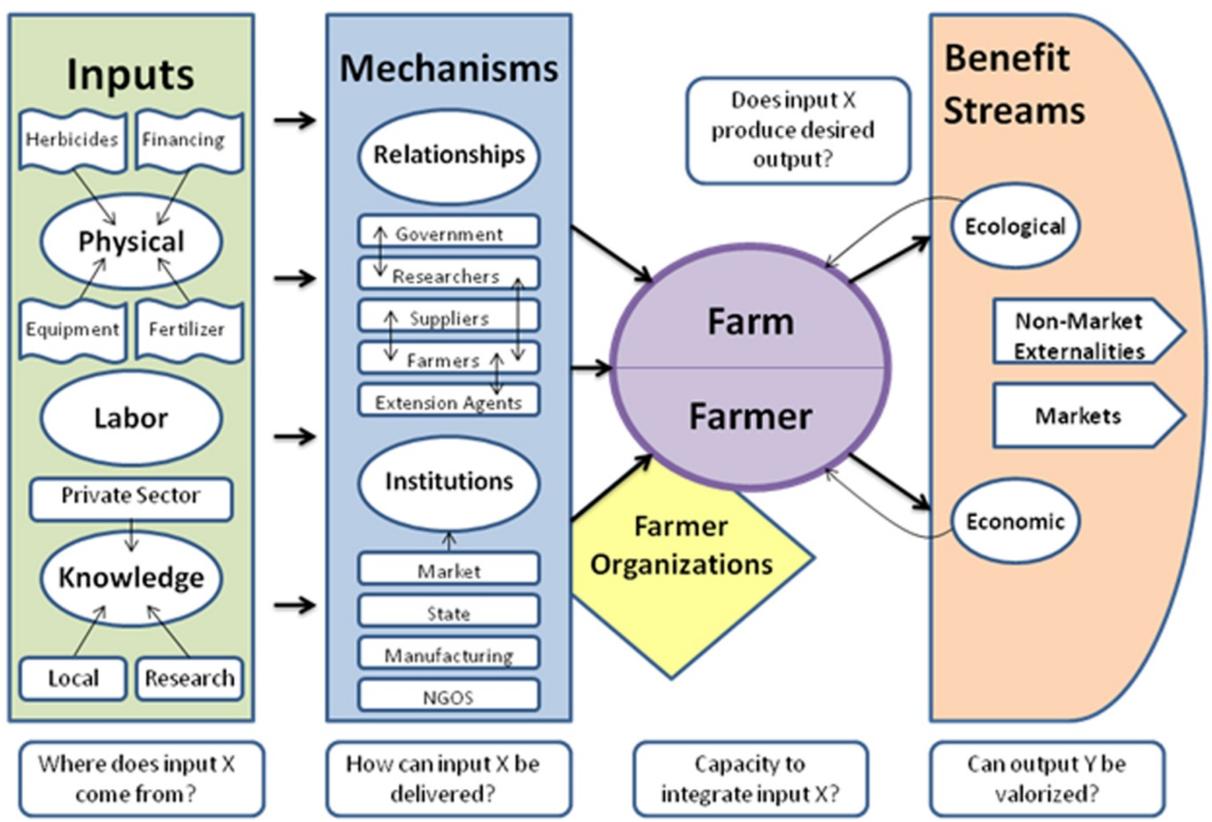
Adaptive management seeks to foster conservation agriculture among small farmers through mutual learning among a wide range of stakeholders. Farmers need to gain the capacity for ongoing adaptation of CA techniques, for they play a major role in solving local CAPS challenges (Knowler and Bradshaw 2006). The emphasis in adaptive management is on knowledge that builds farmer innovation skills rather than offering a prescription for implementation (Bot and Benites 2001). Adaptive management is a repetitive process of learning by doing and working to solve problems as they arise in the situation (Moore and Dillaha 2006; Moore 2009).

Farmers giving feedback to other stakeholders is the key to generating successful collaboration among network actors in solving farmer-defined CA problems. Communication and negotiation of knowledge between diverse stakeholders must occur to overcome network challenges (Knoke and Yang 2008). Successful cases have solved farmer-defined problems and built support networks from the farm up (Ekboir 2002). Future programs seeking to implement CAPS can learn from previous network development processes of real world experimentation that formed strong local innovative networks through adaptive management.

Overview of the model

Before populating the network mobilizing CAPS, it is useful to arrive at an understanding of the functional roles of potential system components. This allows us to identify relevant research questions for system analysis. Based on the global historical progression of CA implementation, we have abstracted a model of CAPS functioning. The model for analyzing CAPS is divided into four stages: inputs, delivery mechanisms, farm/farmer, and benefit streams (Figure 1). Scenarios 1 -3 below capture the recursive nature of the relationships involved in historical CAPS. This model simply captures the functional relations of a single productive cycle for analytic purposes. During the input stage both scientific and local knowledge and physical technology inputs become available to the network stakeholders. The delivery mechanisms stage captures the moment those inputs are distributed to the farmer level. The main feature of the model is the symbiotic farm/farmer unit, where the integration of knowledge and physical technology occurs. The fourth stage is the realized benefit streams, which can be divided into ecological or economic benefits.

Figure 1. Model for analysis of conservation agriculture production systems



Although many questions can be posed, a focal question captures the essence of each stage. For example, in the input stage, research focuses on where input "x" comes from. Research during the second stage addresses how input "x" can be delivered. At Stage 3, integration of inputs at the farm/farmer level is addressed. Customary research presumes that inputs are available and, if outputs are achieved, that they will have their expected impacts. The standard research question asks whether input "x" produces desired output "y" (Rockstrom et al. 2009; Sisti et al. 2004; Junge 2008). Focusing on the benefit stream stage, research investigates whether output "y" can be valorized. Until recently, researchers have rarely studied CAPS other than to determine whether the outputs are realized. Thus, many key questions of CAPS establishment are left unanswered (see Appendix 2 for research questions and hypotheses associated with each stage). Continued research on each stage is necessary to discover the key factors involved in successful CAPS functioning.

Components of the model described

Inputs

The first stage of CAPS is the identification and sourcing of inputs, either physical or knowledge based. Physical inputs need to be accessible to smallholders in their local environment because the establishment of CAPS often involves intensification of the production process (Kienzle 2009). Farmers will likely require herbicides, equipment, and possibly different fertilizer or seeds (Ekboir 2002; Huggins 2008; Wall 2007). While physical inputs are most often transferred through local vendors or extension agents, knowledge inputs are transferred through interactions with a greater range of stakeholders in the CA network (Wall 2007). Through our case study analysis we found that the availability of knowledge and local physical inputs greatly affects the success of CA implementation.

Physical inputs

Physical inputs can be divided into four categories: herbicides, fertilizers and seeds, equipment, and financing. Herbicides are often necessary for the early stages of CAPS implementation because tillage is no longer conducted for weed management. Herbicides have become more available, especially in areas where farmers are implementing CA practices (Wall 2007). However, many farmers, especially in Africa, lack access to herbicides because there has been little previous demand (Ekboir 2002; Bwalya 2005). In South Africa, farmers trying to implement CA practices have no market from which to buy herbicides (CIMMYT 2008). Yet herbicides are often critical to achieving a decrease in labor requirements, which is an adoption incentive stressed by CA proponents (Giller et al. 2009). In lieu of herbicides, increased labor may be required for weeding. If not available within the farm household, this labor may need to be hired or exchange labor relationships mobilized.

Another input component of CAPS is fertilizer from either organic or chemical sources (Knowler 2001). Research in the United States has noted that, in the first four to six years, CA demands extra nitrogen fertilizer to meet the nutritional requirements of some crops because increasing organic matter at the surface immobilizes nutrients (Huggins and Reganold 2008). Many CAPS packages for resource-poor smallholders also involve higher-yielding seeds. For example, in Ghana one of the key new aspects of the CAPS program was new seed varieties (Ekboir 2002). Improved seeds are often used as an incentive to behavioral change for resource-poor farmers (Ekboir 2003).

CAPS require a shift in how power is allocated on the farm (Sims and Kienzle 2006). Without proper equipment and tools CAPS cannot be efficiently established. In many areas CAPS implementation is hampered until the demand for local manufacturing occurs. While manufacturers are often interested in producing direct seeding equipment, production usually does not start until there is sufficient demand to make a profit (Kienzle 2009; Sims and Kienzle 2006). Thus, in many cases the appropriate equipment is not available unless farmers have the finances to import machinery (Bwalya 2005). Most CA equipment is high power, tractor or animal implements, and remains financially out of reach for the vast majority of small-scale farmers.

Because small holder farmers are resource poor, may not experience the long-term financial benefits of CAPS immediately, and additional physical inputs require money, financing is likely to be required for implementation of CA practices (Giller et al. 2009). In Zambia, most CAPS implementers use hybrid seeds and fertilizer on credit, allowing them to implement more CA inputs and increase their chances of successfully practicing CA successfully (Baudron et al. 2007).

Knowledge inputs

Knowledge is an essential component of successful CAPS establishment because it is routinely argued that farmers need to change their "mindset" to overcome CA challenges (Wall 2007; Giller et al. 2009; Knowler and Bradshaw 2006). Clearly there is a knowledge and informational component necessary to the proper implementation of CA practices, but there is also the matter of attitudes and concerning what constitutes culturally correct farming practices. Knowledge is a shared frame of reference among a community of stakeholders defined in part by their relationship to their production system. Farmers require knowledge of CA techniques, appropriate equipment, herbicide applications, and reasonable ways to overcome challenges. Other actors in the CAPS network require knowledge about the basics of CA practices and the role of their specific expertise in CAPS implementation.

Knowledge can come from many sources in the private, local, and research sectors. Chemical and equipment companies will often share knowledge about herbicide properties, dosages, and application techniques with farmers to increase demand for their products. In Brazil, international chemical giant ICI promoted knowledge of no-till practices, hoping that increased implementation of CA practices would boost sales of its herbicides (Ekboir 2002). Farmer knowledge of local soils in Niger informs precision farming decision making regarding the range of agroecological diversity (Osbahr and Allan 2003). Locally, knowledge is often transferred in farmer support groups where there is an environment conducive to sharing among farmers (Bwalya 2005; Rockstrom et al. 2009). Researchers provide knowledge to farmers through workshops or demonstrations of techniques that have been locally or regionally successful. Participatory research approaches lead to successful CAPS programs for both small- and large-scale farmers (Wall 2007). Knowledge (both know-what and know-how) must be locally accessible for farmers implementing CA practices; otherwise, input challenges will hinder successful establishment of CAPS (Feng et al. 2009; Brown and Duguid 1998).

Multiple delivery mechanisms

Delivery mechanisms provide methods of transferring inputs from CAPS suppliers to farmers. Each mechanism has its own strengths and weaknesses. Those should be evaluated because some mechanisms may be more appropriate for certain inputs than others. Actors and institutions involved in a particular mechanism often have their own motivations for transferring inputs, such as creating research opportunities or building demand for inputs to make a profit. Despite the motivation or incentive, the delivery mechanism and the relationships required for its functioning still need to support local farmers and effectively distribute inputs. CAPS farmers and input providers are mutually dependent, so the sustainability of the mechanism should be evaluated.

Relationships and institutions as delivery mechanisms: Building the network

Interactive relationships allow for input transfer and feedback among stakeholders. While the creation of such relationships is crucial in the success of a network, many relationships may not have the incentives and capabilities necessary to transfer inputs (Knoke and Yang 2008). For example, failures of adoption/diffusion are often due to weak linkages among extension, research, and farmers (Giller et al. 2009). These weak linkages often extend beyond research and extension to the private sector and government services. Therefore research needs to examine not only whether a relationship exists but also the quality or strength of that relationship in the CAPS. We have identified seven types of relationships that may provide for the delivery of CA inputs. These possible network relationships, listed in no particular order, all need to develop if a CAPS network is to be successful.

First, local farmers should have a relationship with CA equipment suppliers. Unfortunately, most equipment manufacturers have not initiated production of CA tools at a local level or listened to feedback from farmers implementing CAPS (Wall 2007; CIMMYT 2008). The demand for equipment will need to increase in many areas for entrepreneurs to begin making a profit (Kienzle 2009). Local manufacturing institutions allow for the distribution of equipment to local CAPS implementers but usually do not appear until profits are likely.

Due to the high demand for herbicides when establishing CAPS, farmers should also develop a relationship with chemical suppliers. Once the suppliers realize the increasing demand for their products within CAPS, they start promoting CA practices to boost profits (Ekboir 2002; Wall 2007). One could argue that the current wave of interest in CA is supplier driven. This enthusiasm needs to be translated into adapted input provision at the local level. Indeed, creating opportunities for commercial and artisanal entrepreneurs may be one of the more valuable components of CAPS development.

Next, farmers need to develop relationships with researchers to access the new knowledge that could help overcome production challenges. Successful research programs often use participatory research approaches, although participatory approaches are often different for small- and large-scale farmers (Bot and Benites 2001; Kienzle 2009; Bwalya 2005). Some of the main international research organizations supporting global CA implementation include CIMMYT, CIRAD, and FAO (Baudron et al. 2007; Kienzle 2006; Wall 2007). Many of these organizations have begun to focus on and study the specific challenges of smallholder, resource-poor farmers implementing CA practices.

The relationship between extension agents and farmers is also a critical linkage in the CAPS network, for extension agents often have specialized knowledge that facilitates and encourages local innovation. In Ghana, extension agents offered farmers preseason training not just to share knowledge but also to increase interaction among researchers, extension agents, farmers, and input sellers. This created opportunities for network members to discuss CAPS challenges (Ekboir 2002). In Ghana, extension agents developed another type of relationship with farmers, for they brought reduced cost inputs to project villages (Ekboir 2002). Unfortunately, extension agents are underrepresented in many areas (CIMMYT 2008).

Farmers also need interactions with other farmers, either informally or in groups, collaborating to overcome local CAPS challenges (Rockstrom et al. 2009; Knowler and Bradshaw 2006; Wall 2007; Ekboir 2002). Farmer organizations play a significant role in creating an environment conducive to knowledge sharing while distributing risks and input costs among local farmers (FAO 2001; Wall 2007). In Brazil, farmer organizations greatly affected the process of CA uptake by locally supporting and providing inputs for farmers implementing CA (FAO 2001).

Finally, the weakest relationship in many historically successful CA networks has been the link with government. Most successful networks did not have strong links to the government, although creating a conducive policy environment is a valuable role for government officials and has been highly successful when promoted by local government units (Coughenour and Chamala 2000; FAO 2001). More recent CA network developments have relied on governments to forward CA research and fund extension agents (Ekboir 2002). A country's ministry of agriculture is usually the main entity involved, often contributing funds or resources to CA research projects. Although most countries' ministries of agriculture did not play an early role in CAPS networks, many are now part of CA programs and committees (Kienzle 2009).

These stakeholder relationships should evolve in an adaptive management context to prepare farmers to adopt the techniques for themselves. Consequently, the majority of CA efforts to directly import external knowledge have not been successful. For example, imported knowledge from Brazil created many challenges because the mechanized approach was not appropriate for Zambian smallholder farmers (Baudron et al. 2007). To create a successful network, local farmers need relationships with many actors to access inputs (Mercado et al. 2001; Dixon et al 2007).

Symbiotic farm/farmer unit

The farm and farmer play major integrating roles in local CAPS network development. Unique characteristics are contained in this stage that must be examined to further complement the development of other stages in the system. Bebbington (1999) argues that, to analyze rural livelihoods, we need to understand smallholders' access to capital assets; how people can combine and transform those assets to meet their needs; the ways people can expand their assets through relationships; and the ways farmers can enhance their capabilities to change the way resources are controlled, distributed, and transformed in society. Flores (2008) details how farmer/farm capacities are required to transform inputs in the unit into outputs. These capacities include executing plans, generating financial management, involving and interrelating with other actors, and providing internal management and organization. This section details the assets and capacities of the symbiotic farm/farmer unit to integrate CA practices.

Farmer

Each farmer establishing CAPS has unique characteristics that factor into any modification in his or her mode of crop production. These characteristics can be broken down into financial, human, and social capital. Financial capital allows the farmer to take a risk with crop production through the use of either risk insurance, production credit, a non-farm income, or sufficient wealth to withstand crop losses. A CAPS program in Tanzania chose strong farmer groups to put into operation local credit groups, allowing smallholder farmers to create their own source of credit within their community (Kienzle 2009). Human capital is what the farmer possesses in terms of information, education, knowhow, management, labor, skills, gender, and cultural values. Early farmers adopting CA practices in the United States and Brazil had high levels of agricultural education and possessed the skills to innovatively change the farm's cropping system (Coughenour and Chamala 2000; Ekboir 2002). Farmers also require social capital, usually accessed through the membership of local organizations or community ties. Harry Young Jr., the main pioneering farmer of CAPS in Kentucky, was a leader and member of many local organizations, which gave him many useful contacts (Coughenour and Chamala 2000). Adapting CA techniques needs to occur at the local level, thus these various forms of capital possessed by farmers can greatly improve the probability for successful CAPS establishment. If farmers are to have a more effective role in implementing CAPS objectives, they need to be informed, educated, skilled, and financially empowered within the context of local support networks to implement and maintain CAPS (Kienzle and Sims 2006).

Farm

Just as the farmer possesses certain forms of capital, the farm too can be characterized by the forms of capital that compose it. Farm assets can be classified as physical, built, and natural capital. Physical capital is the type of equipment that the farm operates, such as hand tools, animal traction implements, or motorized equipment. The establishment of CAPS with hand tools on smallholder farms requires different knowledge and resources than that of motorized equipment (Kienzle 2006). The built environment consists of farm infrastructure, livestock, pastures, cropped fields, insects and other pests, and weeds. For instance, the addition of livestock to CAPS can have positive benefits such as reducing fertilizer and agricultural chemical needs while increasing biomass generation for surface residues (Landers 2007).

Natural capital includes the biophysical elements such as soil health and characteristics, topography, rainfall, and temperature. Experiments in Brazil have found that to have minimal soil erosion it is necessary to keep about 70% of crop residues on the field (Landers 2007). It was also discovered that, while CA principles have wide applicability to many soil types and rainfall patterns, they are not suitable for soils with limited drainage (Wall 2007). One of the main reasons to implement CA is to sustain agricultural resources on farms by limiting erosion and conserving water. Thus, many researchers have focused on the biophysical outcomes of implementing CA on farms (Junge 2008; Bwalya 2005; Sisti et al. 2004; Rockstom et al. 2009; Kaumbutho and Kienzle 2007).

Benefit streams

Outputs resulting from CA practices are the most researched stage of CAPS, especially the examination of biophysical benefits. However, outputs are only a precursor to ecological and economic outcomes. Ecological benefits can include decreased soil erosion, increased amounts of carbon sequester, and improved soil health. Soil loss was 42 times higher from a plowed watershed than in a no-till watershed in a Nigerian trial (Junge 2008). CAPS can also be implemented to increase biodiversity; the European Union may use CA to reduce declines in biodiversity necessary to meet its commitment for the June 1992 Rio de Janeiro Convention on Biological Diversity. Implementation of CAPS increases earthworm numbers and provides improved ground cover for birds, insects, and mammals (Jones et al. 2006). There is also a link between carbon sequestration in soil and global warming, for the long-term capture of carbon in organic matter reduces the atmospheric load of carbon (FAO 2001). However, while most farmers want to be able to conserve their farms' resources, they also need a sustainable livelihood with increased income from their CAPS (Knowler and Bradshaw 2006).

Economic outcomes have included reduced turnaround time between crops to give better yields, the addition of crop rotations to provide a cash crop and crop diversification, and decreased fuel consumption. However, for some smallholders, farm degradation occurs because their household priorities rank immediate food security above longer-run sustainability considerations (Knowler 2001). In Ghana, smallholder farmers profited from increased income because CAPS reduced the turnaround time between their crops, allowing for earlier planting and possible earlier yields (Ekboir 2002). Although some farmers have experienced economic benefits due to establishment of CAPS, profitability is still uncertain. Many benefits accrue to society and necessitate widespread implementation (Giller 2009; FAO 2001b). FAO studies have shown that, while many of the incremental costs associated with adopting CA accrue at the farmer level, relatively few of the benefits do (2001). If a generic cost-benefits analysis shows that CAPS generate sustained farm profits, then more farmers are likely to start implementing CA practices. Small farmers require assured profits because they cannot risk low crop yields. While CAPS have a small cost advantage over conventional agriculture production systems, they still largely depend on site-specific conditions (Knowler 2001).

Outcome mechanisms

Just as delivery mechanisms are required for CA inputs, mechanisms are also necessary to distribute CA outputs. The two main mechanisms are markets and non-market externalities. Markets for farmers to sell their CA products may exist in major urban areas, but they need to be accessible for rural producers. In the Zambia project, the two main urban centers had markets, but those markets were not easily accessible to small-scale farmers (Baudron et al. 2007). Non-market externalities come in many forms. Positive forms include a more sustainable agricultural environment and strengthened local relationships due to the creation of a network that can be used to solve other issues. In a sustainable agricultural environment, soil does not erode away in large quantities. It takes an estimated 700 to 1,500 years to form an inch of soil (Huggins and Reganold 2008). In contrast, conventional tillage can cause about an inch of erosion in 25 years. With the University of Kentucky's findings that CAPS decrease soil erosion by 98%, there are wide-reaching benefits of preserving soil for future farmers (Huggins and Reganold 2008). Farmers need visible positive outcomes from CA practices if the objectives of CAPS are to spread.

Story the model tells

The generic CAPS model focuses attention on all stages rather than simply analyzing the achievement of benefits. The ability to separate stages of the process enhances actors' abilities to strengthen their networks' weak links. Motivated actors can strengthen the most important interactions and allow for greater dispersal of CAPS knowledge and inputs to other farmers considering adoption of CA practices. For successful CA implementation, the CAPS network will need to include actors at all stages of the system and provide strong linkages at each stage.

CA pathways and frames of reference

A frame of reference attempts to capture the diversity of interactions within a developing network of social agents (Bijker et al. 1987; Bijker 1995). Technological change in agriculture involves shifting frames of reference. The CAPS technological frame came about when a problem was identified within the conventional agricultural frame of reference – soil erosion and degradation. To understand potential and existing pathways to CAPS, it is important to recognize not only the problem around which a frame of reference is formed but also who is defining a set of circumstances as the problem to be resolved. This allows one to better grasp the constitution of social actors and networks that are mobilized to address the problem. CAPS' frame of reference comprises all elements that influence the interactions of stakeholders with respect to CAPS. Successful networks are formed as stakeholders come to create a mutual understanding of those material, social, and technical elements shaping the CAPS technological frame. Each technological frame is unique, and additional elements may be necessary to give adequate interpretation of the interactions (Bijker et al. 1987).

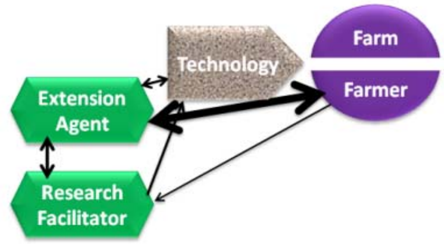
CAPS' technological frame of reference can be summed up by asking a few key questions. First, what is the problem? Farmers attempting to implement CA practices may want to stop erosion, conserve moisture, save time, manage labor, or simply increase their income. Second, who is involved in defining the problem? Stakeholders defining the problem include many actors such as farmers, researchers, government officials, and commercial interests. For farmers, conserving soil moisture may be the problem; but for chemical company representatives, it may be low sales of herbicides. Third, how is the CAPS problem approached? There are many ways of solving CA problems, including a technological change, adaptive management, or farmer problem solving. Fourth, why are CA practices adopted? There are many reasons, including increased income and the resolution of production constraints such as weeds, double cropping, labor management issues, or timeliness. The diversity of CA agroecosystems creates the development of unique frames of reference for many CAPS networks.

Innovation process developing CAPS on 3 continents

Each CAPS case study has a different frame of reference that emerges from historically and ecologically specific circumstances. We have chosen to explore the historical evolution of three CAPS' network development. The importance of initiating local innovation and developing the network needed to support it becomes visibly apparent through this analysis. The three cases represent successive waves of CAPS knowledge diffusion in different agroecological systems. Each network developed uniquely, but certain stakeholder connections can be compared to better understand how successful CAPS networks were formed. Models for each of the scenarios divide each network's development into three phases to help portray the unique development process involved. See pages 13-15 for the three scenario models, which are analyzed in the following section.

Scenario 1: United States

1



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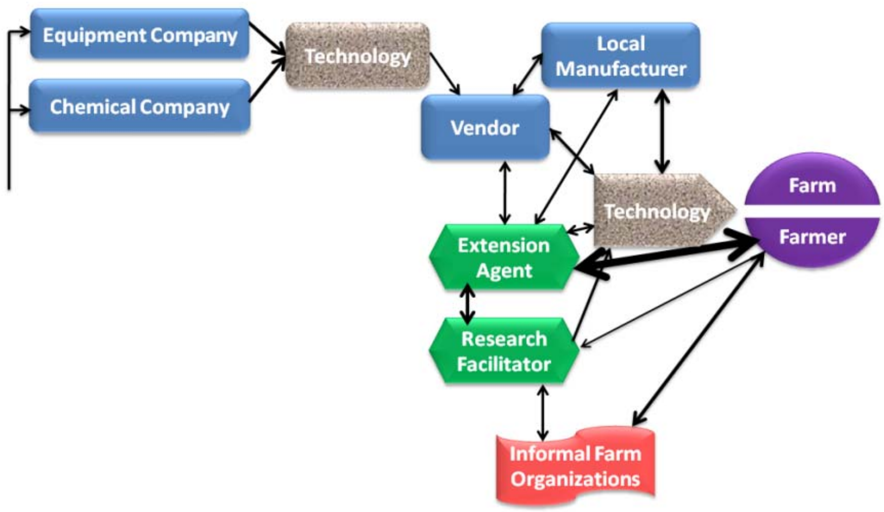

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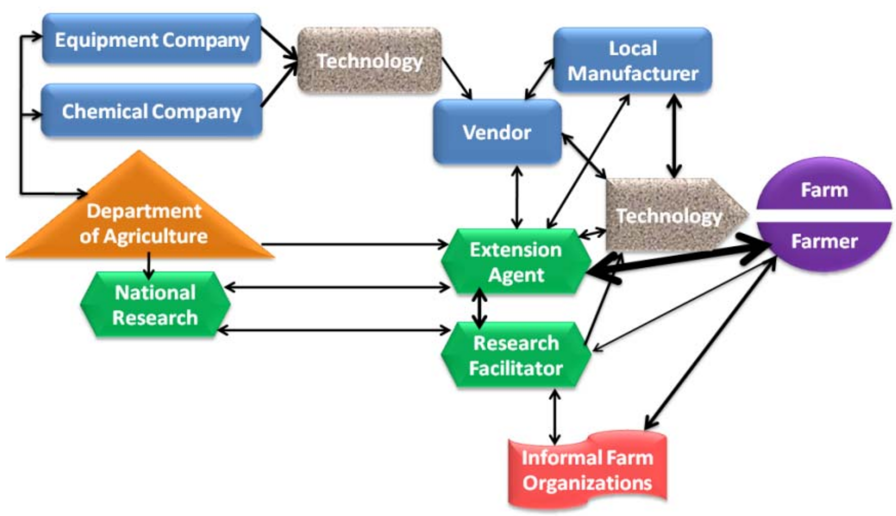

Scenario 2: Brazil

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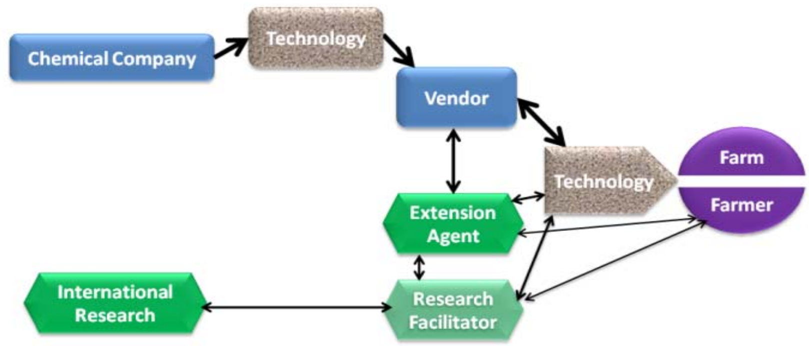

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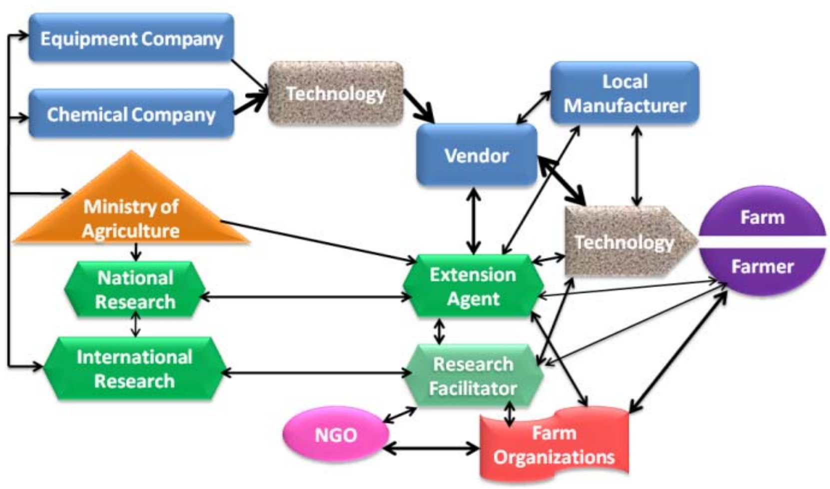

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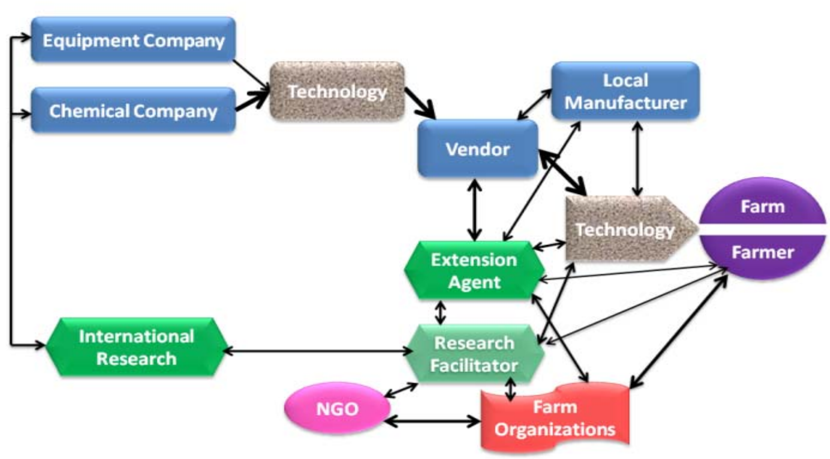

Scenario 3: Ghana

1

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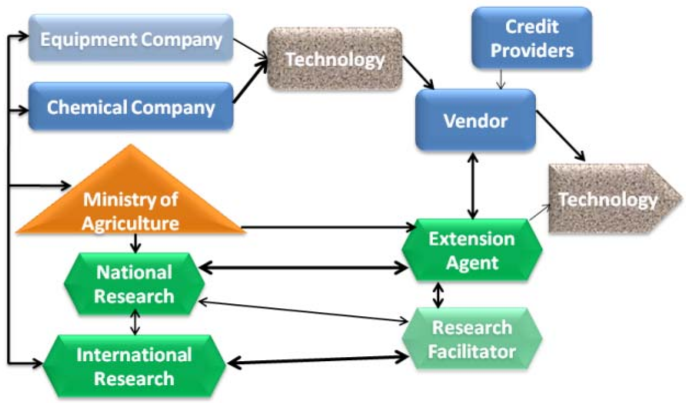

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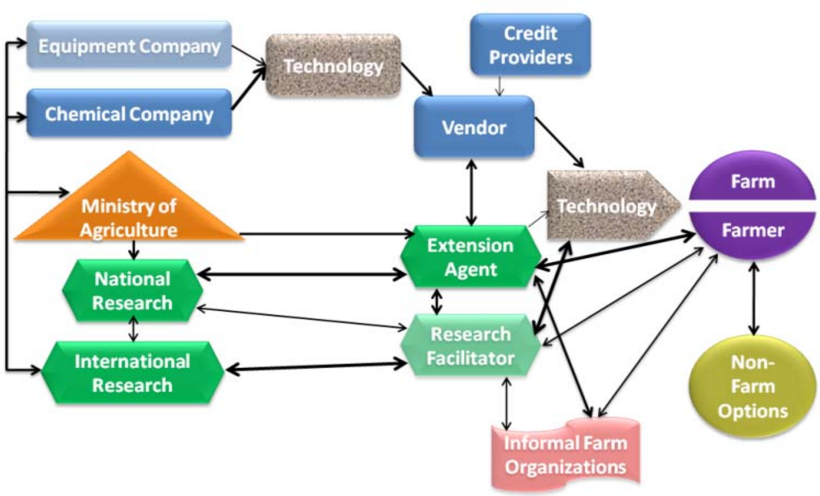

United States CAPS model

In the United States, the process of developing a CAPS network started with innovative farmers interacting with extension agents and one research facility in Illinois. In 1961 and 1962, the Young family farm in Christian County, Kentucky, was among the first to experiment with a combination of no-till techniques, herbicide usage, and seedbeds with crop residues (Derpsch 2008). As a result of many years (1961-68) of trials and collaborations with other farmers and extension agents, Harry Young and nearby farmers finally achieved the correct mixture of herbicides and no-till techniques that satisfactorily controlled weeds and produced thriving crops on their farms (Coughenour and Chamala 2000). Harry Young also decided to try no-till soybean trials after wheat in 1967 to increase income by double cropping. Many American farmers switched to no-till practices after learning of the extra income potential of double cropping soybeans using no-till practices. Local American farmer innovations spurred the initial growth of the CAPS network.

To increase the diffusion of no-till practices in other locations, greater agricultural research and technical resources had to be mobilized (Coughenour and Chamala 2000). The second phase of development produced much greater accessibility to inputs for farmers through chemical and equipment companies, vendors, manufacturers, and informal farm organizations. In 1966, farm equipment manufacturer Allis-Chalmers developed the fluted coulter no-tillage planter for commercial sale, which made the adoption of conservation agriculture technologies feasible for many farmers. By 1969, the Allis-Chalmers dealer had sold 68 no-till planters in Christian County, Kentucky (Wendel 1993). Sales of herbicides also expanded and attracted the interest of chemical companies. When an herbicide sales representative came to the Christian County extension office looking for an explanation of the increased herbicide sales, he got a tour of the no-till fields. Based on farmers' need of additional herbicides for no-till practices, chemical companies recognized a potential new market and began expanding their research and developing more effective no-till herbicides (Coughenour and Chamala 2000).

The Department of Agriculture and national researchers did not join the U.S. CAPS network until it was almost fully developed at the third phase. The Department of Agriculture helped disseminate the knowledge learned from national researchers to other parts of the country (Coughenour and Chamala 2000). Increased nationwide research helped farmers outside Kentucky learn how to adapt CA practices for their own farms.

Brazil CAPS Model

In Brazil, international researchers and chemical companies played a prominent role in promoting the establishment of CAPS. In the late 1960s Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) placed international researcher Rolf Derpsch at the agency that would become the Brazilian Agricultural Research Corporation (EMBRAPA) to work on a project improving Brazilian soybean yields. He found that intensive soybean cultivation severely eroded the soil and began experimenting with alternative methods. Derpsch had read about no-till trials at an experiment station in Germany and teamed up with Herbert Bartz, a local farmer, to run a no-till trial on his farm in Paraná, Brazil (Ekboir 2002). Bartz, through the process of many innovations and knowledge gained from visiting the United States and Europe, managed to minimize soil erosion on his land by implementing no-tillage methods. Chemical company ICI transferred its no-tillage research team from Australia to Brazil, where it soon developed the first Brazilian no-till package. ICI's business strategy was to provide the knowledge of no-till and then hope that farmers would realize its potential and start buying herbicides (Ekboir 2002). Brazilian farmers also began realizing the increased income potential from implementing no-till practices and double cropping soybeans.

While farmers still generated much of the network's innovation, they were strongly supported with knowledge and funds by research facilitators, chemical companies, and vendors. Not all Brazilian farmers obtained successful results with ICI's no-till package -- few herbicides were available, and the imported no-till machines were slow in arriving. Chemical companies quickly imported herbicides as they became available on the market, but it took equipment companies longer to realize there was a demand for locally manufactured CA implements. The availability of machines improved when ICI persuaded Semeato, an equipment manufacturer, to start importing a no-till planter (Ekboir 2002). By 1985, 13 no-till machine manufacturers were on the Brazilian market with Semeato as the leader (Derpsch et al. 1991).

NGOs and farm organizations became part of the Brazilian network after increasing numbers of farmers implementing CAPS began creating local support groups for themselves. After ICI ended its no-tillage activities in the late 1980s, the Association of Zero Tillage Farmers (AZTF) became the hub of the network, distributing information and exploiting economies of scale to address farmers' needs quickly (Ekboir 2002). National researchers joined the network after its development. The Brazilian Ministry of Agriculture joined after starting a credit program promoting no-till methods, although the program first endorsed terraces until the terraces all washed away (Ekboir 2002).

Ghana CAPS Model

The CA network developed differently in Ghana compared with the other two case studies. The network began with input from national and international research teams. In the late 1960s, local individual researchers started studying no-till in Ghana at the same time that similar work began in Europe and the United States. However, the Ghana researchers had few contacts with agrochemical companies or foreign researchers (Kannegieter 1967, 1969; Ofori and Nanday 1969; Ofori 1973). The research studies do not mention interactions or lack of interactions with Ghana farmers. The International Institute of Tropical Agriculture in Ibadan, Nigeria, began its no-till research in the early 1980s.

The second phase of the network's development went beyond research and started involving local farmers in CAPS establishment. In 1993, collaboration among the Crops Research Institute (CRI) in Kumasi, Ghana, Sasakawa Global 2000, and agriculture and technology giant Monsanto began offering a no-till with mulch package to farmers in the forest, transition, and Guinea savannah zones (Ekboir 2002). Because most small-scale farmers had historically planted using no-till methods, the new aspects of the package were improved seeds, herbicides, and fertilizers. There was no dramatic change for farmers who had been planting seeds using a stick or machete into untilled sod (Ekboir 2002). Few of the routine second phase actors play a substantial role in Ghana's network development except when their products were needed for international CA research programs occurring in Ghana. Credit providers showed up with the CAPS programs but faded away when programs ended or funds were cut. The Ghana Ministry of Agriculture also played a role funding extension agents' participation. However, many agents did not receive sufficient knowledge of CA practices to implement CAPS establishment.

During the third phase of network development, CA programs and networks needed the support of local communities. Farmers and informal farm organizations participation are necessary for local CA knowledge sharing. Support and interaction from the no-till network of researchers, extension agents, and discussion groups, was temporarily available to Ghanian farmers implementing no-till practices. However, this phase was never fully realized because the program ended, and relationships and actors disappeared. Ultimately the Ghana CAPS network regressed.

Scenario comparisons

Although each of the scenarios developed uniquely, a few similarities can be derived from the United States and Brazil models' completion of networks compared with the eventual regression in the Ghana case. American and Brazilian farmers were early innovators and adapters of CA practices. Key individual actors, often farmers, extension agents, and researchers, advanced the two networks through persistence and risk taking. Comparatively, the Ghana case was and still is heavily dependent on researchers rather than other network actors. Small-scale farmers in Ghana do not have the livelihood resources necessary for risk taking, and other actors' support in the Ghana network disappeared once program funding dissipated (Ekboir 2002).

Brazil's network was initially supported by chemical companies; American chemical companies supported CA once they realized a demand for herbicides (Coughenour and Chamala 2000; Ekboir 2002). Chemical companies in Ghana may not foresee the profit potential that CA created in Brazil and the United States due to resource poor smallholder farmers lack of purchasing power and thus have less motivation to support the network.

Both the American and Brazilian scenarios developed local manufacturing due to growing demand for CA inputs (Coughenour and Chamala 2000; Ekboir 2002). Many farmers did not have the capacity to create their own equipment and thus, for wide-scale distribution of CA practices, equipment needed to be available. In the United States and Brazil, manufacturers began providing high-powered equipment locally. In comparison, farmers in Ghana mainly use human power for planting and cultivation using sticks or machetes to plant into un-tilled soil. Such farmers would need equipment locally manufactured or imported but are unlikely to have the resources necessary to purchase either.

Farmers played an important role in the beginning of both Brazilian and American CAPS networks, and farmers' organizations gave support by providing local knowledge to smallholders facing similar challenges. Ghana farmers have not implemented CAPS on a large scale. Consequently, there are few networks to support new farmer implementation of CA methods.

While the Brazilian and American uptake of CA practices has steadily increased due to strengthening networks, in Ghana the network regressed after promotion of the CAPS package ended. The American and Brazilian national departments of agriculture began promoting CA and supporting its implementation in other areas of those countries (Coughenour and Chamala 2000; FAO 2001). Ghana's network was based on research projects with no locally sustainable network relations, so when the research ended, the links broke.

Challenges and opportunities fostering technological change in agriculture

Key similarities and differences among the three network development scenarios can be analyzed to evaluate each network's success. CAPS implementation even in areas with strong networks has many challenges, but the biggest obstacles arise in newly developing networks. Previous sections demonstrate that commercial farmers, especially in North and South America, have more readily implemented CA methods, whereas smallholder implementation lags. Yet the global area under CA practices has continued to slowly rise, leading to opportunities for additional farmers to learn and incorporate CA practices. The following are a few suggestions for overcoming challenges and pursuing opportunities when promoting and integrating CA methods.

Incorporate adaptive management to promote local innovation

Local innovation in the analyzed case studies greatly increased the likelihood of success in CAPS establishment. Adaptive management needs to be practiced by network actors so that farmers themselves learn how to adaptively integrate CA practices into their cropping systems. This requires that farmers and their farms become the center of the learning process. It also requires that they develop the knowledge, confidence, and skills to make system adaptations on their own farms.

Investigate hypotheses in CAPS beyond biophysical field tests

Most research on CAPS has focused on the expected outcomes after successful implementation of CA practices. To develop a successful CAPS network, it is necessary to investigate how all system components contribute to achieving the desired outcomes. Research should delve into problems occurring at each stage to help address the systemic problems challenging CAPS establishment.

Strengthen stakeholder relationships to allow for free-flowing resources and knowledge

The development of a strong CAPS stakeholder network is necessary to support farmers implementing CA practices. Interaction between a network's main components and stakeholders allows for the transfer of inputs, outputs, and knowledge. Strong incentives and capabilities promote feedback and problem solving.

Mobilize interest and support for CAPS globally

More research is occurring due to increasing demand by stakeholders in many CAPS networks for knowledge regarding CA implementation. With increased knowledge about the possible environmental and economic benefits, CA practices are increasingly being chosen as an option for many sustainable agricultural programs and by individual farmers for trials on their own farms.

Cultivate support for local adaption approaches

For successful CAPS establishment, the three CA principles must be adapted to fit the local environment. The scenarios illustrate the important roles that stakeholders must undertake in the creation of a successful CAPS network. Challenges and solutions for CA implementation need to be discussed and developed at the local level if farmers are to successfully establish CAPS.

Increase support for CAPS environmental service payments

The pervasive threat of global climate change is increasing the economic value of environmentally beneficial CA practices. Interest is growing in how to economically support environmentally sustainable choices. Farmers implementing CAPS should consider what economic benefits they may realize, from carbon credits to clean water, because of the increasing focus on preserving their farm resources. Only community-based networks will be able to capture these advantages for small-scale farmers.

Confront the challenges of CAPS establishment

Because farmers have been establishing CAPS for more than 40 years, more is understood now about the challenges. Especially in recent years, new challenges have been revealed as smallholders have implemented CA to improve incomes and create more sustainable livelihoods. Recognizing obstacles is an important step toward meeting challenges through the collaboration of diverse stakeholders.

Recognize the variety of CAPS experiences adaptable to local situations

The range of farmers' experiences with CA practices is vast. With more connections among networks, farmers, and other CAPS stakeholders, the opportunities to learn from increasingly diverse knowledge networks expand.

Conclusions

Greater analysis of previous CAPS network developments can prepare future emergent networks with the knowledge to more effectively overcome obstacles. However, CAPS networks developing in areas with small-scale farmers will require adaptations distinct from those serving commercial, often more mechanized farms. There is no guaranteed solution that will help overcome CAPS challenges, especially for smallholders. However, continued research and development of networks significantly promotes and supports farmers striving to establish CAPS.

Appendix 1: Development of conservation agriculture production systems

Historically, no-till was practiced by indigenous cultures, but the first modern reduced-tillage practices emerged in the early 1960s after the introduction of herbicides in the 1940s and 1950s. In the 1940s Edward H. Faulkner wrote two books, *Plowman's Folly* and *A Second Look*, questioning the necessity of the plow. However, the methods discussed in the books were not yet supported by chemicals (Phillips 1974). Farmers in North America began substituting herbicides for tillage as a precursor to introducing no-till practices. It took many years of field trials to discover the proper mix of herbicides, crop rotations, and seedbeds with crop residues to produce increasing yields without tillage. Farmers in no-till trials created knowledge networks that in the United States centered on interactions between other no-till farmers and extension agents. Successful no-till demonstration plots in Europe and farmers' innovative no-till practices in North America led to the introduction of no-till practices in South America. Australia is in the process of adopting no-till technologies that have already taken hold in the United States and South America. While research has transpired on most continents, substantial diffusion of no-till practices has been mainly in the Americas with little implementation in Europe, Asia, or Africa.

United States

After World War II a chemical revolution brought a growth spurt in development and dispersal of herbicides: 2,4-Dichlorophenoxyacetic acid in the late 1940s, Paraquat in 1955, and Aztrazine in 1958. With increasing availability of herbicides to control weeds, American farmers began experimenting with no-till practices. Soil erosion was a major incentive, for other options to control soil erosion, such as strip tilling and contour cropping promoted by the USDA's Soil Conservation Service, both make for inconvenient field operations and are expensive (Coughenour and Chamala 2000). Even after strip tillage was implemented, erosion was still a problem when the soil was tilled for planting.

In 1961 and 1962, the Young family farm in Christian County, Kentucky, was among the first to experiment with a combination of no-till techniques, herbicide usage, and seedbeds with crop residues (Derpsch 2008). The 1,234 acre family grain and livestock farm was jointly run by Harry; his father, Harry Young Sr.; and his brother, Lawrence Young (Coughenour and Chamala 2000). As a result of many years (1961-68) of trials and collaborations with extension agents and other farmers, Harry Young and colleagues finally achieved the correct mixture of herbicides and no-till techniques that satisfactorily controlled weeds and produced thriving crops on their farms.

Harry Young Jr., a key actor, helped start a local support network to experiment with no-till practices (Coughenour and Chamala 2000). In addition to the Young family, the other principal actors in the network were two other local farmers, Burks and Martin; Christian County Extension Agent Reeves Davie; and Shirley Phillips, an extension crops specialist at the University of Kentucky. Harry Young Jr. had an education in agronomy and agricultural economics as well as nine years experience in the extension service, where he still had contacts. Davie, who also had a background in agricultural economics, collaborated with Young to build an effective extension program including courses on record keeping and farm business analysis (Coughenour and Chamala 2000). From 1957 to 1970, the two worked together to promote no-tillage and double cropping systems. Phillips was an agronomy specialist with an extensive knowledge in weed control. Young cooperated with Phillips on extension trials of soybean varieties and chemical weed control in corn and soybeans (Coughenour and Chamala 2000).

Young was concerned with the effects of soil erosion on his farm land. To decrease tilling and slow the erosion, he also needed a way to free his field of weeds. His first attempt in 1959 with the herbicide Dalapon on one field was not successful, and he did not repeat the trial. However, neither did he give up on herbicides, spraying Aztrazine on 77 acres in 1961 (Coughenour and Chamala 2000). While Aztrazine did not kill all the weeds, it reduced them compared with those in the nearby cultivated field. Weeds still inhibit many farmers from adopting no-till practices, but innovative farmers are increasingly finding solutions to infestations.

The only relevant research that benefited Young's network was in Dixon Springs, Illinois. Young and a few other farmers traveled there to see a partial trial of corn planted in herbicide treated, untilled sod that looked like it would yield well. After seeing the trial in Illinois, Young decided to run his own trial in 1962 on 0.7 acre. He applied Aztrazine and modified a planter so it could force seeds into the untilled sod. The trial turned out so well that Young and Davie set up a field day for other farmers and interested officials to observe the results. Young's successful trial plot that year (which attained a corn yield similar to that of a conventional field) persuaded Martin and Burks to join the no-till trials. Farmers and extension agents were the sole participants in no-tillage practices at this stage; agricultural researchers were not involved. In 1963, Young marked off three plots and sprayed Aztrazine at three rates: 5, 3, and 2 pounds per acre. The 5- and 3-pound applications effectively controlled weeds, but the 2-pound application lacked strength. He continued to make comparisons of conventional tilled and no-till corn for the next six years. Martin experimented with an easier way to get seeds into untilled soil by mounting a disc coulter on a tractor to cut into the ground, a technological innovation that preceded the first commercial no-till planter by Allis-Chalmers. Martin's tractor innovation worked well enough that Young tried a similar device on his tractor in 1964. Despite the machinery adaptations, the use of herbicides on no-till farms was still not perfected; the use of increasing amounts of Aztrazine still did not satisfactorily control weeds and left herbicide residue in the fields. Through continued contact with the experiment station at Dixon Springs, Young discovered that Paraquat could be used to knock down the cover crop, solving the problem of Aztrazine residue (Coughenour and Chamala 2000).

In 1962, Davie held an extension meeting for local farmers to discuss the successful outcomes of no-till (Coughenour and Chamala 2000). Meetings and farm demonstrations continued, stimulating the uptake of no-till practices. While initially skeptical, extension agent Phillips eventually became convinced that no-till corn could be grown successfully. With other extension colleagues, he began promoting no-tillage practices, even though it was not research or government initiated. By 1965, most skeptics in the extension service and experiment station in Kentucky had been convinced that no-till corn was feasible. Because not all farmers were as mechanically skilled as Martin, the lack of no-till commercial planters was a major challenge. Still, by 1966 about 20 farmers in the Christian County area had either tried or were ready to try no-till corn with modified planters (Coughenour and Chamala 2000). In the fall of 1966, Davie organized a farmer field day with visits to four farms to spread information about no-till methods. Publicized along many avenues, the Cooperative Extension Service, the event drew more than 325 people from 19 counties (Coughenour and Chamala 2000).

At an extension meeting in 1967, speaking with the researchers from Dixon Springs, Davie suggested that farmers could increase income by planting no-till soybeans after harvesting wheat or barley. Young had kept extensive records of the machinery and man-hour requirements for producing no-till and conventional corn during these years. This data showed that an acre of no-till corn could be produced with half the man-hour requirements of conventional tillage (Coughenour and Chamala 2000). Young initiated double cropping with no-till soybean trials after wheat in 1967. He still had questions regarding the double planting of soybeans, especially because weed control can be an even greater challenge with double cropping. The potential for multi-cropping, including both intercropping and sequential cropping, may be the most important factor in no-tillage agriculture, for it increases land and equipment use, saves time when planting the second or third crop, and provides additional income (Phillips et al. 1981).

Development of more efficient planters facilitated double cropping in two ways: the new machinery could be adapted to plant more than one crop, and it was less labor intensive. Allis-Chalmers, which often tried new methods of crop production, was slightly ahead of its competitors when its engineers began experimenting with no-till machinery (Wendel 1993). In 1966, the company developed the fluted coulter no-tillage planter for commercial sale. This was the final component that made CA technologies feasible for many farmers. Field days continued to be popular in Christian County during 1967 and 1968, especially those conveying information from trials with herbicide applications and double-cropped soybeans.

To increase the diffusion of no-till practices in other locations new partners were brought in and the network expanded (Coughenour and Chamala 2000). Although a small market had been created for mulch planters, the major commercial opportunity in the mid-1960s was for larger conventional planters. Only Allis-Chalmers worked in the mid-1960s to develop a no-till planter. Harry Young and a few other farmers immediately wanted to buy the new Allis-Chalmers planter after they discovered it could be purchased. By 1969, the Allis-Chalmers dealer had sold 68 no-till planters in Christian County, Kentucky. Sales of herbicides also expanded and attracted the interest of chemical companies. When an herbicide sales representative came to the local Christian County extension office looking for an explanation as to the large herbicide sales, they got a tour of the no-till fields. Based on the increasing numbers of farmers needing herbicides for no-till practices, chemical companies realized a market could be created. Soon afterward chemical companies began expanding their research and developing more effective no-till herbicides (Coughenour and Chamala 2000).

For the Young family, no-till practices were highly efficient, effective, and profitable, and their success and enthusiasm encouraged many other farmers to develop similar systems. However, Harry Young Jr. underestimated the challenges other farmers would face, for the central components of the system, critical to adoption, were unique for each individual farm (Coughenour and Chamala 2000). Farmers had to adapt no-till practices and techniques to their own situations. No-till farming is more management intensive than conventional farming. Shirley Phillips identified four major factors encouraging farmer acceptance and implementation of no-till methods in Kentucky during the late 1960s: late wet springs that delayed planting, extremely limited farm labor supply, introduction of a no-till planter, and the availability of Paraquat (Phillips et al. 1981). Due to these factors and others, hectares under no-till in the United States grew significantly from 2.2 million hectares in 1974, 4.8 million ha in 1984, and to almost 20 million ha in 1997 (Derpsch 1984). Innovative farmers greatly expanded no-till practices in many areas of the United States with compatible soils. However, the implementation of no-till practices in the United States has been slower than predicted, and lands under no-till remain a small percentage of total cultivated land (Derpsch 2008). Despite lower-than-expected levels of implementation, the United States provided significant research that helped South America become aware of no-till practices.

Europe

While conservation agriculture research started early in Europe, currently only 15% of Europe's farmland is under some form of conservation tillage and only 1% under no-till (Lane et al. 2006). In Europe, early implementation of no-till practices was driven by the need to reduce crop establishment costs (Basch et al. 2008). Soil erosion and degradation were not major concerns. Europe has a generally stable cool and wet climate that does not experience heavy rainfall or severe windstorms, both of which increase soil erosion. No-till implementation was initially higher in Western European countries compared with Southern and Eastern Europe; but in 2005 Russia and Spain had the most area under no-till (Basch et al. 2008). While some farmers in Europe tried no-till practices on their fields in the 1960s, many problems occurred due to unfavorable soil conditions, few crop rotations, inappropriate machinery, and a lack of effective herbicides. Many soils in Europe are not suitable for conservation tillage because they are easily compactable or have poor drainage (Basch et al. 2008).

In the early 1970s, with the development of a market support system through the Common Agriculture Policy (CAP), many early European adopters of no-till practices reverted to plow-based production once grain prices were guaranteed (Basch et al. 2008). Thus, efforts to solve problems of no-till practices, such as weed control and crop residue management, ceased once the European Union (EU) guaranteed grain prices. Compared with farmers in South America, exposed to world market price fluctuations, European farmers did not have to find solutions to no-till problems to increase yields.

With Europe's decreasing implementation of no-till practices, there was little demand for manufacturing of no-till equipment. European farmers were also limited by tighter herbicide regulations in the EU, where important no-till herbicides such as Aztrazine were taken off the market in certain countries (Basch et al. 2008). Considering the no-till problems that have yet to be solved in Europe, few farmers there are willing to attempt the techniques.

In support of conservation agriculture, the European Conservation Agriculture Federation (ECAF) has been operating since 1999 to promote CAPS by supporting farmers in their efforts to adapt their practices. Farmers implement conservation tillage practices to decrease soil erosion, maintain soil fertility, conserve water, lower farm costs, and improve biodiversity. In the near future, European farmers may also have their subsidies linked to environmental protection, allowing those farmers practicing no-till to receive higher subsidies (Basch et al. 2008). Conservation tillage is knowledge intensive and requires farmers to make significant modifications to their planting dates, amount of mulch on their fields, herbicides usage, and timing of their minimum tillage. Those factors must be adapted to the individual farm if farmers are to succeed in creating the most environmental and economic benefits from implementing conservation agriculture practices (Jones et al. 2006). European farmers who want to adapt conservation agriculture need to be innovative and must have financial and technical support during the years of transition.

The United Kingdom has a significant amount of its cultivated land under conservation agriculture and played an integral role in the early stages of research. The UK's Imperial Chemical Companies (ICI) developed Paraquat in 1955, leading to the advancement of no-till technologies worldwide. By the early 1980s the UK had the second-largest area under no-till after the United States (Derpsch 1984). UK no-till experiments completed by Lloyd Murdock, an extension soils specialist, and James Herbek, an extension grains specialist, found that well-managed direct drilling farm plots could provide yields similar to those of plowed fields when straw residues were burned. Burning straw residues helps to control weeds, especially in fields containing serious weed infestations or continual- cropping winter cereals (Rule et al. 1991). After restrictions on straw burning were initiated, many UK farmers using these methods encountered a buildup of weeds and stopped using no-till (Christian 1994). One UK farm that switched to no-till methods in 1999 reduced its crop establishment costs by 25%. However, the need to control herbicide-resistant blackgrass increased weed control costs from 30 Euro per ha to 112 Euro per ha. To decrease weeds, the farmer switched from winter to spring beans, which helped grass weed control. By switching to spring beans and buying new no-till machinery, which decreased labor requirements, the farm's capital costs could be spread further (Jones et al. 2006).

Other European countries, while having initiated no-till research, have not had farmers implementing no-till practices on a large scale for a variety of reasons. In the Netherlands no-till research started in 1962, but researchers found that wind and water erosion are not sufficient motives for no-till adoption (Ouwerkerk and Perdok 1994). In Germany, no-till research started in 1966, yet fewer than 5,000 ha are actually under no-till cultivation (Friedrich Tebrügge Derpsch's personal communication 1998). In a long-term study at the University of Giessen, no-till was found to be profitable because of the decrease in machinery and operating costs (Tebrügge and Böhrnsen 1997). But to further emphasize the superiority of no-till systems, the beneficial environmental effects must be taken into account (Tebrügge and Böhrnsen 1997). France started long-term no-till experiments in 1970, and Boisgontier et al. (1994) documented the technical and economic data on where and how to develop no-till in France. In Spain, research started in

1982 and found no-till technologies to be useful in terms of lower energy usage and moisture conservation on the clay soils of southern Spain (Giráldex and Gonzáles1994). The areas developing no-till practices represent a small portion of the total cultivated land and, following the international no-till definition, Spanish farmers usually leave only 30% of the soil covered by crop residues (Costa 1996). No-till trials in Italy began in 1968, but implementation began only in the past decade due to Italian farmers' desire to reduce crop costs and the greater accessibility of equipment and herbicides. In 1997, the area under no-till was estimated to be about 2% of Italy's extensively cropped agricultural land (Sandri and Sartori 1997). While early no-till research trials started in many European countries, significant adoption has not occurred compared with North and South America.

South America

According to Ekboir (2002), no-tillage has been the most important agricultural technology adopted in Brazil in the past 50 years; a well-articulated no-till network emerged through the pressing needs of commercial farmers for sustainable technologies. In the late 1960s, GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit) placed Rolf Derpsch at what would become EMBRAPA (Brazilian Agricultural Research Corporation) to work on a project to improve soybean yields. He found that intensive tractor cultivation severely eroded the soil and began experimenting with alternative methods. Derpsch had read about no-till methods at an experiment station in Germany and teamed up with Herbert Bartz, a local farmer, to run a no-till trial on his farm (Ekboir 2002). Bartz managed to minimize soil erosion on his land by implementing no-till.

Bartz's no-till test plots on his farm in Rolanida, Paraná, achieved successful yields. Empowered by his success, Bartz and a neighbor traveled to the UK and the United States to learn more about no-till. Bartz bought a no-till planter and began growing soybeans under no-till in 1972. Bartz and his neighbor encountered many problems with weeds and discovered the planter was inefficiently designed for the high percentage of sticky clay they farmed. The neighbor reverted to conventional tillage. Bartz's wheat crop was destroyed by frost and, already in debt, he was forced to sell all his machinery except his no-tillage planter, which had only scrap value). He had no choice but to use no-tillage techniques on his entire farm, even though weed control was extremely difficult with existing herbicides. A substantial amount of his 650 hectares had to be manually weeded, drawing much mockery from his neighbors (Ekboir 2002).

In the early 1970s, conventional tillage was causing major crop losses in Paraná due to severe erosion, and many farmers were defaulting on their loans. The local manager of a branch of the Banco do Brasil convened a meeting of researchers and extension agents to find a practical solution. They ended up suggesting the use of terraces, an early method of limiting soil erosion, based on the U.S. Soil Conservation Services' recommendations. However, when Manoel Pereira was told that his land was too steep for terraces, he started looking for alternatives. An agronomist suggested that he use no-tillage, which would allow him to space his terraces farther apart. Pereira and a few neighbors were successful in their use of no-till terraces for three years and, to acquire more knowledge, visited the University of Kentucky. Collaboration with the University of Kentucky and extension agent Shirley Phillips emerged from their visit to the United States. On their return, Pereira and his neighbors started the Earthworm Club to exchange no-till knowledge. They also persuaded three neighboring small-farmer agricultural cooperatives to organize a no-till extension program. That extension program turned into the ABC Foundation. The two organizations compensated for the lack of involvement from the public research and extension services.

Funacão Institute Agronomico do Paraná (IAPAR) had a first-class research team in the early 1970s until the state governor barred the institution from researching no-till technology on the grounds that it was only for large farmers and was being promoted by a multinational company (Ekboir 2002). IAPAR was ordered to research technologies for small farmers, and the government did not view no-till as a small farmer technology. The government overturned that ruling later, but IAPAR lagged in no-till research for many years. The no-till package produced in the mid 1970s was tried briefly by a limited number of farmers but still had many numerous problems relating to weed control and inefficient planters.

Due to the expanding interest in no-till practices in Brazil, ICI transferred its no-tillage research team from Australia to Brazil, where it developed the first Brazilian no-till package in 1972. Not all Brazilian farmers obtained successful results with the package, for few herbicides were available, and imported no-till machines were slow in arriving. The third year of implementation is when factors particular to an individual farm, such as evolution of pest and weed populations, need to be addressed, and many farmers were unable to adapt the package to their particular conditions (Ekboir 2002). The availability of machines improved when ICI persuaded Semeato (a Brazilian firm) to start importing a no-till planter (Ekboir 2002). By 1985, 13 no-till machine manufacturers were on the Brazilian market, with Semeato as the leader (Derpsch et al. 1991). Despite advances, conditions were still not practicable for large-scale adoption of no-till due to a lack of cheap herbicides and design issues with the no-till machinery. As in North America, public research and extension institutions remained largely on the sidelines until no-till had been extensively adopted (Ekboir 2002).

By the late 1970s three no-till networks had been created in Brazil, each working independently of the others. ICI had become the hub of the three networks with informal linkages among farmers and researchers. ICI's business strategy was to provide the knowledge of no-till and then hope that farmers would realize its potential and start buying herbicides (Ekboir 2002). Despite ICI's extensive effort in establishing a no-till network and its large investments in creating a market, no-till was still a commercial failure for ICI. Monsanto was able to capture the market because, compared with Paraquat, Glyphosate greatly simplified weed control. The introduction of Glyphosate helped produce a technically efficient CAPS package by the end of the 1970s. However, adoption continued slowly because Glyphosate was expensive, making the package uneconomical (Ekboir 2002). Despite slow package adoption, Monsanto was able to capture the herbicide market, and ICI cut all research and funding activities for no-tillage in the late 1980s (Ekboir 2002).

The second wave of Brazilian no-till implementation occurred in the mid-1980s due to continued problems with soil erosion and water quality. The Brazilian government and World Bank began promoting a credit program for watershed management by farmers' groups, lending them resources to construct high terraces. After the expensive terraces washed away with the first heavy rains, the program switched to promoting no-till methods (Ekboir 2002).

After ICI ended its no-tillage activities in the late 1980s, the Association of Zero Tillage Farmers (AZTF) became the hub of the no-till network, distributing information and exploiting economies of scale by buying in bulk quantities to quickly address farmers needs (Ekboir 2002). AZTF emerged from a few motivated farmers who wished to share no-till knowledge. The association includes two groups of farmers: those who take a leadership role and other associate farmers who seek to access useful information at a reduced cost. Individual researchers interact with AZTF, but the association does not lobby public institutions to redirect resources toward no-till. An issue with AZTF is that it mainly focuses on commercial farmers needs, whereas small farmers are left to depend on NGOs, cooperatives, and public institutions.

The third wave of no-till adoption in Brazil occurred with the clearing and colonization of the *cerrado* in the late 1980s. Farmers expanding the agricultural frontier toward the southwest, central west, and north were mechanized and defined as cropping anywhere from 5 to 50 hectares of land. The new agricultural lands resulting from this deforestation quickly lost their productivity through erosion. If soil erosion could not be limited, the *cerrado's* farmers would have to switch to grazing, which provided much lower economic returns than cropping. However, many of the colonizing farmers came from the southern states of Brazil and brought with them the knowledge of no-till. Thus, farmers began experimenting with no-till in their new location. *Cerrado* soil is significantly different from southern soil, and the no-till package had again to be adapted to the new environment Resistance to no-till was higher among researchers and extension agents compared with farmers in the area who saw immediate economic benefits (FAO 2001). Farmers' associations, input manufacturers and suppliers, and individual researchers collaborated to create an effective package adapted to the *cerrado*.

This activity was spearheaded by Dirk van der Klinken, a South African agronomist who came to the *cerrado* as a seed production manager. With his knowledge and research of no-till, he brought *cerrado* farmers together for two-day training courses. In one of these courses in 1992, van der Klinken persuaded the farmers to establish Zero Tillage Association for the Tropics (ZTAT). ZTAT's initial goal was to spread knowledge that pioneer no-till farmers were generating but had no time to share (FAO 2001). In collaboration with van der Klinken, ZTAT produced a no-till manual and began publishing a quarterly technical news bulletin to keep farmers apprised of no-till advancements. At the same time, no-till also started being promoted in the *cerrado* by herbicide, fertilizer, planter, and sprayer manufacturers through farmer events (FAO 2001). Clubes Amigos da Terra (CAT) were created by ZTAT in 1994; CATs supported farmer-to-farmer exchanges of experiences (FAO, 2001). Large- and medium-scale farmers working through individual CATs and ZTAT have also encouraged and helped smaller *cerrado* farmers implementing no-till (FAO 2001).

In the early 1990s, increasing numbers of mechanizing small farmers began implementing no-till in the southern states of Santa Caterina, Paraná, and Río Grande do Sul when the price of Glyphosate dropped from US$40/liter to under US$10/liter. To encourage this market, Monsanto also started no-till programs targeting small farmers. A farmer survey in Río Grande do Sul identified the main factors of low adoption to be the lack of a local no-till package promoted for small farmers, insufficient number of planters, and inadequate knowledge shared by extension agents. With these survey results Monsanto developed a project in 1993 to find integrated solutions through the collaboration of five public and private institutions. Due to Monsanto's program, the land under no-tillage in Río Grande Do Sul rose from 45,000 to 820,000 ha between 1994 and 1997 (Ekboir 2002).

Despite early difficulties, the area in Brazil under no-till has continued to grow from 1,000 ha in 1974 to 400,000 ha in 1984 (Derpsch 1984). Ekboir (2002) estimated that no-tillage was used on nearly 14 million ha of land in 2000. Brazilian no-tillage crops now include soybeans, maize, wheat, barley, sorghum, sunflower, and beans. No-tillage has enabled farmers to reverse soil degradation and expand agriculture into marginal areas while boosting farmers' profitability and increasing the sustainability of agriculture (Ekboir 2002).

Other South American countries have also experienced rising levels of no-till technology adoption, although not as high as in Brazil. In Argentina, no-till research started in 1974 when pioneer farmers wanted a better double-cropping system of soybeans planted after wheat (Derpsch 2008). Initially many farmers gave up no-till because they lacked herbicides and machinery. ICI helped to diffuse no-till methods across the country by promoting research activities, meetings, and field days. Diffusion of the technologies increased with the formation of Argentine Association of No-Till Farmers (AAPRESID) in 1986, which also organized national conferences attended by more than 1,000 farmers each year. Argentina's major no-till crops are soybeans, maize, wheat, and other small grains. The availability of no-till equipment has exponentially increased with more than 30 different manufacturers in Argentina and a few from Brazil. No-till cultivation has expanded from 25,000 ha in 1988 to 4.4 million ha in 1997 (Derpsch 2008).

Carlos Crovetto brought an Allis-Chalmers planter to Chile in 1978 and planted Chile's first no-tillage corn in an attempt to limit erosion and conserve moisture. After 19 years of no-till, Crovetto claims to have added an inch of topsoil, increased the organic matter from 1.7% to 10.6%, and increased the water holding capacity by more than 100 percent, all while achieving remarkable yields (Crovetto 1996). The main crops under no-tillage in Chile are wheat, oats, and rapeseed. Despite Crovetto's success, no-till farming in Chile has expanded to only about a 100,000 ha. Many farmers practice no-tillage into ashes of burned straw. Continuing to burn straw has not been challenged as a method except by herbicide manufacturers trying to boost their sales.

In southern Paraguay, farmers from the Cooperative Colonias Unidas applied no-till in the early 1980s before any research was completed in the country. The first attempts failed due to lack of knowledge, herbicides, and equipment. Japanese immigrant farmers in eastern Paraguay implemented the first successful no-till trials with the support of the Centro Tecnológico Agropecuario en Paraguay (Derpsch 2008). The center, which extends technical support for Japanese immigrants, is led by a local cooperative leader, Akinobu Fukami, who was also the first farmer in the country to successfully practice no-till. Initial growth was slow; by 1992 only 20,000 ha were under no-till, but the technology rapidly expanded afterward to about 500,000 ha in 1998, mostly soybeans. About 65% of soybean farmers use no-till practices on all or part of their farms. Paraguayan farmers, especially large-scale farmers, have now fully implemented the soybean/wheat double-cropping system. Farmers are able to seed soybeans in favorable circumstances due to the shortened time needed for land preparation under no-till practices (Kubota et al. 2005).

Jean Landivar brought no-till to Bolivia in 1986 when he began using no-till practices on his own 2000 ha farm. Research studies also began around that time but ended without positive results. In 1997 about 102,000 ha of soybeans were under no-till and that winter about 35,000 ha of wheat (Patrick Wall, Derpsch's personal communication, 1997). These numbers suggest that, much as on the Indo-Gangetic Plains, most farmers are using no-till practices only on their double-cropped soybeans and not their other crops. However, South American no-till adoption rates as a percentage of total land under cultivation far surpass those in most parts of the world.

Australia

In the 1950s and 1960s, Australian farmers increased production intensity on their farms to gain more income. Escalating soil degradation followed. In 1964, ICI Australia Ltd. and Plant Protection Ltd. started a joint program to establish no-tillage in Australia (Barret et al. 1972). In the mid-1960s some individual farmers were concerned about soil erosion in their fields and began building contour banks and waterways. In 1969 the Department of Primary Industries (DPI) arranged to test the stubble mulching equipment used for no-tillage in the United States. In 1973, after Darling Downs, Queensland, was declared an area of erosion hazard, about 30% of the land was protected with contour banks and waterways. The soils in Darling Downs are mostly brown clayey loams, self-mulching clays, or hard setting loams (Douglas 1987). The median farm size is 260 hectares (Chamala et al. 1983).

Australian farmers became interested in no-till practices as a profitable way to grow a crop without degrading the soil. Other reasons to implement no-till included timeliness of sowing, moisture conservation, higher yields, improved soil fertility, less labor, fuel and machinery maintenance (Flower et al. 2008). Western Australia has the highest proportion of no-till adopters, but farmers began implementing there mainly in the 1990s after several dry years. The first no-till experiments in Australia were conducted in the eastern states, including Queensland, due to interest from the Queensland Soil Conservation Branch (Derpsch 2008).

The Queensland Soil Conservation Branch (SCB) recognized that erosion could not be completely controlled with contour banks and waterways. SCB officers started by persuading farmers to intersperse strips of grain and grass in their crops and then to leave wheat residue on the surface as mulch. Yet farmers lacked commercially available stubble-handling machinery for weed control and planting. The diverse conditions and limited number of farmers handicapped the ability to develop no-till technologies because machinery and chemical companies had only a limited market for their products. By the mid-1970s, through publications and visits to the United States, the Australian soil conservation officers became more familiar with no-tillage methods. In 1982, although farmers rarely burned their stubble and had chisel or blade plows, they still continued to turn the soil for cultivation because they perceived no problem. Only 3% of farmers had tried no-till, and only 14% thought it might be profitable (Coughenour and Chamala 2000).

In the early 1980s Darling Downs SCB officers decided to implement what would become a farmer-led extension method that divided farmers into problem-solving groups. SCB provided some guidance the first few years and eventually let farmers run the groups themselves. The groups helped farmers develop confidence in their ability to analyze conservation situations and to find workable solutions. The farmer problem-solving groups generated considerable confidence in individual farmers' no-till skills.

Neville Ronnfeldt and his two sons' farm, in Darling Downs was one of the first to start experimenting with no-till methods (Coughenour and Chamala 2000). The initial awareness developed in 1965 after Ronnfeldt burned his wheat stubble. He started to plow the field but was called away and stopped halfway through. When he returned two days later to complete the job, the ground was so hard because it lacked soil moisture that the plow would not go in. Ronnfeldt compared the rock-hard field with a paddock of millet that had been worked only once and where the soil could be easily tilled and contained plenty of moisture. The difference prompted him to think that he needed to change his practices to conserve moisture. To do so, he stopped burning stubble.

During the dry conditions of 1969, when any tillage resulted in dust storms, Ronnfeldt began to think it would be nice to get rid of the weeds without cultivating. However, the use of herbicides did not seem cost effective. Instead, to control erosion in his fields, Ronnfeldt began strip cropping all his land in the flood plain in 1970. At a farmer field day in 1972 Ronnfeldt saw a blade plow demonstration and bought the demonstrator. Six months later he also purchased a stubble planter. Along with conserving soil moisture and decreasing erosion, Ronnfeldt wanted to reduce his farm costs. Rising farm costs were major reasons for farmers to begin thinking how to decrease the number of trips over fallow fields to control weeds. Herbicides were still too expensive to use for many farmers, but Monsanto sponsored Roundup trials on Ronnfeldt's fields. With a few trials of his own, Ronnfeldt decided that the most effective combination of herbicides was Roundup immediately following harvest and 2,4-D midway in the fallow period. He began to try double cropping and eventually started a six-year crop rotation along with allowing his cattle and sheep to range over the stubble briefly in the mid-1980s (Coughenour and Chamala 2000).

In the especially dry climate of the 1990s, the Ronnfeldt's farm went strictly to no-tillage to conserve soil moisture. Other farms in the drought area were severely hindered in their no-tillage system construction due to low farm income, which discouraged purchase of new equipment. As with adoption in many areas, the local farmers had to modify no-tillage so that the practices fit their soil and climate. Implementation of no-till practices has been slower in eastern Australia, with 33% of central Queensland using no-till, 21% of southeast Queensland, and 24% of New South Wales (Rainbow 2008).

No-till was most rapidly implemented in western Australia due to a period of dry years with sustained strong winds in the early 1990s. As a consequence, farmers responded with the adoption of conservation agriculture practices, which increased from about 20% of the crops under no-till in 1992 to more than 80% in 2005 (WANTFA 2009). Much of this increase is due to the Western Australian No-Tillage Farmers Association (WANTFA), made up of farmers determined to find ways to grow high-yielding crops sustainably. WANTFA was formed in 1992 to address farmers' concerns that state authorities were not actively promoting a method to reduce erosion when seeding. Five conservation farming organizations have now been started in the Australian states. Conservation Agriculture Alliance of Australia and New Zealand (CAAANZ) is a new international group uniting those five organizations with a New Zealand organization to improve the flow of technical information across state and national boundaries.

The main reason for non-adoption of no-till in Australia has been the cost of machinery and farmers not being convinced by no-till demonstrations in their areas. Concerns also have included an increased reliance on herbicides for weed management and the risk of encouraging herbicide-resistant weeds. In 2005 Australia had about 9 million ha under no-till (Derpsch 2005).

Asia

No-till has been reported in India, Indonesia, Korea, Philippines, Taiwan, and Thailand (Derpsch, 2008). Land under no-till cultivation in India is significantly higher than in most other Asian countries because substantial amounts of wheat are grown. Indian organizations such as National Agricultural Technology Project (NATP), State Agricultural Universities, Indian Council of Agricultural Research (ICAR), and the Rice-Wheat Consortium for the Indo-Gangetic Plains recognized the importance of no-till technologies three decades ago. Yet only recently have Indian farmers started implementing no-till (Bhan and Bharti 2008). In the Indo-Gangetic Plains, farmers are implementing no-till practices when cropping wheat after rice.

Gobind Vallabh Pant University of Agriculture and Technology in Uttarakhand State developed the first Indian zero-till drill, which gave farmers a no-till option. In 1998, the western Indo-Gangetic Plains' first 1,200 hectares of land were planted in no-till. The area increased to 12,000 hectares in 1999 and exponentially increased to 10 million hectares in 2002-03 (Bhan and Bharti 2008). Such uptake numbers suggest that the no-till system was readily adopted without major adjustments. Manufacturers are responding to the no-till machinery demand, and more than 32 Indian manufacturers now produce no-till equipment (Gupta 2003).

The Indian government began promoting CAPS establishment to decrease erosion, conserve moisture, improve nitrogen availability, protect young seedlings from heat and wind, and encourage better yields in dry years. The intensification of the rice-wheat system has degraded its natural resource base, and CA is increasingly perceived by the research and development community as the way forward (Dixon et al. 2007). Water scarcity issues are due to become significantly larger in the next few years. No-till practices can save extensive amounts of irrigation water. One hectare of wheat sown with no-till practices compared with a conventionally tilled hectare requires about 1 million liters less irrigation water (Gupta 2003). Whereas CAPS are often promoted from a natural resource perspective, farmers usually implement CA practices for the yield and cost-saving effects (Dixon et al. 2007). Farmers can also save fuel and labor by making fewer trips over the field during planting, which yields profits through reduced costs of operations and inputs. In Uttar Pradesh, reducing the amount of necessary fuel, herbicides, and labor made the net savings increase by $35 to $60 per hectare (Bhan and Bharti 2008).

To receive benefits, farmers need to acquire considerable knowledge of residue management, crop rotations, and seedbeds. The Rice-Wheat Consortium for the Indo-Gangetic Plains and the National Agricultural Research Systems of India have been funding and providing information promoting the implementation of conservation agriculture (Abrol and Sangar 2006). Large commercial farmers will be the most likely beneficiaries of such promotions, for they have the education and resources necessary to experiment with no-till practices. The most successful component of CA implementation has been the zero-tillage drill, a mechanical tractor-mounted seed drill that can sow wheat into an untilled rice field (Dixon et al. 2007). While uptake of conservation agricultural practices has increased substantially in

India and more slowly in other Asian countries, most implementation in Asia has occurred on large commercial farms.

Africa

In the late 1960s, individual Ghanian researchers started studying no-till at the same time research started in Europe and the United States. However, the Ghanian researchers had few contacts with agrochemical companies or foreign researchers (Kannegieter 1967, 1969; Ofori and Nanday 1969; Ofori 1973). The research studies do not mention interactions with Ghanian farmers. It was expected that no-till practices might be easily adopted by African farmers because they have historically planted through vegetation in the forest zones (Akobundu and Deutsch 1983). Few herbicides are available locally, and even fewer are available in conveniently sized packs for the small farmer (Parker 1983).

The International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, began no-till research in the early 1980s. Researchers in Ibadan were experimenting with weed control and mulch no-till approaches (Akobundu 1987). Before the idea of no-till emerged, many African farmers used shifting cultivation (swidden), which allowed for a short cropping period and a long fallow period for the soil to regain its fertility (Exumah 1983). With a growing population, farmers could no longer afford to let significant areas of cropping land lie fallow and began continual farming. However, their customary practice of burning off the plant residue leaves the soil exposed and vulnerable to erosion. The use of mulches was challenging because trees and shrubs dominate the vegetation, making herbaceous fallows difficult to maintain. Alley cropping was developed to provide benefits similar to those of mulch, for alley trees are severely cut before crop planting and the prunings mulch the soil. Alley cropping may also reduce the need for herbicides (Ogborn 1983). Since the 1980s, researchers in Africa have noted issues that will hinder growth of no-till methods. In Sierra Leone, several prerequisites were identified: efficient drainage systems for swamps, weed control in areas without access to herbicides, availability of equipment to plant through residue, and available fertilizers (Nyoka 1983). Although research had been occurring in Africa determining crop yields under many trials of no-till, farmers had not yet taken notice.

In 1991 CIMMYT and the Ghana Grains Development Project (GGDP) organized five research station trials and other trials on farmers' fields. In 1993 a no-till with mulch package was distributed to farmers in the forest, transition, and Guinea savannah zones through collaboration among the Crops Research Institute (CRI) in Kumasi, Sasakawa Global 2000, and Monsanto (Ekboir 2002). The new aspects of the package for small farmers were improved seeds, herbicides, and fertilizers -- farmers were already planting with a stick or machete into untilled sod. Thus, the no-till package despite its name did not really bring the concept of no-till to Ghana, only access to new inputs.

Extension agents promoting the no-till package emphasized the need to implement the full package, including improved seeds and fertilizers. Few farmers had the ability to adapt the package; only 10% of no-till users in Ekboir's study modified the package (2002). Farmers who did try to do so were aiming to reduce herbicide use to save money. Research was weak in Ghana and, because small farmers did not use no-till machinery, most of the experiments centered on weed control. A primary consideration of no-till implementation in the tropics is weed growth, for weeds grow more rapidly than in other areas and technology is less developed (Akobundu and Deutsch 1983). Monsanto helped CRI evaluate the efficacy of the herbicide Glyphosate on farmers' no-till fields, and results showed that it was very effective.

The majority of Ghana's population, including the three zone areas where the no-till package was disseminated, works in agriculture. Most of the small-scale farmers cultivate about 2 ha. The land is under pressure due to a growing population, decreasing the period that farmers are able to fallow their fields. Historically, farmers have used few inputs such as fertilize, to increase the soil's productivity (Ekboir 2002). The main cash crops are maize, vegetables, and yams for no-till users and plantain, cassava, and rice by farmers who do not use no-till. No-till technologies have yet to be developed for plantain, cassava, and rice.

Small farmers in the targeted zones were still using traditional no-till methods of planting. However, large and medium-size farms had begun to till more extensive areas; they increased their power by hiring labor or using tractors. The use of herbicides was not customary, and formal dealers did not have the market demand for transporting herbicides to every village (Ekboir 2002). Consequently, during project implementation extension agents created a market niche for themselves selling herbicides, for they were able to be in contact with both formal dealers and farmers. Women farmers have been even less likely to try no-till practices or use herbicides in their fields. Interestingly, medium-size farmers were most interested in the no-till package due to the effectiveness of Glyphosate for controlling weeds and the decline in the amount of labor required for the same or increased output. The decrease in labor enabled farmers to undertake activities such as growing additional vegetables to generate more income, although their main reason for adoption was that it solved labor management problems. Having no labor management problems, large farmers using tractors were never really interested in no-till practices.

By 2002, research on no-till was occurring through projects such as GTZ’s Sedentary Farming Systems Project. CRI researchers and Ministry of Food and Agriculture (MOFA) extension agents followed a participatory approach when working with local farmers to disseminate knowledge. A nascent CAPS network was evolving through these technology transfer events. Farmers received no-till knowledge through on-farm demonstrations routed through farmer groups, field days that brought together many actors but where the host farmer plays the lead role in presenting the activity, and field tours that gave host farmers a chance to show other farmers what was happening in their fields. Most farmers implementing the new no-till package received advice in their first year. About 40% of the advice came from a researcher and 20% from a neighbor (Ekboir 2002).

Support and interaction from the no-till network comprising researchers, extension agents, and discussion groups need to be available to farmers implementing no-till practices. To increase the sustainability of no-till technologies, farmers need more training in soil management, crop rotation planning, certified seed use, and organic matter (Ekboir 2002). Ekboir (2002) estimated that 100,000 small-scale farmers in Ghana used no-till on 45,000 ha in 2000.

In Zambia, conservation agriculture and no-till practices are generally known as conservation farming (CF). CF began in Zambia after several commercial farmers traveled to Australia and the United States in the early 1980s to examine no-till practices for their conservation of fuel (Baudron et al. 2007). In 1995 the Conservation Farming Unit (CFU) and Zambian National Farmers Union started trials of permanent basins at the Golden Valley Agricultural Research Trust. That same year the organization also began promoting hand-hoe basins under Zambian conditions. In 2000, the Ministry of Agriculture and Cooperatives (MACO) supported conservation farming as an official policy of the Zambian government (Baudron et al. 2007). Many institutions and organizations, mainly MACO and CFU, have been adapting CF techniques to support smallholder activities. Farmers implementing conservation farming in Zambia want to restore their fields’ fertility, improve crop yields with few additional inputs, and more efficiently use rainwater.

Several types of conservation farming methods exist in Zambia. Planting basins are the most commonly implemented CF system, for basins do not increase weed pressure any more than during conventional hand-hoe farming (Baudron et al. 2007). Planting basins are shallow, 15 to 20 cm deep, and are filled with inputs such as lime, fertilizer, manure, compost, and soil. Planting pits, also known as Muyamba pits and based on a farmer-generated technology, are filled with crop residue, compost, manure, and layered with soil on top. A Muyamba pit is generally 160 cm in diameter and 60 cm deep, planted with 20 maize seeds, and usually used for several seasons (Baudron et al. 2007). Farmers who own draft animals also have the possibility of using a Magoye ripper to create a groove in untilled soil where seeds can be planted.

After the drought of 2001-02 in Zambia, FAO's Food Security Pack (FSP) program selected 59,500 households in two zones to participate in a program to reestablish the food production base through the implementation of CF and security pack inputs. The majority of farmers in these two zones were rated as requiring emergency assistance after very poor results in 2001-02. Zone I was in an area where crop failures due to inadequate rains are so common that they do not allow for a sustainable livelihood. In Zone II there was normally enough rainfall to sustain crop yields. The overall object was to quantify the impact and understand the constraints and successes of CF under the program (Mwape et al. 2003).

To determine the results of the program, focus group discussions were held in 18 sample areas, interviews were conducted with randomly selected beneficiaries, and questionnaires were distributed. The findings showed that 66% of the sample farmers participated in CF training, and most farmers used hand hoes to prepare planting basins. Many farmers in Zone II were happy with CF performance, and 73% of sample farmers intended to use CF in 2003-04. When preparing for the 2003-04 season about 73% of sample farmers left residues in the field, and 65% intended to rotate their crops. About half of the sample farmers stated that they would cultivate more land under CF. Farmers who viewed CF positively felt the practices had several merits, including early planting, distributing labor requirements throughout the season, economical use of fertilizer, improved moisture conservation, and access to food even to those who could not afford to buy chemical fertilizers (Mwape et al. 2003).

While the results pointed to some success -- maize production increased substantially in Zone II -- CF practices in Zone I did not show successful results. In Zone I, due to annually inadequate rainfall, the study revealed that the best way to deal with food insecurity would be to expand production of small livestock, already a major source of livelihoods. Conservation farming was not a solution for low production areas that were unsuitable for cereal production (Mwape et al. 2004). Many also had low levels of legume and sorghum production. Other constraints included farmers only adopting basin planting and relying on NGO or institution support for inputs. FAO-FSP provided many otherwise unavailable inputs to program participants. Digging basins for conservation farming was also difficult because many farmers had limited labor, usually relying mainly on family labor.

The study concluded that many farmers would go on using some type of conservation farming but mostly because they have no better choice, having limited access to animal draft power. While the general conclusion of the study is that FAO-FSP's program made a significant contribution toward the promotion of CF in Zone II, most implementing farmers are only in the second year of application and have not utilized all CF recommendations.

Despite research and some no-till and conservation farming implementation in Ghana and Zambia, Africa as a whole has not adopted CA technologies, and little information is available about the development of CA in Africa (Derpsch 2008). GTZ's 1998 study seemed to indicate that no-till technologies had already been tested to some degree in Angola, Benin, Ghana, Ivory Coast, Kenya, Mozambique, Niger, South Africa, Tanzania, Zambia, and Zimbabwe (GTZ 1998). On the whole, no-till has been practiced most successfully on large African farms, often those growing maize, sorghum, wheat, and cotton. Equipment for no-till cultivation is mostly imported except for some local production in Zimbabwe and production in South Africa for small farms. Drier locations in Africa are presumed to receive the most benefits of no-till, although research has been done in various climates and soil conditions. Permanent no-tillage can only be productively accomplished in regions with higher rainfall, whereas minimum tillage is more widely implemented on small 1 to 2 ha farms (Derpsch 2008). To make no-till an attractive alternative for African farmers, several problems have to be addressed: traditional land tenure, communal grazing, socioeconomic constraints, and lack of sufficient soil cover (GTZ 1998).

Appendix 2: Conditions for adapting to CAPS

A series of hypotheses about conditions for the adaptation to CAPS among smallholder farmers is considered below in the form of questions that should be asked in the design, implementation, and evaluation of CAPS. These hypotheses are grouped according to the four stages of CAPS: inputs, delivery mechanisms, farm and farmer circumstances, and likely benefit streams as they apply to smallholders. This exercise is based on the case study review characterizing CAPS innovation and diffusion among smallholders. Information from the analyzed case studies pertaining to each hypothesis is examined in light of how these factors may function in particular agroecologies. To develop a strong CA network, it is necessary to investigate how all system components can be mobilized to achieve the desired outcomes, not solely whether the expected outcomes might occur.

Input hypotheses

Are herbicide/fertilizers/seeds available at the local market?

While these CA inputs are readily available to farmers in the United States and Brazil, supply is much more limited in most local African markets. One Tanzanian study stated that commercial supply channels have yet to open but are expected to do so once demand rises (Kienzle 2009). The lack of access to markets and inputs is perceived to be one of the main obstacles for CAPS implementation in much of Africa (Baudron et al. 2007).

Are herbicide/fertilizers/seeds appropriately packaged?

Most of these inputs are packaged in large sizes that, while suitable for commercial farmers, are not appropriate for smallholder farmers. Large input packages were an obstacle for smallholder farmers in Ghana (Ekboir 2002).

Are local substitutes available for inputs?

Locations with significant resources, such as farms in Brazil and the United States, may have substitutes for CA inputs (Coughenour and Chamala 2000). Resource-poor locations with small-scale farms often do not have substitutes or they have not yet been identified as such. Agricultural policies in many areas of the world still encourage farming that relies largely on external inputs and technologies; thus, locally adapted biological resources are discriminated against (Bot and Benites 2001).

Sufficient labor for weeding?

Farmers wishing to implement CAPS will need either enough family labor available or sufficient funds to buy herbicides or pay for manual weeding of their fields. Implementation of CA practices can in some instances increase labor (Mercado 2001). At least in the short term it is generally presumed that farmers need the input of herbicides to have any resulting decrease in labor requirements (Giller et al. 2009). Hired labor was found to be of questionable quality or dependability (Ekboir 2002; Mwape et al. 2004).

Crop rotations to decrease weeds?

Rotating crops is one of the main CA practices necessary to decrease diverse weed and pest generation from the growth of one crop (Huggins 2008). Farmers with small lands often have difficulty implementing crop rotations because there may not be a market for the second crop (Bwalya 2005). Exclusively rotating crops may not be sufficient to decrease weeds.

Possible livestock nutrient management?

The addition of livestock to a CA system can have positive benefits such as reducing fertilizer and agricultural chemical needs, increasing biomass generation for surface residues, and creating lower pasture renovation costs (Landers 2007). On the other hand, livestock may compete for crop residues. Farmers need to ensure that livestock do not seriously decrease the residues left on the field for mulch.

Equipment hypotheses

Forms of farm power available to farmer?

Commercial farmers have many forms of available power due to their resources, but small-scale farmers often lack access to power-increasing equipment. There are three main types of power: human, draft animal, and machine power (Kienzle and Sims 2006). While commercial farmers readily use machine power, even if the machines are imported, smallholders mostly use human power. Small-scale farmers do not have the financial resources necessary to buy imported equipment or sufficient land to justify use of high-powered machines (CIMMYT 2008).

Access to appropriate power?

Smallholder farmers lack access to farm power appropriate for implementing CA production systems, and this creates major CAPS challenges (Bwalya 2005). Commercial farmers using heavy tractors have been the most successful in implementing CA (Wall 2007). Draft animal power is also more profitable than human power (Kienzle and Sims 2006). Smallholders need access to CA equipment of increasing power. Yet Africa lacks locally manufactured equipment of any kind, and the incentives for importation have been few. For example, in Tanzania direct planting implements are not locally available (Kienzle 2009).

Appropriately scaled equipment or tools?

While smallholders usually have access to human-powered equipment and hand-powered tools, higher-powered tools are more efficient for CAPS establishment (Kienzle and Sims 2006). Communities in Ghana are already using no-till hand-held equipment, which is an appropriate implement for smallholders (Ekboir 2002). Sometimes that hand-held equipment is only a stick or machete and could be upgraded to a jabber planter or similar implement that simultaneously penetrates the cover vegetation and places both seed and fertilizer in the hole. While human-powered equipment can be appropriate on small land holdings, increasing the power of the equipment used would create more efficient implementation of CAPS (Kienzle and Sims 2006).

Local manufacturers and availability of maintenance?

Local manufacturers and maintenance are available in North and South America, where there is a large demand for CA equipment (Coughenour and Chamala 2000; Ekboir 2002). However, in most of Africa and other locations with little conventional or motorized agriculture, there are few manufacturers. In Tanzania, manufacturers are interested in producing direct-seeding equipment, but demand is not high enough for sufficient profits (Kienzle 2009).

Use and modify existing equipment?

American farmers began implementing CA practices by innovatively modifying their already existing equipment (Huggins 2008). However, many small-scale farmers in developing networks have not taken an innovative role in modifying equipment and tools for CAPS in their local environments. Farmers often lack the knowledge and/or ability to modify existing equipment for CAPS establishment. Entrepreneurs and artisans will be required to fill this gap in the network.

Knowledge hypotheses

Use and safety of herbicides and equipment?

Extension agents and research facilitators have focused on providing farmers with knowledge as to the safe use of herbicides and equipment (CIMMYT 2008). However, if an area lacks a CAPS network, then farmers may not gain sufficient knowledge. Training programs in safe and effective use will be necessary for all introduced chemicals and equipment. It may be that specialized personnel will be required.

Maintenance of seedbed and equipment?

None of the studies suggests that formal knowledge was presented or available to farmers regarding maintenance of their seedbeds or equipment. Indeed, most knowledge that is transmitted focuses on knowing what the particular technology is and what it is supposed to do. Little knowledge concerning knowhow appears to be delivered, although several projects mention farmer field schools. Most likely this knowledge, if available, can only be developed by farmers in local farmer organizations or from extension agents attempting to solve CAPS implementation challenges.

Knowledge adapted for local implementation?

Attempts to implement knowledge from an external source, such as from the Brazilian CAPS network to Africa, does not usually create positive results (Baudron 2007). CA methods need to be adapted for specific sites; when knowledge is not adapted, it ends up creating more challenges for small-scale farmers (Junge 2008).

Training / education for extension agents?

The cause of low adoption levels in Brazil was often insufficient command of the package by extension agents (Ekboir 2002). Governments often organize and fund the training of extension agents. However, research and extension systems, even when their members are well trained, do not have the capacity to develop complex systems for all farmers (CIMMYT 2008). Part of the process of knowledge creation and transmission requires discussion and interaction with farmers and other input and service providers (Ekboir 2002)

Local knowledge sufficient for innovation and adaptive learning?

Spontaneous adoption or acceptance of CA techniques is unlikely to occur. Farmers will continue to experiment with CA practices on small areas and adopt at a large scale only when they are convinced of the intended benefit streams (Giller et al. 2009). Successful CAPS empower farmers to solve their own problems by introducing new ideas and then letting farmers make their own decisions based on the presented knowledge (Bot and Benites 2001).

Financing hypotheses

Available local credit?

Commercial farmers usually have access to credit, whereas most smallholder farmers have access only through short-term national or international projects. Farmers in Tanzania lack adequate funding, which hinders attempts to implement CAPS (Kienzle 2009). In Zambia, most CA practitioners bought hybrid seeds and fertilizer on credit so they have financial access to these CA inputs (Baudron et al. 2007).

Input supplied in kind?

In some locations CA inputs are subsidized, such as fertilizers in Malawi to improve the soil when establishing CAPS (Knowler and Bradshaw 2006). Yet the sustainability and market distortions of subsidies are questioned, and the argument is made that money would be better spent imparting knowledge to farmers (Bot and Benites 2001).

Self financing?

While commercial farmers have the resources necessary to finance CA implementation themselves, smallholders usually do not. About 33% of farmers mention spending more money on inputs while implementing CA as a problem (Wall 2007).

Delivery mechanism hypotheses: State/NGO/market

Vendors present for input supplies?
As stated in the input hypotheses, vendors and markets are accessible in areas with high rates of commercial agriculture but are often lacking in resource-poor smallholder regions due to little demand (Giller et al. 2009).

Is there a market demand?
Market demand rises as farmers increasingly start implementing CA. In the United States, farmers created demand through the active role of innovative farmers attempting CA production systems (Coughenour and Chamala 2000). Farmers in Africa have not yet created enough demand because they lack the resources necessary to overcome other challenges of intensifying production.

Chemical / equipment companies aware of demand?
During the first few years of CA implementation in the United States, the chemical and equipment companies were not aware of the demand for CA inputs (Coughenour and Chamala 2000). As orders increased for certain products, such as for herbicides and no-till drills, the companies began realizing the demand and the profits that could be made by promoting CA. In Brazil ICI had an explicit strategy to develop CA systems but ultimately lost its market share as Monsanto came out with an improved herbicide product (Ekboir 2002).

Government support or guarantees?
Government support has come late in the development of most successful CAPS programs. Government support has included subsidies for certain CA inputs. However, a conducive policy environment can shape incentives. In Europe, government guarantees on crop prices held up CAPS development because farmers no longer had to worry about crop prices or solving challenges relating to CAPS establishment (Jones et al. 2006). In Brazil, local government support for CAPS led to increased adoption by smaller farmers. Although the state governor in Paraná inhibited public funds from contributing to research on CAPS, this did not block private-sector development (Ekboir 2002).

Farm organization

Group purchases?
Farmer organizations in Brazil often make large-scale purchases to be distributed among many farmers to decrease farmers' costs (FAO 2001). Purchasing inputs in smaller portions often increases the amount that farmers pay. However, in Brazil many farmer organizations are still catering primarily to larger commercial farmers (Ekboir 2002). Nevertheless, smallholders if allowed to participate can benefit from the market power of commercial farm organizations. In areas with developing CAPS networks, farmers' groups are weaker and have not been organized to make group purchases.

Can inputs be purchased and transported from elsewhere?
If inputs are not produced locally, then they must be transported from elsewhere, which is often the case in developing networks. Extension agents in Ghana reduced the cost of inputs for farmers by transporting the CA inputs to villages (Ekboir 2002). Large-scale farmers in east and southern Africa have made substantial purchases of equipment and inputs directly from overseas (Kaumbutho and Kienzle 2007).

Environment conducive to knowledge sharing?
The development of farmer organizations creates a supportive environment for knowledge sharing. Successful networks have interactions among many stakeholders to share knowledge. However, in Africa farmers do not have environments conducive to the development of networks to share knowledge among themselves and other stakeholders (Kienzle 2009).

Network to consult concerning problems?

The American and Brazilian CAPS networks have the capabilities to answer farmers' questions about adapting and implementing CA practices. Weaker networks to not have strong enough interactions among farmers and other stakeholders to allow for farmers to receive input on solutions concerning their CAPS problems (Bwalya 2005).

Network supporting a change in mindset?

Networks need to be more fully developed with the support of multiple stakeholders before a large-scale change in agricultural mindset can occur. Once many farmers, companies, and organizations have switched to supporting CAPS, then the potential for scaling out in a more encouraging environment can be achieved (Knowler and Bradshaw 2006).

Farm/farmer hypotheses

Farmer

Problem to be solved by implementing CA?

Each locale has had to solve different problems to establish CAPS. In the United States farmers wanted to solve problems relating to erosion and then increase their income by double cropping (Coughenour and Chamala 2000). In Brazil, farmers wanted to increase soybean production and also decrease the erosion cause by soybeans (Ekboir 2002). In Africa, farmers were often just trying to create a more sustainable livelihood, but this has rarely translated into implementation of CA techniques (Ekboir 2002).

Sufficient resources and willing to take a risk?

Mechanized farms in the early history of CAPS development had sufficient resources to allow them to take a risk without jeopardizing their livelihoods (Coughenour and Chamala 2000). Smallholder farmers in most areas of the world do not have the resources necessary to take such risks (Ekboir 2002).

Adaptive capacity to solve problems?

Early CAPS innovators in the United States and Brazil often had fairly high education levels, and many had worked as extension agents themselves (Coughenour and Chamala 2000; Ekboir 2002). Farmers in those countries are likely to have had higher levels of education than farmers now attempting to implement CA practices in African countries. Due to a lack of knowledge, in Zambia the approach to CAPS implementation has been prescriptive rather than adaptive, although farmers are encouraged to adapt the system once they learn how to manage it (Baudron et al. 2007). This is a top-down approach. Alternatively, field schools could empower farmers to develop adaptive capacity.

Ability to adjust for labor requirements?

Different studies show contrasting labor beneficiaries from CAPS establishment. In Tanzania, women benefit the most, for planting and weeding the fields is their job (Voegel et al. 2009). In Ghana, men's tasks were simplified (Ekboir 2002). The migration of agricultural labor during the year often requires farmers to change many other aspects of their routine. Farmers may develop problems if they usually contract their planting or spraying, for other laborers may not have knowledge of CA techniques (Ekboir 2002). On the other hand, labor requirements may diminish overall (Ekboir 2002).

Knowledge regarding use of new inputs?

Farmers implementing CAPS in areas with strong networks will likely have knowledge regarding the use of new inputs through farmer organizations, supply companies, researchers, and extension agents. However, farmers not supported by networks will have to experiment with the new inputs; that was the case with American farmers when they first started developing CA practices in the early 1960s (Coughenour and Chamala 2000).

Farm

CAPS appropriate for soil type?

CA principles have wide applicability to many soil types and rainfall patterns but are not suitable for soils with limited drainage (Wall 2007). The speed of breakdown of organic matter varies according to soil temperature, as between temperate and tropical zones.

CAPS impact on pests and diseases?

CAPS establishment has varied effects on pests and diseases, but mostly a greater diversity of pests and diseases has been experienced. More diverse weed and pest management strategies were necessary when implementing CAPS in North America. Rotations should minimize many pest and disease impacts (Huggins and Reganold 2008).

CAPS adapted to livestock?

CA practices in many locations are adaptable to integration with livestock. Although CAPS were initially identified as necessitating a tradeoff between the use of crop residues for mulch or fodder, Baker and Saxton (2007) found that the more stable soil structure of untilled soils allows stock to graze early in the spring on land that if tilled would be greatly disrupted. It is also possible to help reduce the clearing of native vegetation through the use of land intensification by grazing cattle on CAPS fields (Landers 2007).

CAPS compensates for other crop residue uses?

CA techniques require most of a field's soil to be covered by residues, but a small amount of the residue can be taken for other uses. For minimal soil erosion it is necessary to keep about 70% of the crop residues on the field (Baker and Saxton 2007). However, this does not mean that cattle could not be grazed for some time period on the stubble to defer grazing on permanent pasture until later in the dry season (Landers 2007).

Is it necessary to integrate all aspects of CAPS?

Implementation of all three principles of CA will create improved yields compared with implementing only one of the CA principles. The principles complement each other and strengthen the beneficial impacts of establishing CAPS. However, obstacles may inhibit farmers from employing all three principles (Giller et al. 2009). The transition to CAPS for small farmers is likely to be made in stages; indeed, in some sites full implementation of the three principles may not be possible (Dixon et al. 2007).

Benefit streams

Ecological

Soil health (structure, quality moisture) improvement?

Much of the research concerning CAPS has examined the benefits to soil after implementing CA practices. An average of 30 erosion experiments in Brazil showed an average reduction of 79% in soil losses under ZT compared with tillage (Landers 2007). Many research studies have found yield and soil improvements after implementing CAPS in humid tropical and temperate agroecosystems, but there is limited evidence of yield or soil improvements from CAPS in semiarid and dry sub-humid agroecosystems (Rockström et al. 2009). Studies completed on soil moisture showed that the moisture content was higher in the surface soil of no-till plots than in treatments prepared with tillage machines (Junge et al. 2008). CA plots were also found to have reduced soil temperature because the surface is covered by mulch. Favorable moisture and temperature conditions will also have beneficial effects on the activity of soil fauna such as earthworms (Junge et al. 2008).

Increasing biodiversity?

CA techniques have been shown to promote increasing biodiversity. In Europe one of the specific reasons to implement CAPS is to support increasing diversity (Jones et al. 2006). However, that increasing diversity could also include what farmers may consider pests and weeds. Biodiversity needs to be considered at both the micro and macro soil levels.

Leading to long-term carbon sequestration?

With no-till, crop residues are left more naturally on the surface to protect the soil and assist the conversion of plant carbon to soil organic matter and humus (Baker and Saxton 2007).

Economic

Is there a definite short-term income increase from CAPS implementation?

The financial profitability of CAPS is uncertain because results vary from site to site (Knowler and Bradshaw 2006). The double-cropping element of CAPS has helped many farmers in the United States and Brazil plant earlier and then plant a second crop later to increase their incomes (Ekboir 2002). For large commercial farms, inputs will decrease. In Zambia, implementation of CAPS can potentially reduce fuel usage from 120 liters to 30 liters per hectare where mechanical traction implements are used (Baudron et al. 2007). For non-mechanized small farms, income increases may not be achieved in the short term because, while tillage costs may decrease, weed management costs are likely to increase (Ekboir 2002).

Allow for double-cropped grain or soybean system?

In locations with sufficient moisture and growing season, farmers can attempt to double crop their land in CAPS because turnaround time between crops is shorter (Ekboir 2002). Nevertheless, a market needs to be available for the surplus crop for farmers to earn additional income (Giller et al. 2009).

Accessible markets for selling crops?

Small-scale farmers have weak links to output markets (Wall 2007). In Kenya, the market is untapped because physical infrastructure is dilapidated and hinders the transportation of crops to nearby markets (Baudron et al. 2007). In areas with large commercial farmers producing a number of crops, there is market demand for many crops. However, where smallholders mainly produce one crop, there may not be market demand for new crops (Giller et al. 2009).

Economic incentives for ecological benefits?

While most governments have yet to start providing economic incentives for farmers to implement CA, there are some extra economic benefits. For example, reduced fossil fuel inputs decrease farmers' costs while helping the environment (Baker and Saxton 2007). Payments for ecosystem services such as carbon sequestration may be possible if farmers can organize themselves in large enough units for compensation.