EX-ANTE ECONOMIC AND ECOSYSTEM SERVICE POTENTIAL OF SIMULATED
CONSERVATION PRACTICES IN GHANA USING A MINIMUM DATA APPROACH


by


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B.S., Ecole d'Ingénieur de Purpan, 2008
M.S., Ecole d'Ingénieur de Purpan, 2010


A THESIS


submitted in partial fulfillment of the requirements for the degree


MASTER OF SCIENCE


Department of Agricultural Economics
College of Agriculture


KANSAS STATE UNIVERSITY
Manhattan, Kansas


2011

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2011

# Abstract

Given the changing climate paradigm, food and poverty are likely to become more severe in Africa. Farmers can adapt to climate change, especially through conservation agriculture. This study relies on a minimum data approach developed by Antle and Valvidia (2006) to estimate the spatial distribution of opportunity cost for farmers in switching to conservation practices in Wa, Ghana. It assesses the economic feasibility of several scenarios that rely on production techniques currently studied by the CRSP SANREM project. We also explore the possibility that these practices can provide income from carbon sequestration payments implemented by the Kyoto protocol's Clean Development Mechanisms. The methodology uses data from both a recent survey and information from secondary sources to assess simulated management practices. Results indicate that all the simulated management practices would theoretically benefit farmers. In fact, adoption rates for the four scenarios range from 52% to 65%, even without any carbon payment. Adding a proportional payment to the amount of carbon sequestered with these practices does not seem enough to influence farmers switch to switch to alternative scenarios. The analysis shows that these results hold even when additional fixed costs to adopt these practices are included. This case study demonstrates the usefulness of the minimum data approach in estimating the economic potential of conservation practices in Ghana. These production techniques may represent environmentally-friendly alternatives that are more profitable for farmers than current practices. The next step in assessing implementation of such practices would require studying farmers' willingness to adopt these production systems, given their ex-ante economic returns.

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# Chapter 1 - Climate change, agriculture and ecosystem services

## To what extent is climate change threatening African agriculture?

### *Overview*

In 2004, 49 Gigatons of carbon dioxide CO2 equivalents (or GtCO2-eq) were released into the atmosphere (IPCC 2007a). Carbon dioxide is by far the most commonly emitted greenhouse gas (GHG) in the world. Moreover, the agricultural sector is responsible for 10 to 12% of total anthropogenic GHGs emissions. However, these trends differ around the world. Some regions, notably Africa, release few GHGs when compared to others (IPCC 2007b).

The IPCC reports some evidence about Africa's future climate. Annual rainfall is likely to decrease in both the Mediterranean area and northern Sahara (2007b). Temperatures are likely to increase in these regions. In addition, eastern Africa and parts of central Africa will likely see their average rainfall increase (Boko et al. 2007).

The report concludes that weather events will have both higher intensity and higher frequency (Collier, Conway and Venables 2008). Because of changes in such parameters as temperature and precipitation, soil moisture is likely to change (Houghton 2009). Kurukulasuriya and Mendelsohn (2008) concluded that climate change will strongly affect African agriculture. In terms of yearly annual crop revenues, losses may range from 17% to 32% in West Africa and from 28% to 79% in central Africa.

Thus, as Collier, Conway and Venables (2008) state, "For the next half century the key development issues are African adaptation to future climatic deterioration and opportunities for African participation in schemes for mitigation."

### *What makes climate change a unique challenge in Africa*

Collier, Conway and Venables (2008) give three reasons that distinguish the impact of climate change on Africa. The first reason, as outlined in the previous section, is that global warming is occurring faster in Africa than anywhere else in the world. In fact, the IPCC (2007a) points out that Africa is likely to warm during the century and that "the warming is very likely to be larger than the global, annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics".

The second reason that makes Africa a distinct region is that it is a huge continent that includes more than fifty countries, and spans the parallels from 35°N to 35°S. As a direct consequence, forecasting the effects of climate change on the whole continent is more complex, as is setting up adequate policies.

Finally, primary sectors predominate in most African economies, if not all. Consequently, cconomic actors and African people are threatened by climate change more than any other place in the world. Furthermore, Chhibber and Laajaj (2008) note that more than half of African people live in rural areas with two consequences. First, African populations are highly vulnerable to natural hazards because they often produce their own foods in these same rural areas. Second, agricultural production in Africa has declined during the last decade while worldwide production increased. Thus, Africa's ability to feed its own people will depend on its agricultural productivity.

### *The likely economic impact on agriculture*

As Antle (2008) states, "agriculture is arguably the most important sector of the economy that is highly dependent on climate." As explained in the previous section, climate change is a significant threat to African countries, especially for primary sectors. In fact, according to Hertel,

Burke and Lobell (2010), developing countries' agricultural sectors represent more than 40% of value added for all goods and services in their economies. Considering the large proportion of people relying on agriculture, climate change will have a huge impact on African people, according to Collier, Conway and Venables (2008), and earlier to Winters et al. (1998). Kurukulasuriya et al. (2006) point that African farmers do not readily adopt technology, possibly due to cash constraints (Schlenker and Lobell 2010), which may be another reason that climate change will be a threat to Africa.

Researchers have taken different paths to estimate the economic impact of climate change in Africa. One approach relies on laboratory experiments to study the effect of temperature and precipitation changes on yields. This technique allows precise calculations of gains or losses due to changing climate factors. A second approach assumes that farmers are profit maximizing actors and that they adapt their production systems to different climate constraints. Maddison, Manley and Kurukulasuriya (2007) point out that these models "enable researchers to predict the effect of movements in agro-climatic zones on world prices, patterns of trade and production, and consumer and producer surpluses".

Mendhelson, Nordhaus and Shaw (2004) developed an alternative method based on cross-sectional econometric analyses to measure the impact of climate change on agricultural outcomes. This approach involves running regressions between outcomes such as farm incomes or land values and climatic parameters. It was initially used in the US and has also been used in developing countries like Cameroon (Molua 2002), Ethiopia (Deressa and Hassan 2009) and several other African countries (Maddison, Manley and Kurukulasuriya 2007); (Kurukulasuriya et al. 2006). Maddison, Manley and Kurukulasuriya (2007) noted "Agriculture in sub-Saharan Africa appears particularly vulnerable to climate change, with losses in Niger approaching

30.5%". Kurukulasuriya and Mendelsohn (2008) compared two different models that predicted the same range of climate change as the IPCC. Their conclusion is that central Africa may be the most affected area in annual crop revenue loss. This failure ranges from 28% to 72% for the most extreme scenario. West Africa would show losses ranging from 28% to 32%. In Ghana, the loss in annual crop revenue is 1.1 or 1.4 US$ billions/year, depending on which of the two climatic models is used.

Lobell et al. (2008) suggested an alternative approach: statistical time series taking into account the importance of several crops to food security in insecure regions. The authors analyzed the likely impact of climate change on production and highlighted the needs for investments in specific crops in different regions, demonstrating that, to improve food security, investments should focus on maize production in Southern Africa, on yams and groundnuts in Western Africa or on wheat in Sahel.

Recently, Schlenker and Lobell (2010) used panel data analysis to study how weather fluctuations affect production of five major staple crops in Africa (maize, sorghum, millet, groundnuts and cassava). Using such a method has several advantages. Most notably, it provides an overview of the effects of climate change, given current technology. As a consequence, it directly indicates how to prioritize investments for research and adaptation. Once again their study demonstrates the strong impact of global warming on agricultural production, even in the least probable scenario. The median effect on maize production would be -22%, on sorghum and millet -17%, on groundnuts -18% and on cassava -8%.

Although these studies provide insight into the impact of climate change on agricultural production, the whole agricultural trade system will be affected. Moreover, climate change also has an impact on poverty levels.

### *What impact will climate change have on poverty?*

Hertel, Burke and Lobell (2010) used a general equilibrium global trade model (the Global Trade Analysis Project or GTAP) to evaluate the impact of climate change on poverty. The goal of such a study was to simulate likely productivity shocks due to the effects of climate change on agriculture. The model includes the possibility of changing the allocation of foodstuffs between countries. Thus, it allows food flows between areas where food is produced and regions where food is needed to study the role of food trade on poverty. The authors selected five groups of people who earn more than 95% of their income from one source: agricultural self-employment, non-agricultural self-employment, rural wage labor, urban wage labor, or transfer payments (government aid for instance).

Their findings confirmed that maize production was highly sensitive to climate change (Schlenker and Lobell 2010). Not just maize, but sorghum, sugarcane and crops using a C4 fixation biochemical mechanism appear to be very sensitive to climate change. The C4 crop metabolism has very low photorespiration, allowing crops to limit water loss. Consequently, median prices for cereals (rice, wheat, coarse grains, oilseeds, cotton and other crops) are expected to increase by 3.6% by 2030. This price increase is very high, going from a 16% drop for the 95th percentile to a 32% increase for the 5th percentile.

From a macroeconomic standpoint, Hertel, Burke and Lobell (2010) consider the impact of climate change on poverty comprises three factors: the impact on productivity change, the change of regional terms of trade, and the impact on efficiency. The authors note that climate change is responsible for the "highest percentage losses" of agricultural productivity in the sub-Saharan region. Since demand for staple foodstuff is quite inelastic, the direct consequence is an increase in staple prices. Some countries will likely benefit from these higher prices, especially

ones that export food. However, countries that depend on imports will suffer. The last component of the analysis focuses on economic efficiency. The study shows that economic efficiency is likely to decrease more and more. They estimate losses up to 1.5% of the crops' GDP in the more pessimistic scenario to 0.5% in the most likely scenario.

When they combine the impact of productivity shocks on cost of living and earnings, it appears that, in the median case, the shocks correlate positively with poverty reduction in households supported by agricultural self employment and diversified households. However, poverty rises for the urban wage labor group, altough these results depend highly on the contribution of each stratum to national poverty. In the sample of countries that Hertel, Burke and Lobell (2010) studied, only African countries would see their poverty increase, even in the 95th percentile case.

Costs of living are likely to increase for most African countries because of higher staple prices, and because of the structure of their terms of trade. Increasing African income and agricultural productivity would effectively offset these effects. Adaptation and mitigation to climate change should increase incomes of rural people. Mitigation is defined by the IPCC (2007a) as "an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases." Adaptation relates to a change in practices due to weather and climate variation. It includes "crop diversification, irrigation, water management, disaster risk management, and insurance" (Adger et al. 2007). Most of the studies detailed above do not incorporate potential mitigation or adaptation to climate change. This is a growing area of research.

## Can payments for ecosystems services be a part of the solution?

Changes in climatic parameters will affect agro-ecological ecosystems negatively, which may require implementing measures to both adapt and mitigate climate change. Two reasons make mitigation important for the African continent. First, worldwide decrease in GHGs emission would soften the impact of global warming on agriculture in this region, so worldwide treaties on climate change might be a new opportunity to reduce the impact of global warming on Africa. Second, Africa is a major emitter of GHGs from land-use change. In fact, it has 20% of the worldwide emission (Collier 2008), primarily because of heavy deforestation in the region.

### *Definition*

Markets usually fail to provide economic for environmental services. Nevertheless, some mechanisms have begun to give economic value for such externalities. Among them are the ecosystem services defined by the Millennium Ecosystem Assessment as "*the benefits people obtain from ecosystems*" (Alcamo and Benett 2003). Many ecosystems services are related to providing food and water and controlling flood and diseases. They also include climate change regulation. The Food and Agriculture Organization of the United Nations (FAO) (2007) defines externalities as ecosystem services that are consequences of primary activities like food production, so people cannot mitigate their production. Hence, two types of externalities are defined. The off-site externalities affect actors other than the producer, whereas the on-site externalities directly affect the producer of these externalities. In agriculture, an off-site externality might be the impact of over fertilization on ground water that people would latter consume (a negative externality). It can also be a decrease in GHGs emission from agriculture that would benefit a whole society (a positive externality). An on-site externality could be the effect of over fertilization on livestock health on the same farm (a negative externality). It can be

an increase in soil moisture thanks to conservation practices that decrease GHGs emissions (a positive externality).

The PES demand should begin to increase in the near future (FAO 2007). Carbon sequestration programs, which are also included in these PES, fall into two different types. The first diverts land from agriculture to other uses and are called land-diversion programs. The second modifies agricultural activities to achieve environmental goals and are referred as working land programs (Zilberman, Lipper and McCarthy 2008).

There are four different categories of PES and market based instruments: pollution charges, tradable permits, market friction reductions, and government friction reductions (Stavins 2001). Recently, the Kyoto protocol implemented a carbon market for the governments that ratified the accord with the goal of reducing GHG gas emissions (United Nations 1998). The 2009 meeting in Copenhagen, Denmark, failed to extend the Kyoto protocol commitment period that ends in 2012. The next round of negotiation is currently taking place in Durban, South Africa, with a probable focus of implementing a second commitment period.

### *Emission trading principle*

A cap-and-trade system is a market-based approach with the goal of internalizing externalities. Such a system creates economic incentives for actors to decrease a particular type of pollution. The principle of this emission trading system is to first, set a maximum amount of pollution released into the atmosphere (in the case of gas trading systems). This cap is usually set by governing entities that set a national amount of pollutants allowed. This amount is then divided into permits allocated to polluters which can be sold and represent the polluter's right to emit a certain volume of a pollutant. Polluters must hold permits for an equivalent amount of pollutants.

Then, entities that want to increase their emissions can buy permits from those who are below their maximum amount of emission. Thus, this system rewards firms that emit fewer pollutants by allowing them to sell their permits. At the opposite end, firms that pollute more must pay to get new permits to set a higher emission level. That is the trade part of the cap-and-trade system. A few markets have been implemented, both in the US (notably for acid rains) and worldwide. Under the Kyoto agreement, the European Union adopted a cap-and-trade system for GHG emissions, aiming to reduce emissions by 8% by 2008-2012 over the levels in the 1990s. This is currently the largest trading system in the world for GHG emissions and is called the European Union Emissions Trading System.

### *The Kyoto Protocol and its opportunities for developing countries*

Taking into account the new climate and economic paradigm, the Kyoto protocol aims to mitigate climate change effects by decreasing GHGs emissions. Its main goal is to reduce emission levels by 5.2% in 2012 from the 1990 level for the Annex I (industrialized and in transition) countries (United Nations 1998).

To reach this objective, the protocol allows several operations called flexible mechanisms. The Clean Development Mechanisms (CDM) allows entities from developed countries to buy Certified Emission Reduction (CER) from projects in developing countries to meet their cap levels. The Joint Implementation system aims to develop common projects within Annex I countries (developed countries). Finally, the last mechanism authorizes an emission trading system, also known as a cap-and-trade system.

The CDM supports emission-reducing projects in developing countries. It allows a developing country to implement such projects to gain carbon credits (Certified Emission Reduction credits) that can be sold in the world carbon market. This promotes sustainable

development and emission reduction in developing countries. According to the UNFCCC, this mechanism registered more than 1650 projects accounting for almost 3 billion tons of $CO_2$ equivalent in the first Kyoto protocol period (from 2008 to 2012). As shown in Figure 1-1, most of these projects are in south East Asia, and Central and South America. Only one project is currently in underway in Mali, and one in Ghana.

**Figure 1-1Clean development mechanism current projects**
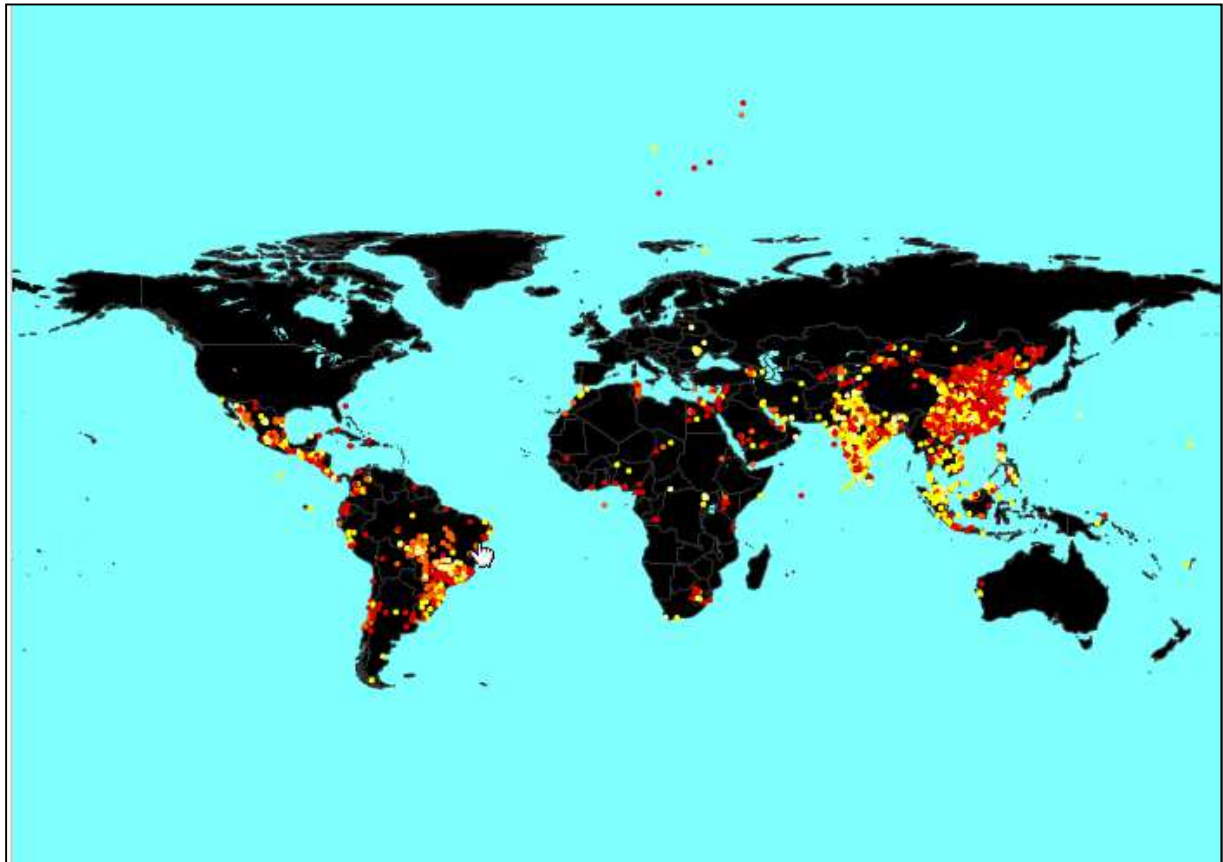


Source: United Nations Framework Convention on Climate Change

- CDM project, Large scale, one location
- CDM project, Large scale, several locations
- CDM project, Small scale, one location
- CDM project, Small scale, several locations

## *Current carbon markets*

The Kyoto protocol increased interest in the potential to sequester carbon in agricultural sinks to generate carbon credits, both in agriculture and forestry. Thus, carbon sequestration may represent a new source of income for farmers. Following the ratification of the protocol, many countries implemented their own GHG markets to meet the Kyoto requirements in terms for GHG reduction. In parallel, business interested in carbon trading have become involved in other voluntary markets, not based on regulatory constraints, although not all allow agricultural credits.

Under the Kyoto cap-and-trade system, countries face several options in complying with protocol requirements. They can reduce emissions and sell the credit saved, or they can buy additional credits to prevent fines. Thus, both carbon credit and carbon offsets are commodities on the market. They are generally traded in tons of carbon dioxide equivalent, which is not equal to a ton of soil organic carbon.

Moreover, two different types of credit exist (Williams, Mooney and Peterson 2009). Regulatory credits are usually auctioned or attributed to a GHG emitter. These permits can be seen as allowances for firms and countries to pollute. On the other hand, project-based credits are generated when a program aims either to reduce GHG emissions or sequester carbon, in some cases, through agriculture. Whereas both types of credits can be traded, project-based credits bear a risk for the buyer. In fact, a seller may not fulfill its sequestration objective. Moreover, project based credits can be generated over time, whereas regulatory credits are fixed by the regulator (Williams, Mooney and Peterson 2009). In the case of the Kyoto protocol, GHG allowances must be reduced by 5% by 2012 over the 1990 levels.

The program in this case study focuses on project-based credits creation. Three types of such allowances can be traded on the market. The Emission Reduction Units (ERU) refer to projects related to the Joint Implementation of the protocol whereas the ReMoval Units (RMU) are created through forestry and land-use change programs. Finally, Certified Emission Reductions (CER) refer to credits generated under the Kyoto's CDM. By the end of a compliance period, countries that ratified the Kyoto protocol must combine enough credits and offsets to reach their GHG emission objectives. Otherwise, they face a fine defined in the protocol (Williams et al., 2009).

The most important market for the Kyoto mechanism is the European Union greenhouse gas Emission Trading Scheme (EU ETS). Its first phase ran from 2005 to 2007. The second phase is currently operating and should end in 2012. Its third phase will run from 2013 to 2020.

### *Agricultural ecosystem services and poverty*

Pagiola et al. (2005) and Zilberman, Lipper and McCarthy (2008) have studied the relationships among poverty, agricultural development, and ecosystem services in developing countries.

To provide ecosystem services, agriculture can change the environment in three ways: climate change, water degradation, and biodiversity loss. To increase ecosystem services, farmers can first change their production practices, implementing sustainable production practices, for example. Such changes are called working land programs because they change the way land is cultivated. Second, farmers can use land-diversion programs, where land usually allocated to crops and livestock production is used for another purpose. The fallow land option implemented by the European Common Agricultural Policy is a good example of such a land-diversion change. Third, farmers can also change their land use habits, for instance, converting

forest to agriculture (Food and Agriculture Organization of the United Nations 2007). These changes imply different types of actors and have different effects from both microeconomic and macroeconomic standpoints.

The FAO (2007) describes four dimensions in which these changes in agricultural production can provide ecosystem services. First, ecosystem services are not independent and can interact with each other, either positively (as when we would increase a habitat for a species that may benefit other species) or negatively (as if this species would threaten other species). Secondly, natural parameters such as soil characteristics, climate, water and topography can be positive for some environmental services but negative for others. Third, some ecosystem services can be provided only in a particular region. Thus, the political and economic context makes ecosystem services relevant only for regions where they can be implemented because of political and economic stability. Finally, ecosystem services can benefit an individual or the whole community, even if the resources that provide these ecosystem services are privately owned. Private actors can be motivated to participate to these ecosystem services. For instance, in the case where farmers adopt working-land programs such as no-till practices, ecosystem services benefit farmers and communities because no-till helps mitigate climate change.

However, broad generalization is not possible. The interactions between ecosystem services and agriculture must be studied on a private and microeconomic scale. In fact, soil management, productivity, poverty reduction and ecosystem services are linked (Lal 2004; Foley et al. 2005; Perez et al. 2007). Hence, estimating ecosystem service costs and the impact on agricultural productivity become important.

# The carbon gap

## *Carbon sources and carbon sinks*

In agriculture, carbon is partly released through microbial decay, burning of plant litter and soil organic matter (IPCC 2007a.). Carbon is a major component of organic organisms; a plant incorporates carbon atoms into its structure because of photosynthesis. Consequently, soils have a high potential for carbon sequestration, accounting for twice the amount of carbon in the atmosphere. Because plants consume carbon in the atmosphere and store it in the ground, soils become carbon sinks, while carbon sources release carbon into the atmosphere, often through human activities like manufacturing and energy production.

The FAO (2007) outlines the advantages of sequestering carbon through agriculture. This practice is not costly to implement and it also yields other agronomic benefits like increased organic matter and improved nutrient and water retention in soils. However, carbon storage in agricultural soils is reversible: changes in production practices can release sequestered carbon to the atmosphere. According to the report, almost 2.3 billion tons of carbon could be sequestered worldwide.

## *Potential for carbon sequestration*

The FAO (2007) differentiates carbon sequestration from above-ground biomass and carbon sequestered below ground. Above ground biomass can be increased with tree plantations and shrubs. Agroforestry, tree plantations, and sylvopastoral systems are among the techniques that increase above ground biomass and thus carbon sequestration. Palm et al. (2005) estimated that changing forest management sequester 213 tons more of carbon per hectare over the life of a forest and that an improved fallow production system could sequester 4.6 tons of carbon over eight years. The FAO (2007) argues that the more carbon can be sequestered through

afforestation or reforestation and that annual crop and pastures "*store a small fraction of that amount*", where dead plant material and carbon dissolved in groundwater are sources of sequestration.

One third of land with a high potential to sequester carbon are found in 15% of the total cropland area (FAO 2007). Furthermore, 25% of this area is located in Africa. A deeper look into these data highlight that carbon sequestration potential is higher if appropriate cropping systems are implemented in these areas.

## The SANREM project

The SANREM (Sustainable Agriculture and Natural Resources Management) project is based on three observations: African farmers are facing climate change, they must adapt their production techniques, and they might consider opportunities involved in carbon sequestration programs. The SANREM project is a Collaborative Research Support Program (CRSP) funded by USAID. Its main goal is to "[s]upport sustainable Agriculture and Natural Resource Management decision makers in developing countries by providing access to appropriate data, knowledge, tools, and methods of analysis; and by enhancing their capacity to make better decisions to improve livelihoods and the sustainability of natural resources."

The leitmotiv of the project's research is supporting sustainable agricultural and natural management practices that develop niche markets, are eco-friendly, and are competitive. A formal analysis would help explain to what extent farmers would be willing to adopt conservation practices. Thus, we must examine costs and benefits farmers would face when adopting such practices. The project supports research all over the world. Kansas State University (KSU) is involved in the long term research award number 8, "Improving soil quality

and crop production through CAPS in West Africa." CAPS stands for Conservation Agriculture Production Systems. KSU research focuses in two countries: Ghana and Mali.

Such a project involves different actors, with different objectives. African farmers expect, as a main outcome, agricultural practices that can help them to adapt to climate change. The goal of SANREM is to assess the impact of climate change on agricultural production and to study adaptation techniques on a microeconomic scale.

## Study objectives and approach

Considering the potential for implementing conservation practices, and given the opportunity for farmers to benefit from payments for ecosystem services (PES), the main goal of this thesis is to perform a case study in Northern Ghana, in the Wa area to find to what extent these objectives can be achieved. Although it is still experimental, the SANREM project is nonetheless interested in a further implementation of a carbon payments scheme. Field experiments are currently examining conservation agriculture production systems. The additional carbon that these practices sequester over current farming practices may represent a new source of income for farmers. We will study ex-ante to what extent farmers may adopt conservation practices and carbon payments as an incentive for farmers to switch to such practices. This case study is designed to improve our understanding of these tradeoffs.

## Thesis organization

In the following section, a brief literature review aims to better explain carbon sequestration and its role in adopting conservation agriculture production systems. It details studies that have evaluated carbon sequestration from an economic standpoint.

This leads to a description of the case study area and current farming practices in the area. Alternative conservation management practices are then simulated to assess their economic profitability in farming communities in Wa.

After this, costs and revenues of both current and simulated management practices are calculated using field data and information from secondary sources. Using a minimum-data approach with a model developed by Antle and Valvidia (2006), we will predict participation in carbon contracts at different carbon price levels in the market.

Both the cost/revenue calculation and the results from the minimum data simulations will lead to key findings, particularly farmer participation in carbon contracts when different conservation agriculture production systems are simulated. These findings should allow policy recommendations on implementing carbon contracts and the profitability of conservation practices in this area.

# Chapter 2 - Problem definition and methodology

## Narrowing the problem

To evaluate the potential of conservation practices and PES, a literature review can provide evidence of the economic analysis of ecosystem services. In this review, the adaptation phenomena provide an introduction to a microeconomic evaluation of the extent to which African farmers can adapt under climate change. Secondly, a brief review of sustainable practices that sequester carbon will give a deeper understanding of the production techniques considered in this study. Then, some discussion provides insights into the different approaches that can evaluate the economic profitability of PES. This section will highlight the method chosen in this case study to assess the profitability of conservation practices in Wa and will lead to the description of the data used for analysis.

## Literature review

### *Can African agricultural-households adapt production to face decrease in earnings?*

The adaptation phenomenon is the "[a]djustment in natural or human systems to a new or changing environment" (IPCC 2007a.). Soil fertility maintenance is one example of reactive adaptation as are introduction of new crops and erosion control. Anticipatory adaptation could involve soil and water management, or different types of economic incentives.

Adaptation is a key factor for food security. Food production and rural poverty both influence African farmers' reactions to climate shocks. Stern (2006) emphasizes that economic development is essential to adapting climate change. However, adaptation in developing countries is currently limited by both human capacity and financial resources (UNFCCC 2007).

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Antle (2008) sees adaptation to climate change as a result of the supply of agricultural production and the demand for foodstuffs, as outlined by Hertel, Burke and Lobell (2010). Collier, Conway, and Venables (2008) have a slightly different point of view. They describe different kind of adaptations among three main economic entities: African private actors, African public sector, and international organizations.

The public sector could supply information about crop varieties. International organizations also have an important role in providing food aid considering the "costs of African adaptation to these adverse externalities."

Private actors will likely adapt to climate change by trying to avoid the announced decrease in agricultural productivity and the associated increase in commodities prices. According to these authors, people will face three choices due to the impact of climate change on agriculture. They can shift to other economic sectors, they can migrate to regions where climate change actually enhances agricultural productivity, or at least does it no harm, or they can change their production techniques. Antle (2008) argues that adaptation at the production site will increase pressure on water resources in arid regions. Furthermore, both population density and agricultural production are likely to increase. Thus, better management of natural resources and implementing different production techniques help farmers adapt. These two interrelated elements are integral to conservation agricultural production systems.

### Technical issues: How will agricultural practices affect soil productivity and carbon sequestration?

Any crop can sequester carbon thanks to their biological mechanisms. However, can carbon sequestration into soils be improved? Many studies have investigated what agricultural techniques provide the most carbon sequestration. We have some evidence that some agricultural

practices allow more sequestration than the usual production systems. Ringius (2002) and later Wilman (2011) noted some practices that can improve carbon sequestration: no tillage, cover crops, and converting crop land into forests or letting it lie fallow. Some of these techniques are part of conservation agriculture production systems. The FAO (2001) defines conservation practices as those based on tillage reduction, leaving crop residue on soils, and not burning residue after harvest. No tillage is already used in South America and Africa (IPCC 2007a), and in other developing countries as a new way to increase productivity and create more sustainable production systems (Lal 2004; Pretty 2008; Hobbs, Sayre and Gupta 2008; Naab et al. 2008a; Naab et al. 2008b; Wilman 2011).

Conservation agriculture has many benefits, and not all are in actual production. For example, no-till practices increase the level of soil organic matter. Moreover, they rely more on decomposition/mineralization associated with crop residue instead on collecting crop residue. Consequently, these practices increase soil organic because no-till keeps carbon in soil instead of releasing it into the atmosphere. Moreover, when crop residue are not burned, grazed, or removed, the residue itself represents another form of carbon storage. Finally, these techniques can be adopted in already cultivated agricultural fields (Zivin and Lipper 2008).

Global statements about conservation practices benefits are, however, impossible because of differences in climate, soil parameters and agricultural practices. These benefits must be assessed carefully taking the context into account. Furthermore, climate change will affect the context, particularly in Africa. Climatic and weather parameters are becoming more and more unpredictable across this region. Some studies have demonstrated that conservation agriculture will benefit farmers in developing countries (Pretty 2008; Hobbs, Sayre and Gupta 2008), but ex-ante empirical assessment is important in studying the feasibility of conservation practices. In

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addition, carbon sequestration associated with conservation practices must be estimated and economically evaluated. Empirical experiments may help validate these more intuitive conclusions.

The FAO (2004) does note that, in the long term, changes in land use could increase soil carbon and later (2007) argues that "retention of crop residue and substantial addition of farmyard manure" can lead to carbon sequestration into soils up to 40 tons per hectare. An important research step then is to explain and quantify this sequestration potential.

Zivin and Lipper (2008) point out "Payments for the carbon sequestration benefits of the system provide a potential opportunity to support the adoption of the system and make a significant contribution to agricultural development and climate change mitigation." Zilberman, Lipper and McCarthy (2008) add, "One of the most promising areas of future research in this field is empirical work using spatial data on poverty, agricultural productivity, and potential ES supply to further investigate the potential benefits the poor may realize with PES programs."

### *Incentives to adopt conservation agriculture*

Even if conservation practices, theoretically, help productivity and may reduce poverty, this system must provide incentives strong enough for farmers to adopt these practices. Antle and Diagana (2003) and Zivin and Lipper (2008) studied incentives to adopt production systems that increase carbon sequestration. The latter study focuses on risk in this adoption process, notably on the risk of the transition to a new production system (Food and Agriculture Organization of the United Nations 2001; Bishop-Sambrook et al. 2004; Hobbs, Sayre and Gupta 2008). The authors divide this risk into technology impact and productivity impact (Zivin and Lipper 2008), showing that risk and uncertainty are the major barriers to adopting conservation agriculture. As a result, incentives that compensate for this risk should cover the adaptation period until the

alternative system reaches maximum productivity (Antle and Diagana 2003). PES may cover this risk premium. Zivin and Lipper (2008) suggest that switching to conservation agriculture could bring returns of US$0.90 to almost 15US$ per hectare per year.

### *Is carbon sequestration economically profitable for farmers?*

Costs and benefits of adopting conservation practices that sequester carbon must be explicit (Zivin and Lipper 2008). In fact, as the FAO (2007) puts it, "the economic feasibility of the required land-use changes is not yet clear." Researchers generally agree about the way carbon sequestration would reward farmers. To reach a viable point, farmers would need to engage in carbon contracts detailing conditions under which farmers would be rewarded for carbon sequestration. Monitoring carbon credits and the contract would be necessary. Because of these carbon contracts, farmers would adopt environmentally harmless management practices that would also sequester carbon. Hence, contracts would reward farmers only for additional carbon sequestration over earlier practices in that region. The monitoring system would have to make sure that farmers follow the practices defined in the contracts. This system should assess the economic profitability of these practices to assess the feasibility of the contracts. Two main approaches could empirically assess the economic feasibility of ecosystem services.

### *Full data approach*

Just and Antle introduced the first approach (1990). They proposed a theoretical framework to analyze the synergy of agriculture and environment.  Many studies have used theoretical framework that relies upon a software, relying on the Tradeoff Analysis software (Pautsch et al. 2001; Antle and Diagana 2003; Feng, Kling and Gassman 2004; Wu et al. 2004; Lubowski, Plantinga and Stavins 2005; Diagana et al., 2007).

**Framework**

This method uses site-specific data to assess the interaction between agriculture and environment. This type of analysis uses spatially explicit data and complex econometric models linked to biophysical models (e.g. crop growth models) and environmental process models (e.g., NUTMON). It may also rely on crop growth models like DSSAT/Century to simulate changes in soil carbon stocks under alternatives management practices and under different price scenarios (as in Diagana et al. 2007). Part of the approach is based on the calculus of the net present value to switch to carbon sequestration practices, as shown below:

(Equation 1)
$$NPV\,(i,s) = \sum_{t=1}^{T} Dt\big(NR(pt,wt,zt,s) + Pt\Delta Ct(i,s) - Mt(i,s)\big) - I(i,s)$$

where *NPV* is the Net Present Value, and $\Delta Ct$ *(i,s)* represents the soil carbon increase after changing from *i* to *s*. *Pt* is the payment per ton of carbon sequestered per period. *Dt* represents a discount factor $(1/(1+r))^t$ with an annual interest rate of *r*. *NR (pt,wt,zt,s)* is net return per hectare for system *s* in period *t*, given product price *pt*, input prices *wt*, and capital services *zt*. *Mt (i,s)* is the maintenance cost per period and *I(i,s)* is the fixed cost for changing systems. As a consequence, farmers might adopt a pro-carbon management if *NPV (i,s)>NPV(i)* (Antle and Diagana 2003).

The model uses an econometric process simulation that may combine output supply functions and input demand function. The Tradeoff Analysis software described in Stoorvogel (2001) is specific to each study site. Econometric and crops growth models must be designed and calibrated for each site. Consequently, it is used only when spatially explicit and precise data are available. Referring to both the requirements in terms of precise data and the time necessary for

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their collection, this approach is referred as a full-data (FD) analysis by its authors (Antle and Diagana 2003).

**Empirical experiences around the world**

The Tradeoff Analysis software has been tested empirically in Senegal, Peru and Kenya in Antle and Stoorvogel (2008). While part of Antle and Stoorvogel (2008) focused on carbon sequestration in soil using system and environmental, experimental and farm-survey data, they also used econometric process simulation models to simulate working-land programs and soil carbon contracts that required changes in agricultural practices, such as a management of soil organic matter or different water management. Antle and Stoorvogel (2008) suggested that farmers in Kenya and Senegal adopt agricultural techniques ike incorporating fertilizers or crop residue and shift to terracing and agroforestry practices in Peru. Measuring and monitoring used randomly selected samples. The costs of this sort of monitoring may not be sufficient to track carbon sequestration (Mooney et al. 2004).

In the kinds of analysis outlined by Antle and Stoorvogel (2008), even if farmers are willing to participate, such contracts can be affected by a number of factors, and the risk was not incorporated into the analysis. The authors also reported that farmer participation depends on spatial distribution of opportunity costs to switch to alternative production systems. Furthermore, their conclusions suggest that the likely impact of carbon contracts will be to raise rural incomes and reduce the rate of soil carbon loss. In some cases, carbon contracts may stabilize soil carbon stocks at a higher level than would otherwise be feasible, for example, when organic matter can be increased at a relatively low cost.

**Ghanaian studies relatives to this approach**

To assess carbon sequestration with site specific data, Koo (2007) used a Decision Support System for Agrotechnology Transfer (DSSAT) model with the Century model. Using soil samples from 132 farm fields in Wa, northern Ghana, the author studied carbon sequestration in the top 20 cm of soils. His results show an above the average increase in carbon sequestration for cereal based cropping practices, notably for legume and tuber-based practices. Moreover, residue retention and fertilizer use increased soil carbon retention. Furthermore, when farmers followed an appropriate crop management system, the annual average amount of carbon sequestered across the region was 173 kg per hectare per year. Moreover, management practices relying on no-till methods sequester significantly more carbon than systems with tillage. Koo (2007) also assessed the efficacy of fertilizer use and concluded that, when fertilizers are not available, no-till based practices yield the highest soil carbon sequestration. From a global standpoint, his study showed that conservation practices like no-till and appropriate residue management represents real potential for carbon sequestration if used correctly, and if economically profitable. Finally, Koo (2007) noted that US$4000 could be generated through carbon payments over 12 years in the region, at a price of US$4.00 per MgCO2 and over a total of 132 fields.

Another study in Wa went further and estimated the feasibility of using carbon markets to support conservation practices and increase the income of farmers in Wa (Gonzalez-Estrada et al., 2008; Naab et al. 2008a.). These authors notably used the theoretical framework developed by Antle and Diagana (2003) and assessed different crop management systems in Wa. To estimate the amount of carbon that could be sequestered under simulated scenarios, their study used the DSSAT/Century models. They calculated the Net Present Values of conservation practices over 20 years to evaluate the economic costs, including a fixed carbon payment. The

level of this Certified Emission Reduction (CER) payment was US$7.51 per ton of carbon

dioxide equivalent (equal to US$27.5 per ton of soil carbon sequestered). Finally, the study

assessed different agricultural systems' contributions to farm income with and without carbon

payments using an optimization model.

The conclusion was that switching from current practices to the simulated management

strategies would lead to an increase of the net present value farm profits of 2 to 32% over 20

years. Further, the net present values would increase with increasing level of inputs and when the

proportion of residue returned to the soil increases, holding the level of inputs constant.

Moreover, management practices that allow the highest carbon sequestration were not

necessarily the most profitable for farmers. Going still further, the authors ranked different

management practices into four groups according to their relative costs, from inexpensive, to

medium-cost, expensive, and very expensive strategies.

The study ranked production strategies according to sequestration possibility, to their

costs, and to their NPV. However, no tradeoff analyses have been conducted to derive the

adoption rates within farming communities in Wa. Moreover, the study's findings rely on a fixed

price for carbon. Nevertheless, as seen in the introduction, the price of carbon is subject to two

factors of variation: the future of the Kyoto protocol, and the dynamic equilibrium of the carbon

market that creates price changes.

### Minimum data approach

Full data analysis is particularly time consuming because it requires precise on-site

environmental, economic, and agricultural data to run the several models required to perform the

analysis. Moreover, these kinds of precise data may not be available in every region or

impossible to collect in a short time. Antle and Valvidia (2006) developed an alternative method

using a minimum-data (MD), which relies on a spatially explicit production model that derives the supply of ecosystem service, using a small set of representative data.

The purpose of such an approach is to develop a quantitative analysis of the supply of ecosystem services and to derive ecosystem services participation estimates. This approach uses data available from secondary sources and that may be collected faster than data required to perform an analysis with more complex models. Moreover, Antle et al. (2010) demonstrated that the MD results are comparable to more detailed modeling processes. Since its development in 2006, the minimum data approach has been used in many areas, in both developed and developing countries (Antle and Valvidia 2006; Antle et al. 2010; Claessens, Stoorvogel and Antle 2008; Immerzeel, Stoorvogel and Antle 2007; Nalukenge, Antle and Stoorvogel 2009). Smart (2009) incorporated the risk aversion parameter into the model. The MD is the approach we will use in this case study. The section below presents its methodological basis.

## Implications for the study: Approach and data used

Both time and data for performing a detailed analysis in Wa are in short supply, so a faster, but still accurate, method has been used to assess conservation agriculture production systems. Moreover, to build upon existing studies in Wa, carbon sequestration was evaluated from an economic standpoint. The analysis took into account market volatility, that is, different carbon prices. We also wanted the extent to which farmers would adopt alternative practices. For all these reasons, the minimum data approach appeared to be an appropriate tool for this assessment.

### *Methodology and principle of the analysis conducted*

In this case study, we considered how carbon contracts should be introduced to the Wa farmers. We assumed that they would receive payment for switching from current practices to

practices that sequester more carbon through conservation practices. This payment would reward farmers for any additional carbon sequestered over their current practices (i.e., compared to a baseline scenario). Different management practices were simulated to compare the ecosystem services produced and assess farmers' participation in carbon contracts under different management practices. We assumed that carbon contracts would require farmers to adopt precise management practices. Moreover, because we assumed that these contracts reward only an increase in carbon sequestration, farmers cannot enter a contract if they do not follow new management. Because the information was available, the management practices assessed in this analysis were Koo's (2007). They are described in the next section.

Estimating ex-ante what agricultural practices would be adopted by farmer required estimating ex-ante parameters, including how much carbon would be sequestered under alternative practices, and the cost of each of these practices. Thus, an estimate of costs and revenues of each management practice was performed first. Then, the minimum data model was used to estimate farmers' adoption of management practices. Before detailing simulated management practices, we provide of the study area.

### Data sources

In this study, information about yields and management practices characteristics were derived from soil samples and farm management surveys conducted in four villages (Nakor, Kparisaga, Kumfabiala and Bamahu), over more than 132 farmer fields from July 2004 to April 2006. These data were analyzed by the Savannah Agricultural Research Institute. Information on land-use history, residue management, fertilizer application, soil organic carbon contents and soil texture were collected. Koo (2007), Naab et al. (2008a), Naab et al. (2008b) and Gonzalez-Estrada et al. (2008) used these data in studies performed in Wa. Data about farmers'

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management practices were gathered during this survey and synthesized in Gonzalez-Estrada et al.'s (2004) case study.

Koo (2007) used soil samples to estimate the amount of carbon that could be sequestered under different sets of management practices using DSSAT, associated with the Century model 4.0. The Century model adds a soil organic matter-residue module to DSSAT (Gisman et al. 2002). The combined model (DSSAT/Century) could simulate crop growth and soil organic dynamics under different management practices. This simulation covered a period of 20 years, with 2006 as the initial year using soil organic content and texture measurements from samples as initial soil properties. Weather data (temperature, solar radiation and rainfall) were generated using data from measurements that the Savannah Agricultural Research Institute has recorded over 8 years. Several soil data (soil organic carbon and soil texture at 20 cm depth, water holding characteristics, root growth factor, bulk density, and soil pH for different soil layers) were used as inputs for the DSSAT/Century model, along with simulated cropping sequences. For each scenario, crop growth and soil carbon dynamics were predicted, and the amount of carbon sequestered and the anticipated yields were calculated by the DSSAT/Century models.

The SANREM CRSP has gathered more recent data from 201 households in 2010, over three districts in the Upper West Region: Wa West, Wa municipal and Lawra, and over an area of 1186.68ha. Demographic information was collected along with agricultural and non-agricultural assets, land use, labor, grain transaction and output use data. Other information (affiliation to organization, food security, knowledge, beliefs about conservation practices and data about the agricultural network) were also gathered. A preliminary report was released in the SANREM CRSP collaborator network (Yahaya, Hashim and Dalton 2011). A demographic description of the population surveyed is given below.

**Table 2-1 Demographic Statistics of the population surveyed [1,2]**

|                                          | Mean | Std. Deviation |
|------------------------------------------|------|----------------|
| Household size                           | 8.2  | 3.5            |
| Age of Household head                    | 43.8 | 13             |
| Age of first wife of household           | 31.8 | 14.1           |
| Number of adults in the household (>15yrs) | 4    | 2.1            |
| Number of children <15 years             | 4.2  | 2.4            |

[1] Data calculated from surveys performed by Yahaya in 2011

[2] A total of 201 households were surveyed

*Site characteristics*

Since a carbon contract would only reward additional amounts of carbon sequestered over usual farming practices, baseline practices are essential for comparison with the other management scenarios. Describing the type of agricultural activities in Wa is also important. Wa is in the northwest corner of Ghana and has a mean temperature of 32°C. Yearly rainfall averages 1200mm during the rainy season, which extends from May to October. Soils are mostly sandy and are classified as ferric lixisols and luvisols. The region is characterized by subsistence farming where farmers usually farm two types of land: bush and homestead. Bush farms are usually a few kilometers from the homestead.

Koo (2007) states peanut, sorghum and maize as farmers' preferred crops in Wa in 2003. He also reports that the proportion of fallow decreased from 50% in 2001 to 16% in 2005. In addition, cereal production, notably millet, increased. Recently, Yahaya, Hashim and Dalton (2011) report that maize (40%), millet (10%) and groundnuts are the most common stored crops. We chose these three crops to define the baseline scenario described in the next section. Moreover, Yahaya, Hashim, and Dalton (2011) 42% of the households surveyed followed a mono-cropping system including crops like peanuts, maize, millet, rice, sorghum, soybeans, and yam. Maize, peanuts, millet and rice were the crops most produced in the region at that time.

Yahaya, Hashim, and Dalton (2011) also add that few households practice mixed cropping associating legumes and cereals, e.g., associating millet and peanut cultivation.

Considering these facts, the cropping systems used for our analysis were the ones that predominate in the region, and the one for which data were available when simulating alternative management practices. Consequently, the five management practices and the three crops studied by Koo (2007) were used according to the following cropping system: continuous maize, continuous millet, and continuous groundnut. The baseline production system was a four year rotation with two years of maize, one year of millet, and one year of groundnut. The five management practices that were used for analysis are described below.

### Current farmer practices (FP scenario)

As explained in the previous section, current farmer practices include growing crops like maize, millet, groundnuts, yam, cassava, rice and sorghum. Fertilizer is not commonly used in Wa for the three crops of interest. The median cost of NPK application for maize is US$7.41ha/yr (with an average US$51.59ha/yr and a standard deviation of US$90.38ha/yr), according to the most recent survey. However, these data are highly skewed. Thus, in the baseline scenario FP, we assumed that farmers do not use fertilizer. One reason for applying so little fertilizer is its prohibitive cost (Koo 2007).

Moreover, farmers usually rely on stored seed for the next year's crops. Hence, the median cost for maize, millet and groundnuts seed is highly skewed with a cost of US$3.06/ha/yr for maize (average US$11.05/ha/yr and standard errors of US$ 27.81/ha/yr), US$1.53/ha/yr for millet (average US$4.21/ha/yr and standard errors of US$ 7.79/ha/yr) and US$11.23/ha/yr for groundnuts (average US$16.59/ha/yr and standard errors of US$ 25.96/ha/yr). Furthermore, other inputs (herbicides, pesticides, or fungicides) are rarely used for the three crops of interest.

In fact, annual cost per hectare for maize, millet, and groundnuts have a median cost of US\$0/ha/yr (and associated average of US\$1.89/ha/yr, US\$ 1.33/ha/yr and US\$0.66/ha/yr, with standard deviation of US\$13.64/ha/yr, US\$10.87/ha/yr and US\$3.58/ha/yr). These highly skewed indicate that current farmer practices do not include any seed costs because farmers rely on seed from the previous harvest nor chemical or fertilizer inputs. Recent observations in Wa are consistent with these assumptions (Koo 2007; Gonzalez-Estrada et al. 2008). Data may be skewed because a few farmers use a lot of inputs, but most use none at all.

Concerning the other practices, farmers leave crop residue in the field after harvest until the following planting season. While on the fields, most residue decompose through livestock action or microorganisms. At the beginning of the rainy season, farmers cut the crop residue, collect them and either burn them, use them as fuel, feed them to their livestock, or use them as building materials. Finally, roots and remaining residue are removed from the fields after burning. Burning may contribute to soil fertility, but the potential for sequestering carbon through crop residue is lost. After burning the residue from the previous growing season and before planting seeds, farmers usually till their land, often with hand-hoes. Koo (2007) reported that only 4% of the fields were mechanically tilled.

All these characteristics describe the baseline scenario we will be refer to as current farmer practices (FP) in this case study. The simulated yields over 20 years for these practices in the DSSAT/Century model are the following: 1320.50kg/ha/yr for maize, 643.75 kg/ha/yr for millet, and 1373.30 kg/ha/yr for groundnuts (Koo 2007).

### *Yields and carbon sequestration simulated*

Yields associated with the management scenarios described in the next section were simulated using the DSSAT/Century model (Koo 2007). Simulations for 20 years were

performed with soil samples taken from surveyed households. DSSAT/Century simulations operated under three main assumptions. First, the initial fraction of Soil Organic Matter pool (SOM1) was assumed to be 1% in all fields. Moreover, it was assumed to not influence the overall SOM dynamic. Second, it was supposed that the initial fraction of SOM (SOM3) was equal in each field. Finally, we assumed that the present fraction of SOM3 followed a decreasing exponential evolution after implementing a management practice.

The increase over the current farmer practice was calculated using the following formula (Naab et al. 2008a):

(Equation 2) $Change\ in\ SOC\ relative\ to\ FP\ (kgha^{-1}yr) = \dfrac{((TRT_{in} - TRT_{i0}) - (FP_n - FP_0))}{n}$

where $n$ is the year, $i$ is the management system, $TRT_{in}$ is the amount of SOC for management system $i$ in year $n$ and $FP_n$ is the amount of SOC for FP in year $n$. The following sections provide the results of the calculation for each management practice. For comparison, West and Post (2002) and Lal et al. (1999) estimated that conversion from conventional to reduced tillage would increase carbon sequestration by 720 kg/ha/yr.

### No-till management (NTL scenario)

As previously noted, conservation practices may increase soil carbon sequestration. No-till is one method that has been frequently highlighted for its potential to sequester carbon into soil. Hence, the first simulation scenario used this technique.

The no-till management (NTL) scenario has been assessed to sequester an additional 152 kg/ha/yr (when considering a four year rotation with two years of maize, one year of millet, and one year of groundnuts). The simulated yields are 1327.55 kg/ha/yr for maize, 766.15 kg/ha/yr

for millet and 1382.20 kg/ha/yr for groundnuts, over 20 years. In our case study, in switching to NTL, farmers would stop hand-hoeing their fields but would continue relying on the previous season's seed stock.

This scenario assumed that farmers would not use fertilizer. One main advantage of no-till is that it improves soil structure. Tilling soils generally accelerates erosion, destroys soil structure, and decomposes residue faster (Hussain, Olson and Ebelhar 1999; Reicosky 1997). In our case study, farmers were assumed to remove only 25% of the crops from their fields.

Ekboir, Boa and Dankyl (2001) report that no-till techniques require more pesticides per hectare to fight weeds, plant diseases, and increased pest pressure, all of which are frequently observed when shifting to no-till, particularly in developing countries. Thus, these authors estimate 3 liters per hectare per year additional chemical pesticides for no-till trials in Ghana (including the northern savannah). That would cost farmers an additional US$19.29/ha/yr.

However, shifting to no-till practices eliminates the labor involved in hand-hoeing and residue removal, reducing costs by 22% (Ekboir, Boa and Dankyl 2001; Boahen et al. 2007). According to recent trials in Wa, labor requirements decreased by 20% in maize production when switching to no-till (Yahaya 2011b.). In this subsistence, small-scale farming region, we can assume that farmers would hire less labor.

Finally, one main feature of no-till is that it requires specific machinery to sow sesed without tilling the fields. Ekboir (2001), Boahen et al. (2007), and Yahaya (Savanna Agricultural Research Institute, personal communication, October 2011) note that this additional fixed cost is difficult to estimate in Ghana. In Ghana, unlike other developing countries like Pakistan, Brazil, or India, no hand-operated planters have been developed. Boahen et al. (2007), however, report that the FAO financed the development of jab-planters for small-scale farmers at the Agricultural

Engineering Department of the University of Science and Technology at Kumasi. The price of such a planter has been set at US$20. Local farmers rejected the planter because of its relatively high cost. Thus, planting sticks and machetes remain the planting tools used by farmers.

### *Fertilization based management (FRT scenario)*

The second simulated scenario relies on fertilizer application available from the Ghanaian government (government subsidies make NPK 15-15-15 fertilizer US$0.54/kg according to Ahwoi (2010)). Simulating such a scenario allowed us to assess how policy incentives affect adoption conservation practices. Fertilizer might be provided to farmers to encourage them to switch to conservation practices.

This scenario still relies on hand-hoeing to approximately 20 cm deep and on removing most residue for use as building material, livestock food, or fuel. Fertilizer applications were assumed to be 40 kg/ha/yr on maize, 20 kg/ha/yr on millet, and null on groundnuts. Tennigkeit et al. (2009) estimated the cost of additional labor at 15 more days/ha/yr at US$2/man day (Yahaya, Savanna Agricultural Research Institute, personal communication, October 2011).

According Koo's (2007) DSSAT/Century simulations, this scenario would increase carbon sequestration by 18 kg/ha/yr, which is relatively low compared to the NTL scenario. Nevertheless, average yields reached following this method would average 3664.65kg/ha/yr for maize, 1027.30 kg/ha/yr for millet and 1373.30 kg/ha/yr for groundnuts, when simulating yields over 20 years.

Finally, in this scenario, we assumed farmers would continue using the previous season's seeds and would still not use any pesticides.

*Residue management practices (RSD scenario)*

The slash-and-burn method has been criticized because it does not return crop residue to the soil and reduces the amount of soil organic carbon. In the residue management practice scenario (RSD), we wanted to assess residue-based management in soil carbon sequestration. In this scenario, farmers till their soils as they currently do but leave most (75%) of the crop residue on the fields to be incorporated into the soil when the fields are tilled. This management practice yield the following would lead to the following yields: 1438kg/ha/yr for maize, 840.80 kg/ha/yr for millet and 1393.65 kg/ha/yr for groundnuts (Koo 2007). The DSSAT/Century model estimated additional amounts of carbon sequestered of 67 kg/ha/yr in this region (again, using a four year rotation with two years of maize, one year of millet and one year of groundnuts).

Furthermore, switching to this management practice assumed that farmers would continue to use their own seeds, but no fertilizer or any other chemical inputs (as in the FP scenario).

Runge-Metzer (1988) calculated the extra labor required to incorporate crop residue into soils in Ghana. Compared to the baseline FP scenario, the RSD scenario would require 6 more man days per hectare per year. With wages of 2US$ per manday (Yahaya, Savanna Agricultural Research Institute, personal communication, October 2011), that would represent an additional cost of US$12/ha/yr.

*Recommended management practices (RMP scenario)*

The last management practice simulated in this case study was defined by Lal (2004). It is referred as recommended management practices. It involved a set of conservation practices, including land preparation to residue management, which would eventually lead to the most carbon sequestered. Indeed, the simulation performed by Koo (2007) suggests that this scenario

would yield additional carbon sequestration of approximately 224 kg/ha/yr. Moreover, average estimated crop yields over 20 years are: 3691.35kg/ha/yr for maize, 1192.25kg/ha/yr for millet and 1382.20kg/ha/yr for groundnuts.

In this simulation, farmers would use the same amount of seed (and thus the same seed costs). However, this scenario relies on using fertilizer at the rate of 40kg/ha/yr for maize, 20kg/ha/yr for millet, and no fertilizer for groundnuts. Additional labor cost was estimated by Tennigkeit et al. (2009) at 15 more days/ha/yr at US$2/man day (Yahaya, Savanna Agricultural Research Institute, personal communication, October 2011).

This scenario is based on using no-till, which would require an additional 3 liters of chemicals per hectare per year as explained in the NTL scenario. Finally, in using no-till, labor requirements would decrease by 20%, as has been recently observed for maize production in Wa (Yahaya, Savanna Agricultural Research Institute, personal communication, October 2011).

Table 2-2 below summarizes the five scenarios used in this case study, for which Koo (2007) simulated yields and carbon sequestration rates.

**Table 2-2 Simulated management practices used for the study (Koo, 2007)**

| Scenarios | Tillage | Fertilization | Residue removal for cereals (legumes) | Additional carbon sequestered (kg/ha/yr) |
|---|---|---|---|---|
| Farmers' Practices (FP) | Hand-hoeing | No | 100% (75%) | 0 |
| No-till (NTL) | No-till | No | 25% (25%) | 152 |
| Crop residue (RSD) | Hand-hoeing | No | 25% (25%) | 67 |
| Fertilization (FRT) | No-till | Yes | 100% (75%) | 18 |
| Recommended management practices (RMP) | No-till | Yes | 25% (25%) | 224 |

### *Costs and revenues analysis*

Costs and revenues must be included in any decision to adopt technology. In our case study, this is also true. Farmers would switch from their current practices to other agricultural practices only they are profitable. Hence, we conducted a cost and revenue analysis for each management practices. Each of the three different crops of interest (maize, millet and groundnuts) was evaluated for the five scenarios explained previously: current farmer practices (FP), no-till (NTL), fertilization (FRT), crop residue (RSD) and the recommended management practices (RMP).

Moreover, to highlight the role of carbon payment and increased yields for alternative systems, a marginal analysis could evaluate the weight of carbon payments and increased yields in total increased revenue.

This analysis assumed four year rotations with 2 years of maize, one year of millet, and one year of groundnut, i.e. the scenario for the current farmers' practices. The output prices of

the crops were US$0.3848/kg for maize, US$0.57/kg for millet and US$0.7033 for groundnuts (value derived from the FAOSTAT database). Moreover, the carbon payment was set to US$0.042/kg of carbon sequestered (equal to a price of Certified Emission Reduction at US$11.60 ton of carbon dioxide equivalent)[1].

However, this analysis considered averages values, especially for crop yields and carbon sequestration rates under the different management practices. Thus, it did not take into account the time needed to reach expected yields changing agricultural practices, which is crucial when assessing the feasibility of conservation practices; farmers may not observe increased yields immediately after implementing a new practice.

Even if such a cost/revenue analysis gave good initial insight into the feasibility of conservation practices, further analysis must incorporate this transition period to reach maximum productivity. Moreover, deriving the adoption rates for the different scenarios would be of interest. Finally, the analysis must evaluate the practices for different prices for carbon sequestration.

### *Minimum Data model approach*

Our first analysis used a fixed price of carbon at US$0.042/kg of carbon sequestered. However, markets are dynamic, so the price of carbon varies; assessing profitability when prices vary becomes necessary. Moreover, the cost/revenue evaluation may have no influence farmers' attitudes toward adopting conservation practices. Thus, we need further analysis. Antle and Valvidia (2006) introduced a spatially explicit production model for evaluating ecosystem services. This tool is particularly useful when we do not have a complete set of spatially explicit

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[1] Where 1 ton of carbon dioxide equivalent=3.62 ton of soil carbon sequestered

and precise data that would allow conducting a precise assessment, as someone might want to do with the Tradeoff analysis software (Stoorvogel et al. 2001).

For the SANREM project, assessing the ex-ante conservation practices' adoption to brings policy a step closer to implementing a carbon payment scheme. Tools that would give an *ex-ante* assessment of farmers' reactions to conservation practices have already been discussed. The model developed by Antle and Valvidia (2006) provides results significantly close to those provided by a full-data approach (Antle and Stoorvogel 2008; Antle et al. 2010). Hence, it is a useful precise assessment tool to provide a back-of-the-envelope analysis.

For these reasons, the minimum data model fit the goal of this study. The objective of using this model is to provide an *ex-ante* assessment of the scenarios previously discussed. However, the logic of this approach must be explained before the results are given.

We will first describe the model briefly and clearly identify the data needed to run the simulation. Then, the logic used to run the model for carbon sequestration in Wa will be explained. Finally, the logic behind the model set up will explain both the assessment and the findings.

**Theoretical simulation of adoption rates and estimation of ecosystem services supply**

The starting point of the model is that farmers want to maximize their economic well-being. Thus, they make production decisions based on activities' expected returns. Thus, those who need ecosystem services must provide incentives to farmers to increase the supply of those services. In the case of carbon sequestration, demanders of ecosystem services would propose carbon contracts to farmers. Farmers would then adopt certain conservation practices to get payment for additional carbon sequestered when adopting alternative farming practices. This

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would be a win-win strategy (economic gains for farmers and environmental gains for demanders of ecosystem services).

Let consider two competing systems *a* and *b* in a particular region, with *a* being a baseline scenario and *b* being an alternative production practice that provides additional ecosystem service. Over time, farmers adopt management practices that maximize the expected discounted returns (*v*) they can get from their land use over time. *v* is a function of *p*, the output price, of *s* site index and of the kind of production system implemented (*a* or *b*). In our case study, *v* (the net present value of each management practice of interest) is derived from the costs and revenues of each simulated practices. Thus, the approach is to model the average expected returns over the relevant time period.

Furthermore, considering that each system, *a* and *b*, may comprise different activities, such as livestock, crop or fish production, we must know how what production activities are involved in each system. Therefore, we weight each activity in the system considered. In our case, land allocation is not available from data because the scenarios are simulated and not yet observed. Thus, we based our analysis of four year rotations with two years of maize (thus, maize is 50% of the rotation), one year of millet (25% of the rotation), and one year of groundnuts (25% of the rotation). This assumption may be subject to sensitivity analysis. Thus, the expected return for system *z* (either *a* or *b*) is:

(Equation 3)
$$v(p, s, z) = \sum_{i=1}^{n} w_{zi} v_i(p, s, z)$$

where $w_{zi}$ is the weight of activity *i* in system *z*, and $v_i(p,s,z)$ is the net return of activity *i* in system *z*. *p* indexes the output price, and *s* the site. With no payments to adopt an alternative

system *b*, farmers will adopt system *b* only if net returns are more than for the baseline system *a*, that is to say, if the difference in terms of net returns is negative. Hence, if:

(Equation 4) $$w(p, s) = v(p, s, a) - v(p, s, b) < 0$$

Otherwise, farmers stay in production system *a*. Now, let us assume that additional ecosystem service *e* is produced at each site *s* when *b* is used. This ecosystem service produces *e* units per hectare per time period considered. Recall that system *a* has no rewarded ecosystem service and that carbon contracts pay farmers only on ex-ante additional carbon sequestered. Thus, farmers would only get a payment for additional carbon sequestration over FP.

To derive the supply of ecosystem service produced in the area, we can define a density function $\varphi(w)$ by ordering each land unit according to the value of opportunity costs *w(p,s)*. Thus, with no carbon payment, the proportion of land units under system *b* is given by the spatial distribution of the opportunity cost, i.e., by:

$$r(p) = \int_{-\infty}^{0} \varphi(w) dw$$

(Equation 5)

If we remember that *e* is the expected amount of carbon sequestered in the region with *H* hectares of cropland, the baseline supply of ecosystem services per period is given by:

(Equation 6) $$S(p) = r(p) * H * e$$

where *H\*e* is the total amount of carbon that can be sequestered in the region. If no payment is offered to farmers, *S(p)* represents the baseline of ecosystem services that farmers would produce in the area.

Now, let consider the case where an entity would offer a payment $p_e*e$ to an ecosystem services provider (in our case, farmers that enter into carbon contracts) proportional to the additional amount of carbon sequestered $e$. If we introduce this payment into the opportunity cost calculated in Equation 4, farmers will now shift to system $b$ if

(Equation 7) $$w(p,s) - p_e * e < 0 \longleftrightarrow w(p,s)/e < p_e$$

That is to say, farmers will choose alternative system $b$ if the opportunity cost per unit of carbon sequestered is less than the price paid for carbon contracts. At that point, farmers face three possible choices:

- Case 1: farmers adopt system $b$ because is it more profitable than system $a$. That is to say $w(p,s)<0$;

- Case 2: system $b$ is more profitable than $a$ given the payment for ecosystem services $p_e$. In that case, $w(p,s)>0$ but $w(p,s)-p_e*e<0$. Farmers switch to $b$ because the payment for ecosystem service $p$ is higher than the opportunity cost per unit of ecosystem service.

- Case 3: $w(p,s)>0$ and $w(p,s)-p_e*e>0$. In this case, the payment for ecosystem service $p_e$ is less than the opportunity cost per unit of ecosystem service. Hence, farmers will remain in system $a$.

The production decisions described above can be used to derive the supply of ecosystem services and the adoption rates (cf. Figure 2-1), defining the spatial distribution of opportunity cost per unit of ecosystem service as $Ø(w/e) = \varphi(w/e)$. Thus, in case 1, the proportion of land where farmers use system $b$ without any carbon payment is given by Equation 5. The associated

baseline supply of ecosystem service is thus given by Equation 6, at the point where $p_e = w/e = 0$.

In case 2, the payment $p_e * e$ will increase the proportion of farmers switching to practice $b$. Then, Equation 4 changes and the additional proportion of land where farmers switch to system $b$ is given by

(Equation 8)
$$r(p, p_e) = \int_0^{p_e} \varphi(w) dw$$

Thus, the regional ecosystem service supply would be

(Equation 9)
$$S(p, p_e) = S(p) + r(p, p_e) * H * e$$

As the payment $p_e$ increases, the proportion of land in system b approaches 1-r(p). Finally, in case 3, the opportunity cost is higher than the payment for ecosystem services, so farmers will stay in system $a$.

Figure 2-1 shows the probability density function associated with the change in production systems. The left hand-side of the figure represents the spatial distribution of opportunity cost under the assumption of normally distributed returns. This distribution function allows us to derive the supply of ecosystem services on the right hand-side of the figure. One can note that, as the proportion of land units that switch to system $b$ approaches its maximum, the supply of carbon sequestered tends to be a vertical asymptote. This curve tends to the maximum amount of carbon that can be sequestered in the region, i.e. tends to $H*e$.

The variance of opportunity costs must be estimated to derive the shape of the supply curve. In fact, as the variance of opportunity cost increases, the supply curve rotates counterclockwise and when the variance decreases, the curve approaches a step function at the value *w/e* where the mass of the distribution lies.

**Figure 2-1 Derivation of the supply of ecosystem services from the spatial distribution of opportunity cost per unit of ecosystem services**
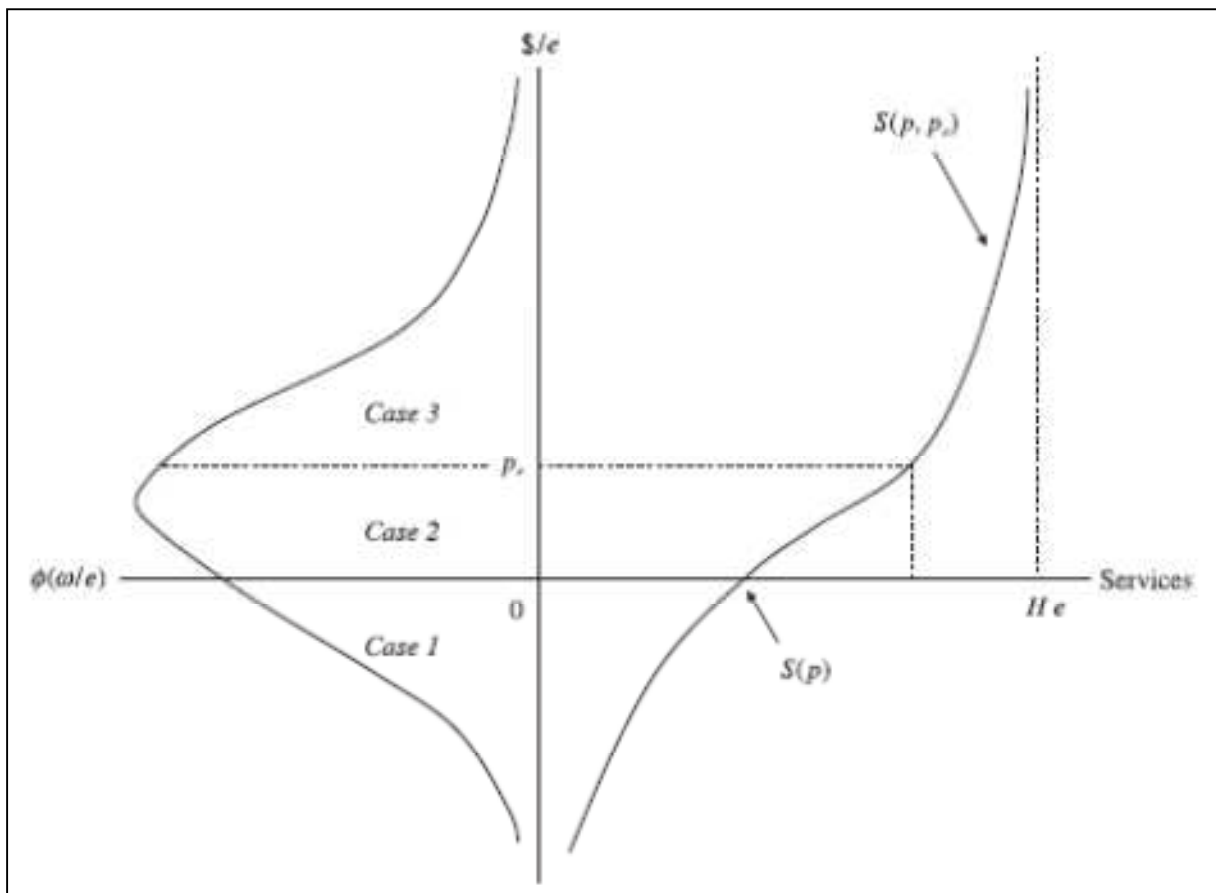


Source: Reproduced from Antle and Valvidia (2006)

Assuming that switching from one production system to another may change production net returns, the opportunity costs can also include the cost of capital needed to change from

practice *a* to *b* (*F*). This cost may include the cost of machinery to perform some special task required by a production system. Moreover, transaction costs *TC*, which could include participation in a government program for ecosystem services, can also be integrated into the model to stimulate the participation of farmers in the program. In such a situation, farmers would join carbon contracts when

(Equation 10) $$v(p, s, b) + p_e * e - F - TC > v(p, s, a)$$

Moreover, the time needed to reach maximum productivity must also be taken into account. Antle and Valvidia (2009) added a feature to the model allowing growth in production productivity over time. For instance, implementing no-till practices may decrease yields at first but may increase them over a longer time. Thus, a planning horizon where productivity reaches its maximum must be set. This transition item is designed to be exponential. It is modeled as follows:

(Equation 11) $$\gamma_{2it} = \frac{1 - \exp(-G_{2i} * t)}{1 - \exp(-G_{2i} * T1)}, with\ 0 < \gamma_{2it} \leq 1$$

where $G_{2i}$ is the transition rate for activity *i* from system *a* to system *b*, *T1* is the horizon where productivity reaches its maximum, and *t* a year of analysis in the planning horizon. This gamma factor is then integrated into the output yield and then into the net returns calculation.

### Minimum-data model parameters definition

To be consistent with the cost and revenue analysis, the same production costs, output prices, and base value of carbon payments have been entered into the model (assuming a four year rotation with 2 years of maize, one year of millet, and one year of groundnuts). Our logic when using the model differs somewhat from the usual analysis. While other analyses estimate a

single possible alternative system within a few agricultural zones, we evaluated several different systems within the same region. Thus, the current farmer practices FP characteristics provided the parameters for the baseline scenario of the model. Then, four different regions were created, each simulating a situation where an entity would propose that farmers enter carbon contracts and thus implement precise management practices. The first region simulates the adoption rate if carbon contracts were based on the NTL scenario. The second simulates FRT, the third assesses RSD, and the fourth evaluates RMP.

Furthermore, as previously explained, we used the minimum data model to allow the carbon payment to vary and thus allow us to derive the associated adoption curve. Hence, the opportunity cost analysis was conducted using different sets of carbon prices. Here, the model allowed the base value of US\$42.10/ton to change from 0% to 200% of its value (i.e., up to US\$84.20). Furthermore, the depreciation rate for present value calculations was set to 12%, as in Gonzalez-Estrada et al. (2008) study in Wa.

In the section describing the model, we saw that farmers' decisions are based on the spatial distribution of the difference in expected net returns. The variance of this difference between net returns in *a* and *b* is given by

(Equation 12) $$\sigma^2_{a-b} = \sigma^2_a + \sigma^2_b - 2\sigma_{ab}$$

Whereas yields data can be used to estimate the variances of each system with coefficient of variation, the covariance between activities sometimes can be calculated from the available data. Thus one can set the variance of activities *a* and *b* equal to each other, which would be a correct approximation, because each activity relies on the same crops under different

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management techniques. In this case, the expected variance of opportunity costs can be estimated by

(Equation 13) $$\sigma^2_{a-b} \approx 2\sigma^2(1 - \rho_{ab})$$

where $\rho$ is the correlation between returns from system $a$ and activity $b$, and $\sigma^2$ is the variance of system $a$ or $b$. When the $\rho$ value approaches 1, the variance of the difference tends to zero. In the case of conservation practices that aim at a higher carbon sequestration than traditional practices, the correlation is likely to be high (Antle and Valvidia 2006; Uri, 2000). In our case, the alternative systems have not yet been observed but they have been simulated. Moreover, alternative systems $b$ were modified from baseline current farmer practices (FP). The closer the alternative system is to the baseline, the closer the correlation will be to 1. However, the less similar the system, the closer the correlation is to zero. Consequently, this parameter was set at 0.75, a value admitted as a likely possibility. Some sensitivity analysis changing this value would be useful.

Similarly, a correlation parameter within-system provides information about the correlation between the returns of two activities within a system (e.g., between maize and millet production under no-till). In our case, this correlation between activities (or within systems) is set to 0.30. According to Antle (2011), these correlations are usually small, and sensitivity analysis does not cause any significant changes in the results. Thus, he recommends setting up relatively small values, when they cannot be estimated.

Besides the data allowing the net present values calculation, a few other parameters must be set up to fit the logic of this assessment. To evaluate the net returns of management practices including a carbon payment, we must set up a base price for the ecosystem service for Equation

6. In our case, this price is the average price for carbon sequestered to reward farmers for using different management practices. Moreover, as previously explained, such ecosystem service programs can generate project based carbon credits. Under the Kyoto protocol, the Clean Development Mechanism allows sellers in developing countries to commercialize Certified Emission Reduction. According to Linacre, Kossoy and Ambrosi (2011), 8€ or US$11.50 (on 08/30/2011) would be a plausible price for a Certified Emission Reduction. That amount stands for a ton of carbon dioxide equivalent, which equals US$42.10 per ton of carbon sequestered.

**Minimum data application**

The method detailed by Antle and Valvidia (2006) relies on secondary data to create parameters for the spatial distribution of net returns of systems and to derive land allocation decisions using the theoretical framework previously explained. The model design allows comparing mean expected returns of each region for each activity of interest.

To evaluate the expected value for each competing system *v* in Equation 1, data must allow net returns to be calculated. In our case, data were gathered from both secondary sources and from a recent precise survey in Wa.

Furthermore, as outlined by Antle and Valvidia (2006), we also need spatial variability of these expected returns. When variability of net returns is not available, the coefficients of variation CV of net returns can be estimated by the coefficient of variation of yields (Antle and Capalbo 2001). Thus the CVs have been calculated as follows:

(Equation 14) $$CV \ of \ net \ returns = CV \ of \ yields = \frac{\sigma}{m}$$

where *m* is the mean yield and $\sigma$ is the standard deviation of the yields. The results are in Table 2-3. However Antle and Valvidia (2006) add that when estimating yields instead of using

actual yields, simulated variances and variances from aggregated data underestimate observed field-level yield variability by a factor of 1.5 to 3. Hence, as a rule of thumb, he recommends increasing estimates of variability by a factor of two when using such simulated or aggregated data.

**Table 2-3 Coefficient of variation for crops under different management practices[1,2]**

|  | Management system | CV | Adjusted CV (=2*CV) |
|---|---|---|---|
| Continuous maize | FP | 50.01 | 100.02 |
|  | NTL | 43.33 | 86.65 |
|  | FRT | 23.17 | 46.34 |
|  | RSD | 36.11 | 72.22 |
|  | RMP | 24.08 | 48.16 |
| Continuous millet | FP | 46.53 | 93.06 |
|  | NTL | 35.85 | 71.70 |
|  | FRT | 29.09 | 58.19 |
|  | RSD | 31.28 | 62.56 |
|  | RMP | 27.29 | 54.57 |
| Continuous groundnut | FP | 48.75 | 97.50 |
|  | NTL | 49.39 | 98.77 |
|  | FRT | 48.75 | 97.50 |
|  | RSD | 49.19 | 98.38 |
|  | RMP | 49.39 | 98.77 |

[1] Where FP is current farmer practice; NTL is the no-till scenario; FRT is the fertilization scenario; RSD is the residue scenario, and RMP is the recommended management practices according to Lal (2004).

[2] Author calculations from Koo (2007) simulations data

**Software interface**

The TOA MD software has been released in both SAS and Excel. This thesis used the Excel interface. The model uses nine template spreadsheets for setting parameters, coefficient of variation, costs, productivity growth rates, yields, etc. Using these information, the software creates templates to run the simulation and produces figures for both aggregated and non-aggregated results. The user imports data to the templates and can run simulations and derive the

adoption rates. The logic of the model and its approach are in Figure 2-2 (Antle and Valvidia 2009).

Once we had an estimate of mean and variance of the difference in expected returns between *a* and *b*, the model parameterizes the distribution of opportunity cost and uses Equation 5 for the baseline case (or Equation 8 if there is a carbon payment) to estimate the proportion of land units in system *b*, i.e., the participation of farmers in system *b*. The model then uses Equation 6 for the baseline case (or Equation 9 if there is a carbon payment) in order to derive the supply curve given the proportion of land units, the production of ecosystem services, and the total area of the region. This assumes normally distributed returns, knowing that the difference between these two normally distributed random variables is itself normal.

The model does this once for the baseline case FP (with no payment for carbon sequestration) and perform the same analysis for each level of carbon price, for each management practice. Hence, it derives the adoption rates and the ecosystem supply curves for each management practice.

**Figure 2-2 Logic of the Tradeoff Analysis Minimum-Data software**
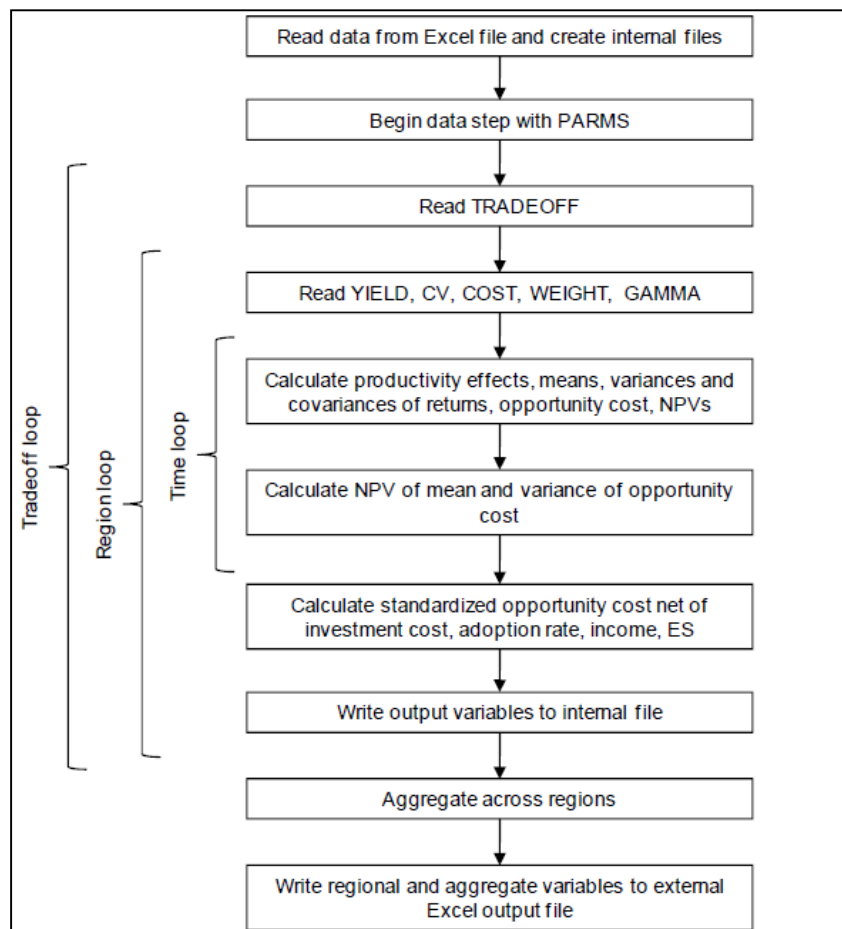


Source: Reproduced from Antle and Valvidia (2009)

# Chapter 3 - Results

## Chapter organization

As a first indicator a cost and revenue analysis was performed, giving the anticipated benefits of each management practice vis-à-vis the baseline. Thanks to these first calculations, we can use the tradeoff analysis minimum data software to derive the adoption rates for each practice. Thus, we could compare the profitability from the cost and revenue analysis to the one from the minimum data approach. A first set of simulations were run from a static standpoint, i.e., without including productivity growth rates. When we included the productivity transition, the analysis yields dynamic adoption rate curves. Finally, other simulations were conducted to evaluate the robustness of the approach to different parameters.

## Costs and revenues analysis

The following table displays the costs and revenue analysis for each simulated management practice, for the three crops of interest, assuming a 4 year rotation with two years of maize, one year of millet, and one year of groundnuts. We assumed prices for maize of US$0.38/kg, millet of US$0.57/kg, and groundnuts of US$0.70/kg. A price of 0.042 US$ per kg of carbon sequestered was used. The area surveyed in 2011 was 1186.68 ha. The analysis did not include any fixed costs. The results are in Table 3-1.

**Table 3-1 Cost and revenue analysis by crops for each simulated scenario** [1]

| Data in kg/ha and US$/ha | FP | NTL | FRT | RSD | RMP |
|---|---|---|---|---|---|
| Crop yields | | | | | |
| Maize | 1320.50 | 1327.55 | 3664.65 | 1438.00 | 3691.35 |
| Millet | 643.75 | 766.15 | 1027.30 | 840.80 | 1192.25 |
| Groundnuts | 1373.30 | 1382.20 | 1373.30 | 1393.65 | 1382.20 |
| Carbon (delta) | 0.00 | 152.00 | 18.00 | 67.00 | 224.00 |
| **Total Revenue w/o carbon pmt** | 587.26 | 607.62 | 1092.93 | 641.52 | 1123.14 |
| **Total Revenue w carbon pmt** | 587.26 | 614.01 | 1093.69 | 644.34 | 1132.54 |
| **Carbon revenue** | 0.00 | 6.38 | 0.76 | 2.81 | 9.41 |
| **Revenues from yields improvements** | | 20.36 | 505.67 | 54.26 | 535.88 |
| Total variable cost per crop | | | | | |
| Maize | 115.01 | 109.00 | 166.54 | 127.01 | 160.53 |
| Millet | 122.25 | 114.65 | 163.01 | 134.25 | 155.41 |
| Groundnuts | 101.98 | 98.83 | 131.98 | 113.98 | 128.83 |
| **Total variable Cost** | 113.56 | 107.87 | 157.02 | 125.56 | 151.32 |
| **Total cost** | 113.56 | 107.87 | 157.02 | 125.56 | 151.32 |
| **Net benefits** | 473.70 | 506.14 | 936.67 | 518.77 | 981.22 |
| **Part of carbon revenue in net benefits** | 0.00% | 1.26% | 0.08% | 0.54% | 0.96% |
| **Part of yield increasing in net benefits** | | 4.02% | 53.99% | 10.46% | 54.61% |

[1] Where FP is current farmer practice; NTL is the no-till scenario; FRT is the fertilization scenario; RSD is the residue scenario, and RMP is the recommended management practices according to Lal (2004).

Revenue reveals the expected yields for the switch to an alternative scenario. Remember that these simulations were performed for a 20 year period and that the expected yields would probably not be immediately observed after implementing the practices. Scenarios based on fertilizer use (i.e., FRT and RMP) led to the highest increase in yields compared to current farmer practices. On the other hand, both NTL and RSD exhibit higher expected yields than baseline practices.

Now, we can look at the simulated values for carbon sequestration and at the additional income from the carbon payment. Carbon revenue ranged from US$0.76/ha/yr with the FRT scenario up to more than US$9.41/ha/yr for the RMP scenario. This is consistent with previous

estimates of US$1 to US$15/ha/yr (Zivin and Lipper 2008). Tennigkeit et al. (2009) in Kenya estimates values ranging from US$1.15 for an alternative scenario with no external inputs to USS$8.65/ha/yr when using improved seeds and fertilizers (and to US$27.40 for agroforestry management). Furthermore, these additional revenues are less than additional revenues due to yield improvements. This revenue ranged from an additional US$20.36/ha/yr for the RSD scenario to US$535.88/ha/yr to the RMP scenario. We also found that whereas the FRT option yields the second most revenue, what comes from the carbon payment is small. A closer look highlights that the FRT scenario increases yields significantly but relatively little carbon sequestration.

Considering the costs associated with each simulated management practice, total benefits ranged from US$473.70/ha/yr for current farmer practices up to US$981.22/ha/yr for RMP.

In these simulations, the carbon payment as part of total benefits is small. It ranges from 0.08% for FRT up to 1.26% for NTL. Yields increase in net benefits from 4.02% for NTL to 53.99% for the RMP scenario.

To look at the marginal costs and revenues under different simulated scenarios, a costs and revenue analysis was conducted. The results are displayed in Appendix A. They showed that improvements in total revenue for the simulated practices range from an additional US$20.36/ha/yr for no-till (NTL) to an additional US$545.29/ha/yr for the recommended management practices (RMP).

Including the marginal costs for each management practice increases net revenues from an additional US$25.79/ha/yr for RSD to US$526.81 for RMP. NTL would bring additional revenues of US$32.44/ha/yr, and FRT would add US$462.93/ha/yr.

These findings agree with other studies (Tennigkeit et al. 2009) in Kenya that show a net loss of US$10 with no external input (equivalent to NTL) to a net increase of US$309/ha/yr with improved seeds and fertilizer.

Even compared to similar studies, the values lack a dynamic perspective. A more detailed analysis would take into account the transition period to reach maximum productivity with alternative practices. Moreover, the analysis did not estimate farmers' opportunity costs to switch to alternative practices. Finally, the analysis did not show changes in the price of carbon contracts.

## Simulation of carbon contracts with the minimum data software

To assess the four different scenario studied, we simulated four different regions of 1186.68 ha each. This corresponds to the area surveyed most recently in 2010.

The goal of the following analysis was to assess the adoption rate in the region if carbon contracts relied on these four management practices. Thus, we assumed that in region 1, farmers implement NTL, that in region 2, they implement FRT, that in region 3, they implement RSD, and that in region 4, they implement RMP. This analysis allowed us to compare the profitability of the simulated scenarios.

### *Static analysis*

#### *Adoption rate estimation*

The first analysis was a static analysis, not taking into account the productivity transition feature of the model, for the four management practices. Thus, we calculated farmers' opportunity costs to adopt the scenarios with different values of carbon payment. The participation rates were derived according to Equation 8 comparing each management practice

with the current farmer practices associating a density function. Management practices adoption

curves were compiled on a single graph. The results of this first analysis are displayed below.

**Figure 3-1 Adoption rate estimate in static analysis**
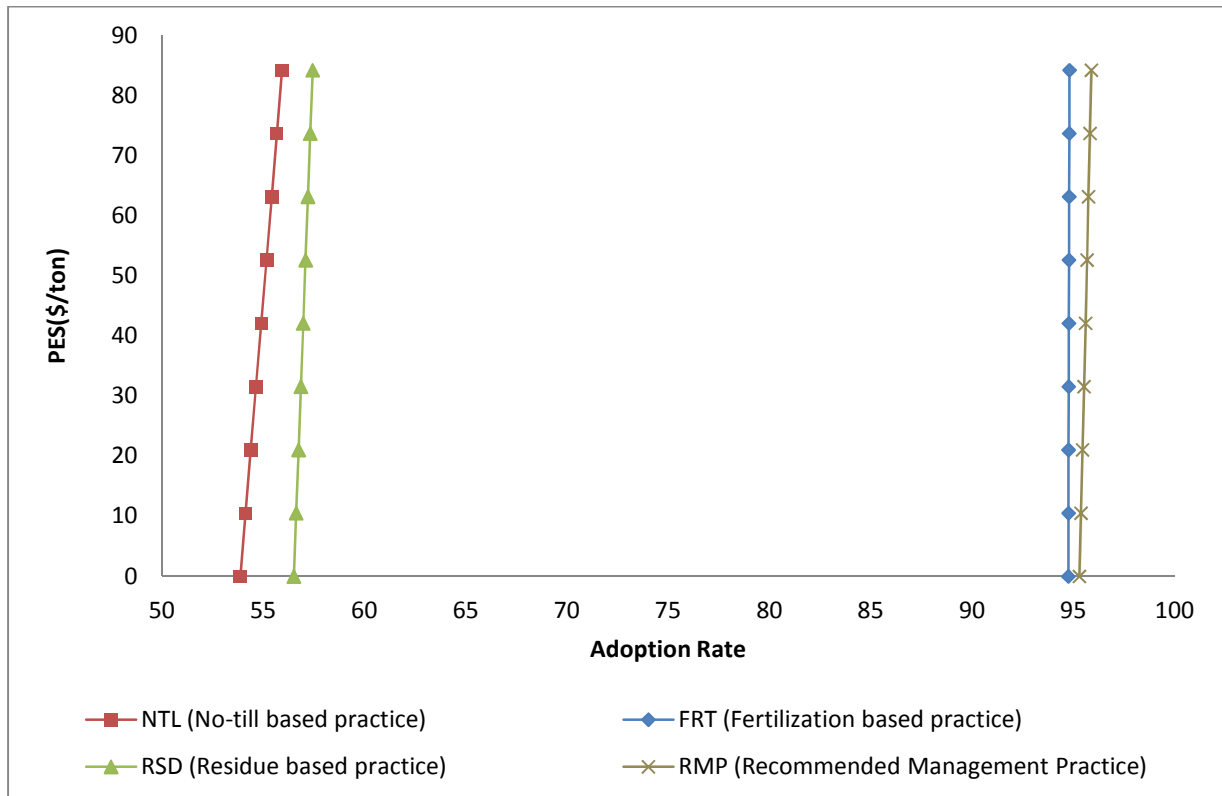


Figure 3-1 shows farmers' participation in carbon contracts with the four different

management practices. Implementing carbon contracts would be linked to the need for farmers to

comply with one or another of the management practices described in the methodology section.

These might include using fertilizer, ending the practice of hand-hoeing or removing crop

residue. With current practices, farmers rarely use fertilizers, and they do hand-hoe their fields.

In comparing carbon contract adoption rates, we can clearly see two groups of practices

with similar results. In fact, NTL and RSD showed a participation rate of approximately 55%.

On the other hand, practices FRT and RMP show participation rates over 95%, even when no

carbon payments were made, i.e. when $p_e$=0. That means that the opportunity costs for these four

practices were all negative and that the alternative practices had higher returns than the current practices.

Moreover, this difference between FRT and NTL may be interpreted as follows. FRT and RMP systems are based on fertilization. In current practices FP, fertilizer use among farmers equals zero. Management practices based on fertilizer (both FRT and RMP) use led to a large increase in yields in the DSSAT/Century model output. Thus, farmers have more revenue because of higher yields, which would make them more willing to enter carbon contracts to gain access to fertilizer because they know this input will improve crop production and their revenue.

Furthermore, simulated curves were not sensitive to different levels of carbon prices, especially for the FRT and RMP scenarios, which mean that the carbon payment $p$ would not be sufficient to push farmers to adopt alternative practices. This result is consistent with the costs and revenue analyses where carbon revenues represent only a small part of additional net revenues. However, revenues due to an increase in yields would be higher. The proportion of carbon payments in total additional benefits was especially small for FRT and RMP practices. For NTL and RSD scenarios, the numbers were slightly higher. That explains the relative higher elasticity of NTL and RSD curves compared to the FRT and RMP curves.

Concerning NTL and RSD, improved yields and carbon sequestration rates might not be enough to convince farmers to switch to them. However, these practices are relatively cheap to implement. The main additional cost would probably be the learning costs. Thus, in terms of both labor and associated costs, they provide a gain for farmers, as shown in the previous costs/revenues analysis. Moreover, even though NTL and RSD adoption rates are much lower than RMP and FRT, the curves obtained demonstrate that more than half of surveyed farmers would willingly shift to these practices.

These observations highlight the important role of fertilizer use for farmers. In fact, the analysis showed that most farmers would be willing to enter into carbon contracts to gain access to fertilizers. To conclude, the simulated adoption rates are high, with the lowest predicting that more than 50% of farmers would switch to no-till.

Why do farmers not currently use these practices when they appear to provide higher returns than their current practices? While a variety of constraints, such as lack of fertilizer or cash, could explain this, recall that the static analysis does not include a dynamic perspective. That is to say, a static analysis does not take into account the period necessary to reach maximum productivity. Adoption curves may exhibit different trends when the same analysis includes a maximum productivity transition period. We did do this type of analysis, and the results are included later in this thesis.

### *Change in ecosystem service*

The minimum data software can explore the impact of different levels of payments on the production per ecosystem service, i.e., on the carbon sequestration rate into soils per hectare. The software used Equation 9 to derive the ecosystem supply of carbon sequestrated and repeated the analysis with different prices for carbon. The results obtained are in Figure 3-2.

**Figure 3-2 Change in ecosystem service in static analysis**
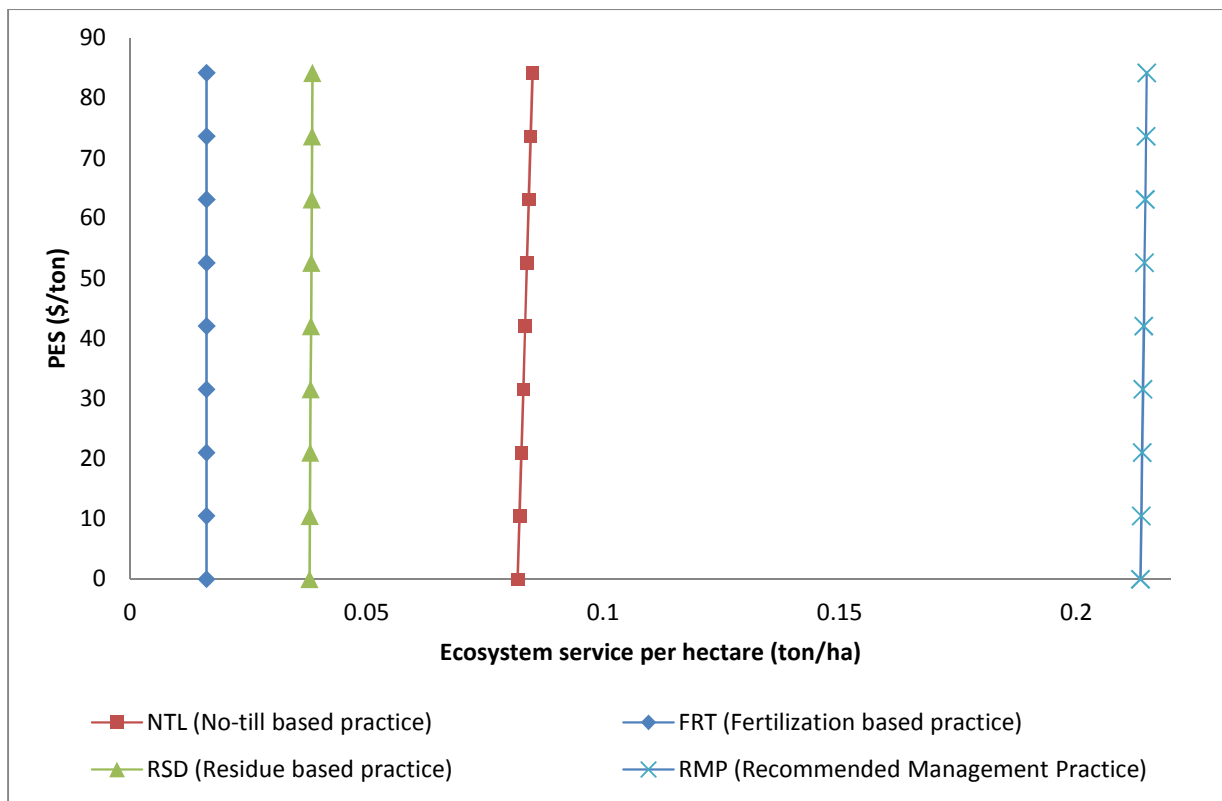


RMP sequesters more carbon per hectare than the other 3 practices, and recommended

management should be more efficient agronomically (Lal 2004). If carbon contracts are

introduced in Wa, RMP would be the most effective for sequestering carbon in soil. The

simulation also showed that the curves derived from these changes are very inelastic and did not

change as carbon prices increase, a direct consequence of the inelasticity of adoption rates noted

in the previous section. Whether the price increases or decreases, farmers would change their

production decisions slightly as they choose to enter carbon contracts. Thus, relatively the same

inelastic amount of carbon would be sequestered per hectare.

Adoption rates in Figure 3-1can be compared in light of the information in Figure 3-2.

Whereas the participation rates simulated for FRT should be very high, its ecosystem service

remained relatively low, sequestering less than 0.05 tons of carbon per hectare, whatever the price of carbon was. Moreover, no-till was second in ecosystem services per hectare but came last in adoption rate. These observations are consistent with the DSSAT/Century model data on carbon sequestration. This shows that scenarios that sequester the most carbon do not necessarily exhibit the highest adoption rate.

### *Change in income per hectare*

The minimum data model used for the analysis calculates the net return for each scenario. It can also analyze the impact of different level of payments for ecosystem services on changes in income per hectare. The results displayed in Figure 3-3 show the additional income provided when switching from current practices to another management practice.

**Figure 3-3 Change in income per hectare in static analysis**
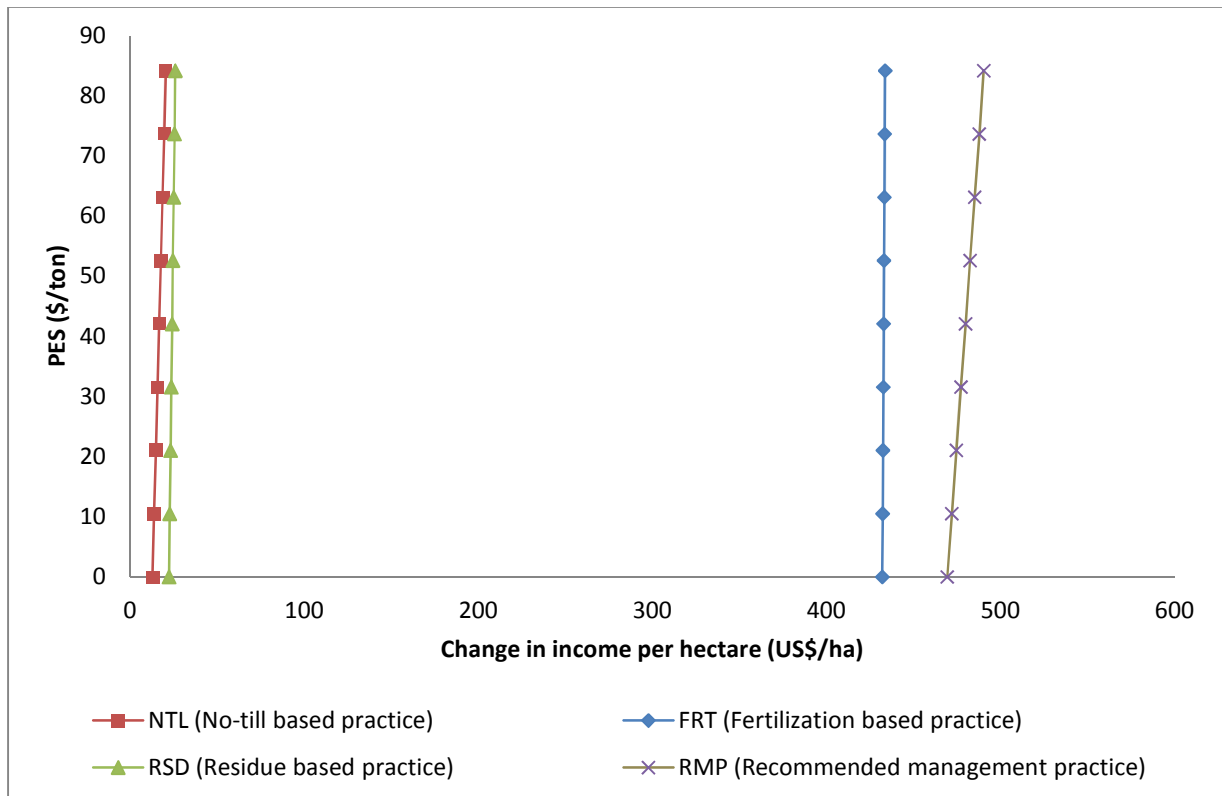
This change allows us to groups the four practices into two. The first one includes NTL and RSD. The second comprises FRT and RMP.

The main feature of this graph is that every scenario provides additional income to farmers over their current practices. That means the simulated practices are more profitable. The two groups (FRT and RMP as opposed to RSD and NTL) showed a large gap in income. This could be explained either by an increase in carbon sequestration (and thus in carbon payment) or an increase in yields (and thus in additional revenues).

When we look at these curves, they appear to be inelastic vis-à-vis the carbon price PES. That is to say, when carbon payments increase, total income did not increase much. Thus, the carbon payment had relatively little effect on income per hectare. This feature is confirmed in the first cost and revenue analysis that showed how little carbon payment affected net benefits. Hence, differences in income change may be mostly due to the increase yields and the subsequent increase in revenue.

In fact, the increase in yields is substantial when switching to fertilization practices (FRT and RMP), but yield increases for other simulated practices management practice are not so high. We observed in Table 3-2 that maize production under current practices yields 1320.5kg/ha. This yield increases slightly to 1327.55kg/ha under no-till and still more, to 3691.35kg/ha, when implementing RMP. Hence, income grows much more under RMP. This is consistent with our findings from costs and revenue calculations.

### *Static analysis summary*

This first analysis gave an idea about the potential of each management practice to increase income and to sequester carbon in soil, as well as the likelihood that new practices will be adopted by farmers. Both FRT and RMP would lead to a substantial increase in income per

hectare. However, only RMP produced significant ecosystem services, whereas FRT led to the

least carbon sequestration. Thanks to the yields increasing, however, these two scenarios should

see a high adoption rate (more than 95%). On the other hand, the other two scenarios (RSD and

NTL) showed less increase in income per hectare than RMP and FRT do. However, they seem to

sequester more carbon in soil. Both the simulated increase in yields and the ecosystem services

production should lead to adoption rates of more than 50%, confirming that these conservation

practices provide positive opportunity costs to farmers who switch from their current practices to

one of these scenarios.

The above analyses are static, i.e., considering that simulated yields would be obtained

directly when switching from FP to an alternative system. Although this analysis confirmed the

findings of the costs/ revenues analyses, the results were not realistic. We had to consider the

productivity transition period necessary to reach a maximum productivity.

## *Productivity transition period*

### *Use of the maximum productivity transition feature of the minimum data model*

An analysis to integrate changes in productivity over time would show, particularly for

conservation practices, increases in yields which cannot be expected immediately when

switching agronomic practices. Using a planning horizon *T1* over which maximum productivity

is attained, the model can integrate this transition period into the assessment (see Equation 11).

Our analysis assumed that maximum productivity was reached after ten years. This period lies

within a feasible range given the results reported in the literature. Lal (2004) considers 5 to 20

years as a reasonable period. In our case, Excel calculated yields equations to estimate

logarithmic growth rates. Recall that the model assumes productivity follows an exponential

trend with a logarithmic form transition path. Yields data have been taken from the

DSSAT/Century model output. These values, along with the associated $R^2$ are in Table 3-2.

**Table 3-2 Logarithmic growth rates and associated $R^2$ from DSSAT/Century simulated yields[1]**

|  | Management system | Logarithmic growth rate | Associated $R^2$ |
|---|---|---|---|
| Continuous maize | FP | -0.089 | 0.536 |
|  | NTL | -0.078 | 0.486 |
|  | FRT | 0.021 | 0.078 |
|  | RSD | -0.059 | 0.409 |
|  | RMP | 0.022 | 0.083 |
| Continuous millet | FP | -0.042 | 0.533 |
|  | NTL | -0.023 | 0.205 |
|  | FRT | -0.03 | 0.392 |
|  | RSD | 0.000 | 0.000 |
|  | RMP | -0.068 | 0.621 |
| Continuous groundnut | FP | 0.077 | 0.294 |
|  | NTL | 0.077 | 0.296 |
|  | FRT | 0.077 | 0.287 |
|  | RSD | 0.077 | 0.294 |
|  | RMP | 0.077 | 0.296 |

[1] Where FP is current farmer practice; NTL is the no-till scenario; FRT is the fertilization scenario; RSD is the residue scenario, and RMP is the recommended management practices according to Lal (2004).

Most $R^2$ values were insignificant, with two third of the values below 0.50, which may mean that the exponential form was not a good fit for yields and returns evolution through time, given the simulated management practices and the assumptions made when simulating yields with the DSSAT/Century models.

To have a better idea about the growth rate for each crop and its significance, each management practice was projected with growth rate and associated $R^2$ in Figure 3-4. Thus, the

higher on the vertical axis, the closer the exponential growth estimate. Moreover, as points move toward the right side of the graph, the productivity growth increases.

**Figure 3-4 Logarithmic growth rate in yield and associated R² for each crop and management practice of interest**
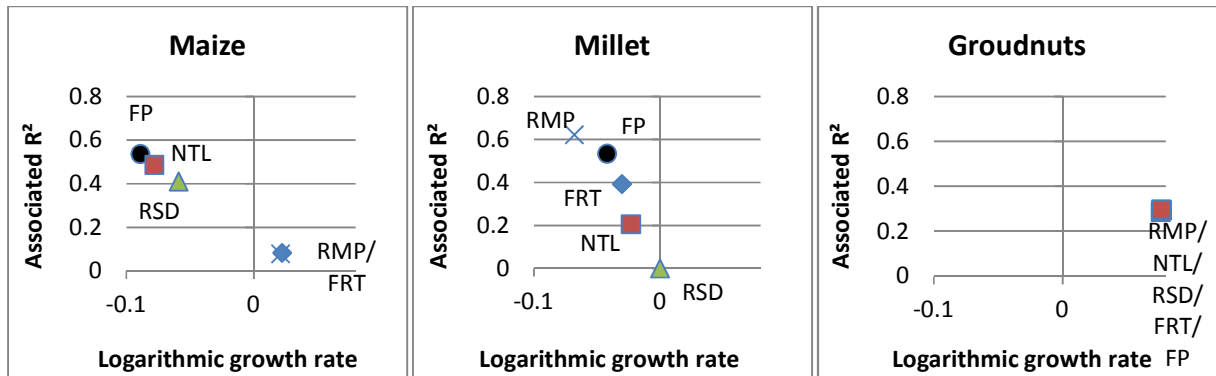


The maize graph shows logarithmic estimations are a reasonably accurate trend for NTL, RSD, and FP. These three scenarios exhibit a negative growth rate. RMP and FRT scenarios have a positive growth rate. However, their R² is very low.

The graph for millet shows negative logarithmic growth rates for each scenario. Only RMP and FP have an R² above 0.50. The graph for groundnut yields shows a positive logarithmic growth rate with an R² significance of approximately 0.30.

These graphs provide a snapshot of the significance of different crop logarithmic growth rates for each management practice. The global trend is that the growth rate tends to be negative for millet and maize with a relatively high R²; the growth rate is positive for some practices (FRT and RMP for maize) but with low significance. This logarithmic growth rate is positive for groundnuts, but it has a relatively low R².

If we look at yield trends over 10 years, this makes sense. Figure 3-5 displays the trend in yields for each of the five practices and for each crop. These curves do not seem to follow exponential trends, with the evolution appearing to be more linear than exponential. That

probably explains the negative values we found for the growth rate and the insignificant associated R².

**Figure 3-5 Trend of yields simulated for the three crops, over 10 years**
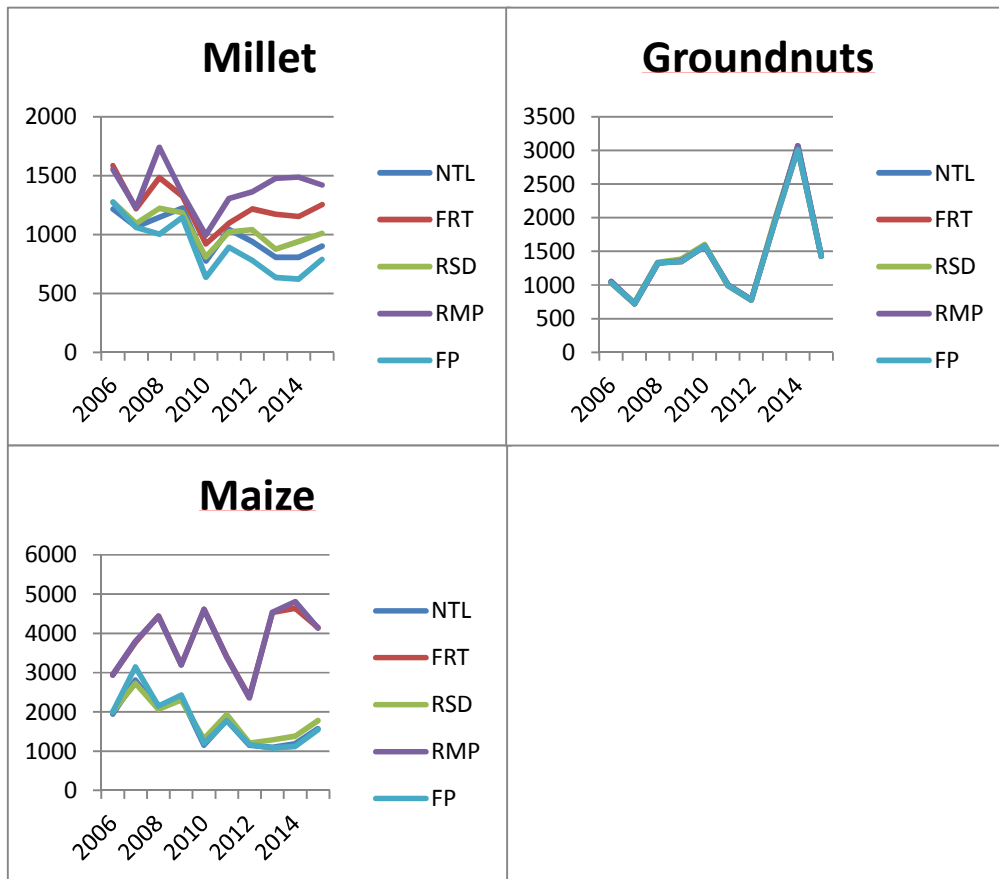


*Adoption rate estimation*

If we plug in the productivity growth rate, as calculated in the previous section, we have a dynamic analysis of opportunity costs and can derive the associated participation rate curves. The discount rate for net present values calculation has been set to 12%.

**Figure 3-6 Adoption rate estimation in dynamic analysis**
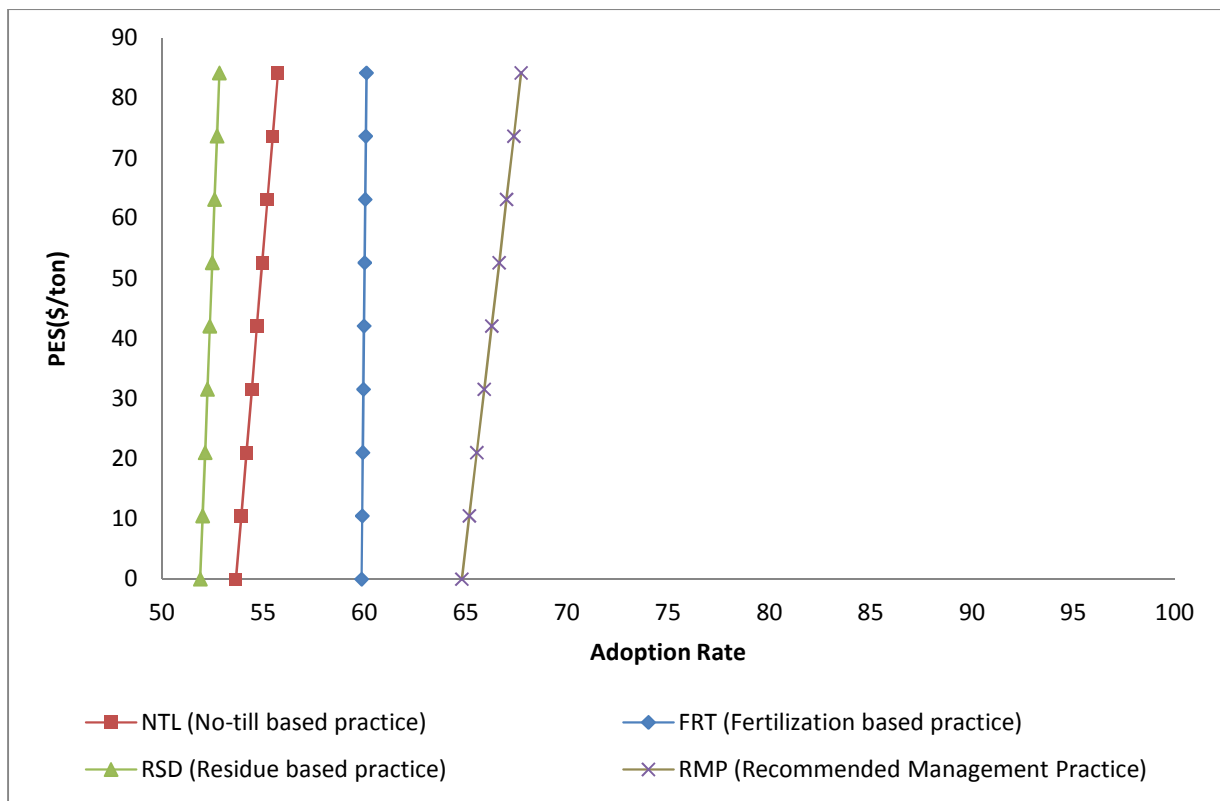


Comparing both the static and the dynamic outputs, it appeared that adoption rates were lower when the time necessary to reach maximum productivity was taken into account, which made sense because we no longer assumed that expected yields would be observed immediately when switching to alternative system.

Two groups of management practices occurred in terms of adoption: the ones based on fertilizer application (FRT and RMP) that lead to the highest simulated adoption rate and ones not based on fertilizer use (RSD and FRT). Both FRT and RMP adoption rates decreased by about 35% once the productivity effect included. On the other hand, RSD simulated adoption rate decreased by about 5%. Finally, the NTL scenario did not change significantly.

This drop in adopting fertilization based practices might be caused by the period necessary for fertilizer to have its highest effect on yields. The static model could not capture

that period, and so led to much higher simulated adoption rates. However, FRT and RMP still showed the highest participation rates.

Moreover, these curves were slightly more elastic than the earlier ones, which may mean that, when we include the productivity transition period, carbon revenue represents a bigger part of the net benefits than in the static analysis. Over time, then, adoption rate were more and more linked with carbon price variation. This finding makes perfect sense because carbon sequestration is supposed to increase over the long term.

Furthermore, fertilizer becomes even more important when estimating carbon contracts, as does having accurate yield simulations. Although the carbon payment represents less of the increase in revenue when switching to alternatives practices, actual yield must be close to simulated yield to achieve these adoption rates.

### *Change in income per hectare*

In addition, we wanted to examine the evolution of changes in income per hectare in the dynamic analysis (see Figure 3-7).

**Figure 3-7 Change in income per hectare in dynamic analysis**
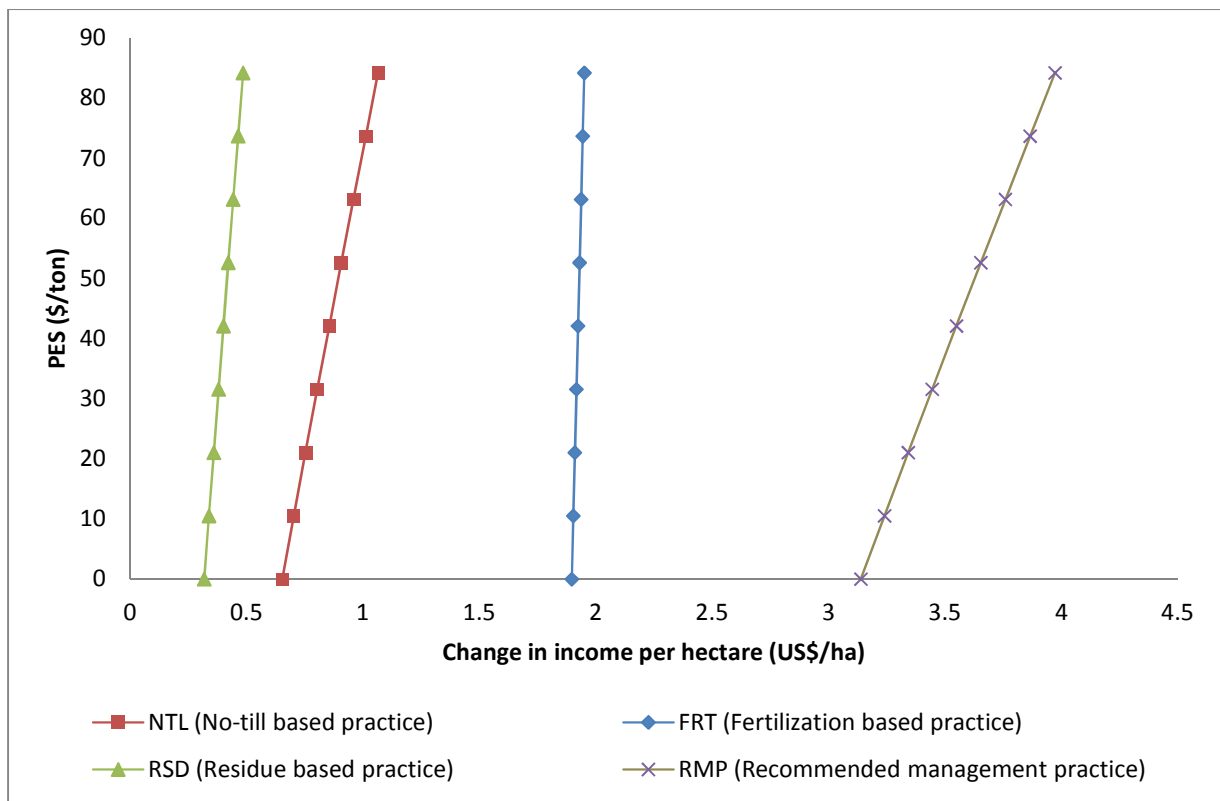


In Figure 3-7, we included the productivity transition period in the model, and the curves became more elastic. That is to say, the higher the payment per unit of carbon sequestered, the higher the change in income per hectare. Whereas the static analysis reflected the importance of yield to additional income, these curves showed that, over time, carbon revenues contributed proportionately more to increases in income because of the relative elasticity of the adoption rate curves. In fact, the changes in income with increasing price per unit of carbon sequestered means more farmers would be willing to adopt alternative production systems if carbon prices increase.

Moreover, while the FRT practice produced the least ecosystem service, due to the increase in yields, this practice was second only to RMP in changes in income per hectare. Thus, even if this practice does not sequester a significant amount of carbon, the increase in yields provided more income per hectare, which may explain the high adoption rate observed in the

dynamic analysis (FRT is the second highest in terms of simulated participation in carbon contracts).

Finally, while the static analysis showed more change to income per hectare for RMP and FRT, these changes were much smaller when we integrate the transition productivity period. This validated the hypothesis that the gap observed in the static analysis was due to the time needed to reach maximum productivity. However, the viability of these results was probably affected by the non-exponential trend of yields and the relatively low $R^2$.

*Change in ecosystem service provided*

Going a step further, the environmental impact of such a dynamic analysis should examine the change in ecosystem services per hectare when integrating this productivity transition period into the analysis (cf. Figure 3-8).

**Figure 3-8 Change in ecosystem service per hectare in dynamic analysis**
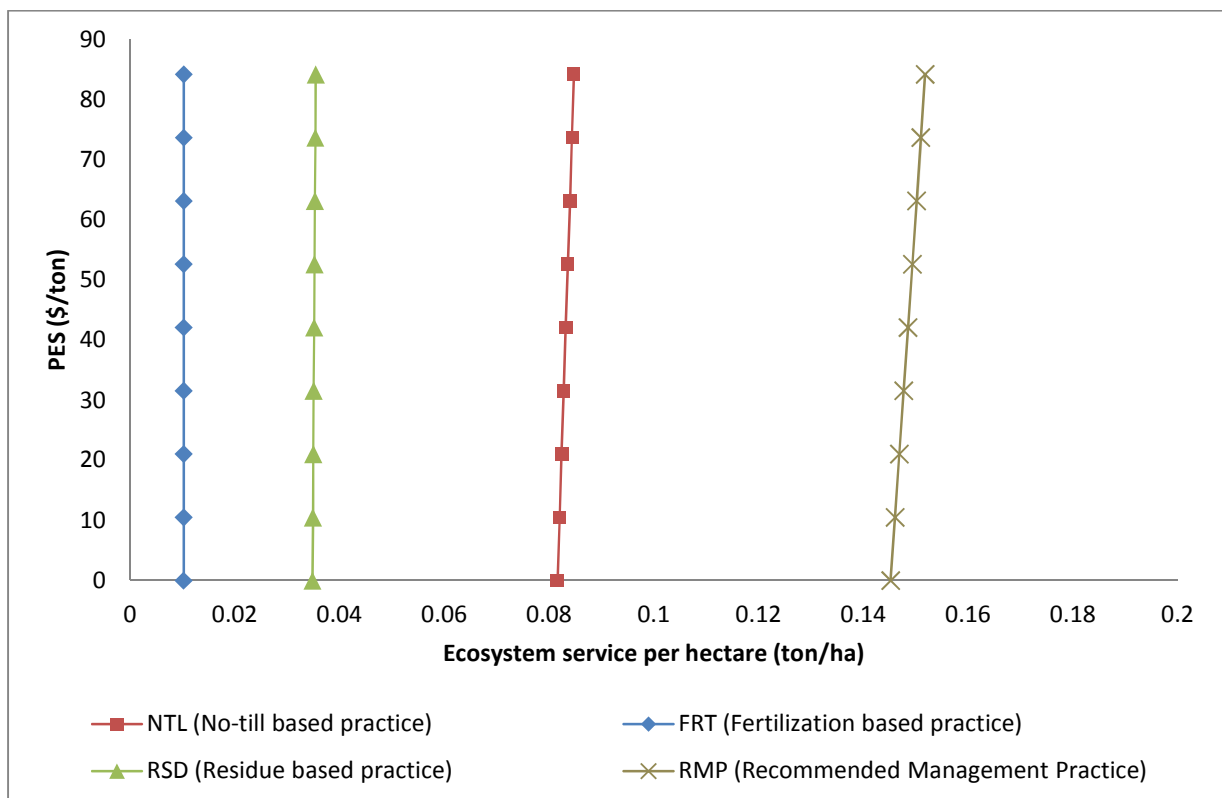
If we look at the differences in carbon sequestration per hectare, the RMP scenario again leads among the different practices, with about 0.14 ton sequestered per hectare without any payment, a lower number than the one in the static analysis. This emphasizes that carbon sequestration is not immediate; it is a process that occurs over time.

Furthermore, we can see a slight increase in elasticity, especially for RMP. This may mean that, over time, and with increasing prices of carbon, soil carbon sequestration may increase and as income increases when the payment increases, farmers should choose an alternative practice. This would lead to increased total carbon sequestered per hectare.

### Dynamic analysis summary

When we included a transition period to reach a maximum yield, simulated participation decreases, and income per hectare increased less. These findings reflected a long term characteristic of both switching to a different production system, and sequestering soil carbon. When comparing the different scenarios, RMP appeared more likely to be adopted, thanks to its high change in income per hectare. It also produced the most ecosystem services (carbon sequestered) per hectare.

However, the no-till scenario yielded relatively high ecosystem service and an elastic change in income per hectare. This scenario should be adopted by more than 50% of farmers. The RSD scenario and FRT produce the least ecosystem services. However, thanks to an associated increase in yields, the fertilization practice yielded a relative high change in income per hectare, and an adoption rate of about 60% without carbon payment. Finally, RSD should attract more than half of farmers to switch to this system.

This additional analysis provided more insight into a long term perspective on carbon payment and increasing yields. However, the simulations were based on a four year rotations

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with 2 years of maize, one year of millet, and one year of groundnuts. Even if this allocation reflects the current allocation of land, different crop rotations may provide different participation rates.

## Sensitivity analysis with different crop rotations

The analysis was first launched assuming a four year rotation with two years of maize, one year of millet, and one year of groundnuts. That is to say, weights of crops were set at 50%, 25%, and 25% for maize, millet, and groundnuts. However, if we relax this assumption and test different rotations, we may find another crop rotation would lead to a higher adoption rate.

### *Cropping system based on maize*

In the basic analysis, using current farmer practices, we previously assumed a four year rotation for the different management practices. However, the alternative practices are not yet implemented, so simulating different crop land allocations might be useful. Using sensitivity analysis, we may find the optimal land allocation leading to a higher participation rate in carbon contracts.

We explored the possibility of a three year rotation based on two years of maize and one year of groundnuts and millet. Then, we assumed a continuous maize system in the region. As shown in Figure 3-9, the aggregated value for carbon sequestration would be the following:

- for the shorter rotation: NTL would sequester 144kh/ha/yr; FRT would sequester 24.8kg/ha/yr; RSD 59kg/ha/yr; and RMP 218kg/ha/yr.

- for continuous maize: NTL would sequester 136kh/ha/yr; FRT 31.8kg/ha/yr; RSD 52.7kg/ha/yr; and RMP 212.8kg/ha/yr.

Finally, the adoption rate goes from 15 to 75%.

**Figure 3-9 Adoption rate with different weights for maize production**
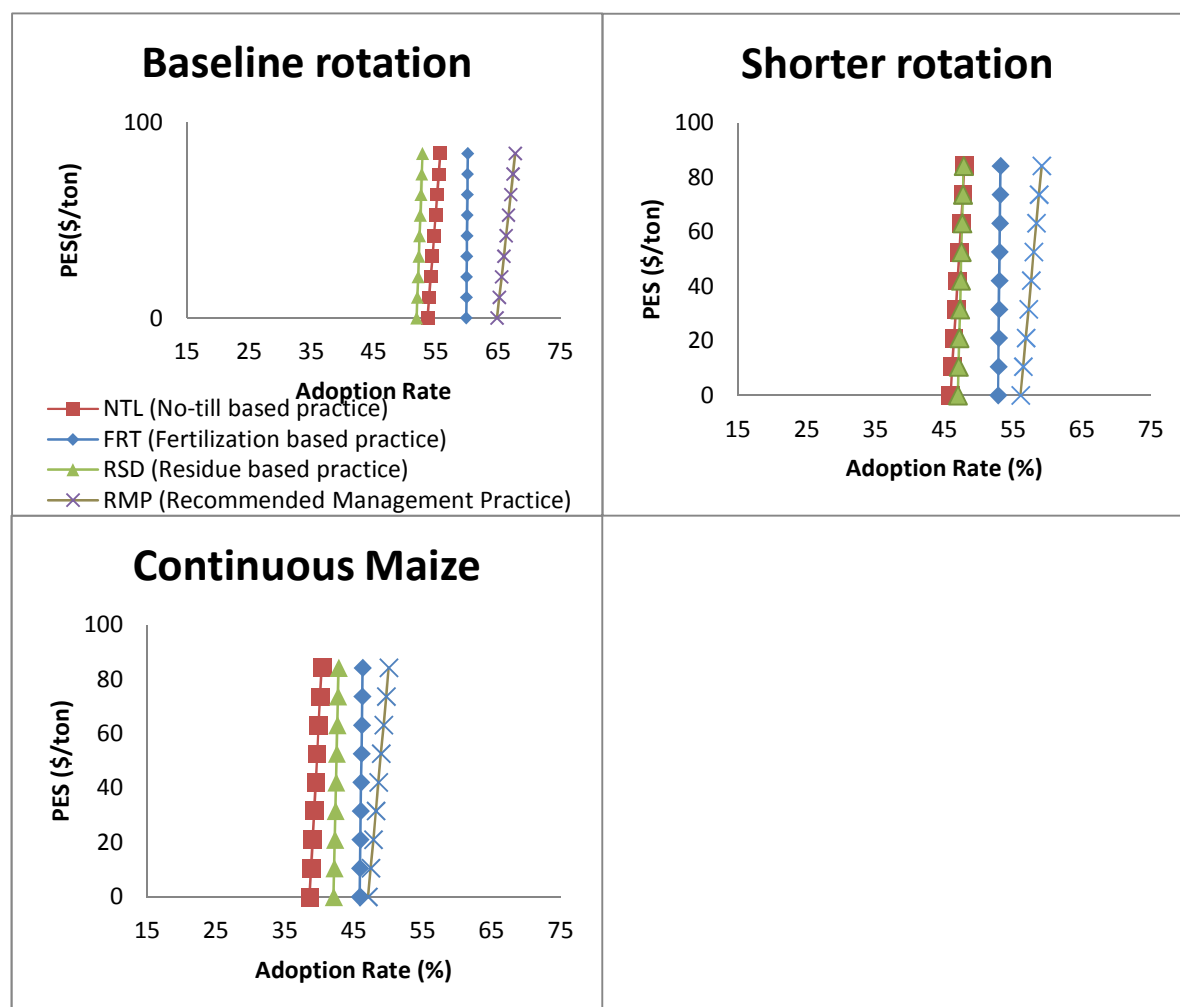


In Figure 3-9, we see the recommended management practices based on a four year rotation still should lead to the highest adoption rate at 65%. This rate increases to 70% with a PES at 80US$/ton. Then, the FRT baseline rotation provides a 60% adoption rate. Third, with an adoption rate of 55% with no payment, is based on an RMP scenario with a shorter rotation.

As more maize is added to the rotations, the simulated participation rate becomes smaller, indicating the opportunity cost of switching from current FP to an alternative system decreases

when the proportion of maize increases. Diversification of production systems appeared to be more profitable for farmers.

### *Cropping system based on millet*

A similar approach simulated an increase of millet acreage. We explored the possibility of intensive millet production, assuming a four year rotation with two years of millet and two years of maize and millet. We then assumed a three year millet rotation with one year in maize and groundnuts. Finally, we experimented with continuous millet. In each case (see Figure 3-10), the aggregated value for carbon sequestration would be the following:

- For the rotation of 2 years of millet followed by maize and millet: NTL would sequester 166kh/ha/yr; FRT 11.6kg/ha/yr; RSD 80.5kg/ha/yr; and RMP 251kg/ha/yr.

- For the three years of millet followed by maize and groundnuts: NTL would sequester 178kh/ha/yr; FRT 9.42kg/ha/yr; RSD 93kg/ha/yr; and RMP 286kg/ha/yr.

- Finally, for continuous millet: NTL would sequester 190kh/ha/yr; FRT 7kg/ha/yr; RSD 105kg/ha/yr; and RMP 322kg/ha/yr.

Finally, please note that the adoption rate scale goes from 15 to 75%.

**Figure 3-10 Adoption rate with different weights for millet production**
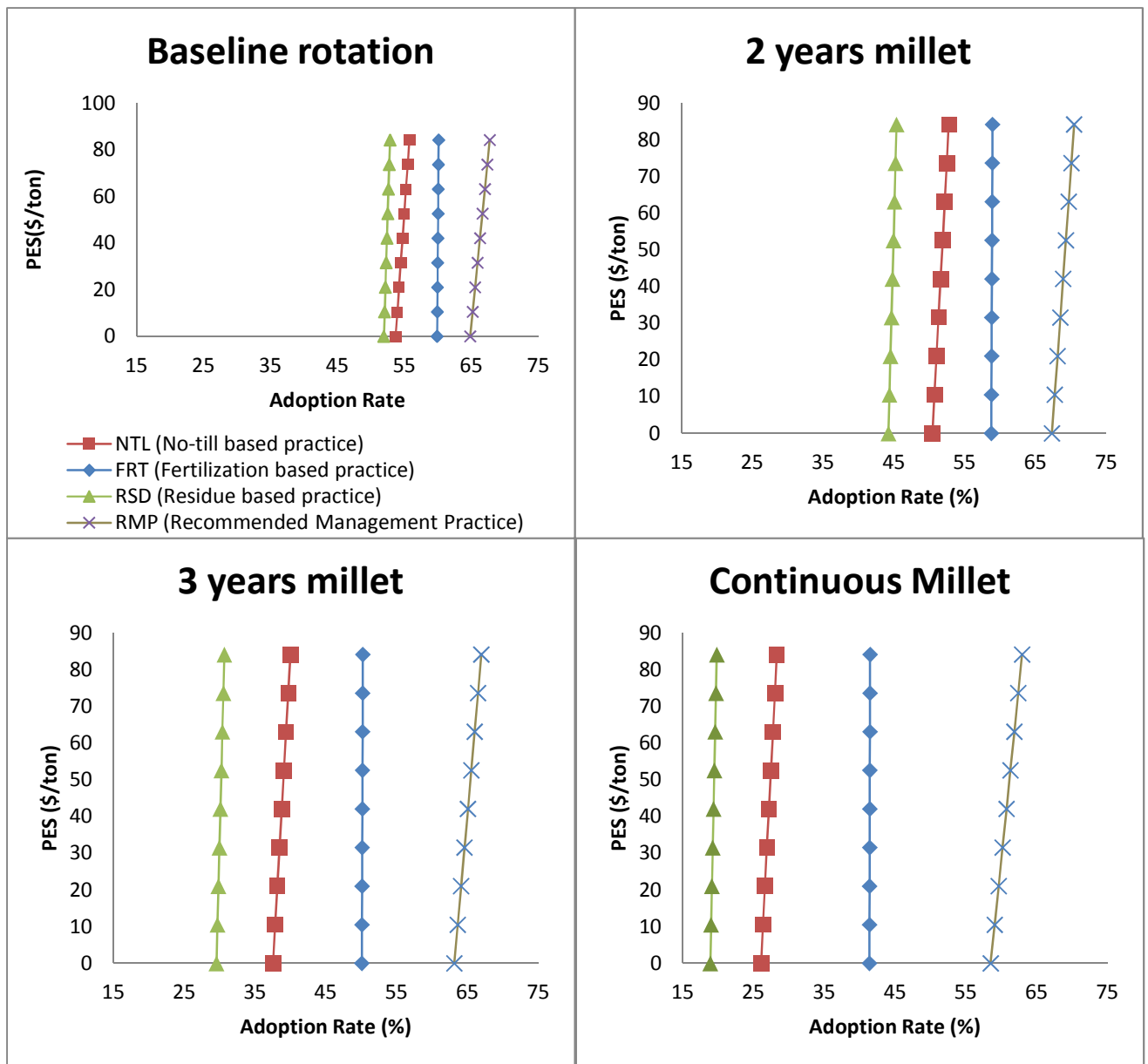


In the curves obtained for this simulation, we can see that scenarios using RMP for one year, two years, and three years of millet would lead to the highest adoption rate, approximately 65% with no carbon payment and up to 70% with a carbon payment at US$80 per ton of carbon. FRT in the baseline rotation is second. Finally, FRT based on 2 years of millet shows a simulated

adoption higher than 55% without any carbon payment. The two others scenarios (RSD and NTL) showed the highest simulated adoption rate with millet in the baseline rotation.

Moreover, as for the maize analysis, the more millet in the rotation, the lower the predicted participation rate. Again, diversification of production systems seemed to work better for farmers.

### *Cropping system based on groundnuts*

A similar approach considered an increase in groundnuts in the crop rotation. We explored the possibility of increasing groundnuts in the rotation, assuming that groundnuts are grown for two years in a four year rotation scheme and that farmers would grow maize and millet the other two years. Then we explored a three year groundnut rotation and continuous groundnut (see Figure 3-11). In each case, the aggregated value for carbon sequestration would be the following:

- For the 2 year case: NTL would sequester 155kh/ha/yr; FRT 9kg/ha/yr; RSD 69kg/ha/yr; and RMP 207kg/ha/yr.

- For the 3 year case: NTL would sequester 151kh/ha/yr; FRT 4.9kg/ha/yr; RSD 64kg/ha/yr; and RMP 176kg/ha/yr.

- Finally, for continuous groundnuts: NTL would sequester 146kh/ha/yr; FRT 0kg/ha/yr; RSD 59kg/ha/yr; and RMP 146kg/ha/yr.

Finally, please notice that the adoption rate scale goes from 15 to 75%.

**Figure 3-11 Adoption rate with a groundnut based production system**
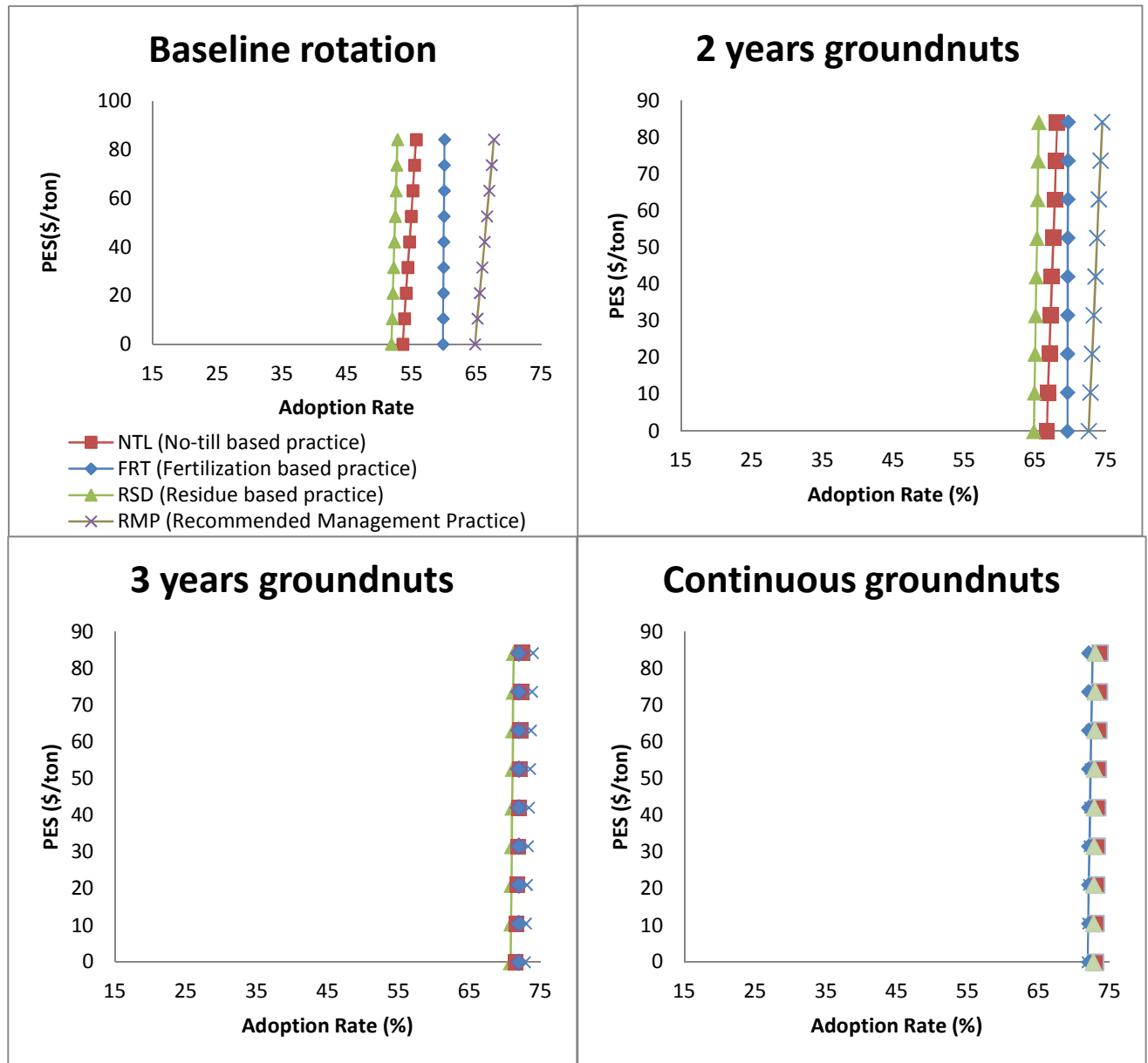


In these cases, the adoption rate lied between 65 and 75%, representing the highest estimated adoption rate in these sensitivity analyses. Compared to the baseline rotation, an increasing proportion of groundnuts in the crop rotation seemed to correlate with an increase in participation rate, even when considering NTL and RSD management practices. This was very

different from the two other cases using maize and millet possibly because of high prices for groundnuts compared to maize and millet.

### *Main findings when varying rotations*

When analyzing these trends, we could conclude that farmers and those needing ecosystem services should design carbon contracts based on increasing the proportion of groundnuts. However, our analysis highlighted the relatively low impact of carbon payment on the benefits of switching to alternative systems. Moreover, the differences in simulated participation may be linked to the higher prices for groundnuts than other crops. Third, when estimating the variance of net returns, we used the variance of yields as a proxy. A closer look at Table 2-3 reveals that groundnut production has a relatively high coefficient of variations for every management practice simulated. Moreover, simulated yields for groundnuts production did not change much from one management practice to another (cf. Table 3-1) and the growth rates had a weak $R^2$.

Finally, this study assumed that carbon contract participation rates do not face any transaction or fixed costs. Because some of these practices rely on using inputs and on special machinery and because there might be additional learning costs, this assumption is probably not true. In the next section, we test the robustness of the model with different levels of additional costs.

## Sensitivity analysis with additional costs

Adoption costs may mount considerably when simulating carbon contracts participation rates. In fact, setting up carbon contracts will assume an entity to monitor compliance. With the assumptions for concerning use of inputs for every scenario, verifying farmer compliance with

the adopted system is also essential. Failing to implement a low-cost monitoring system may lead to defaults on carbon contracts (Antle and Stoorvogel 2008).

However, adoption costs, especially in ex-ante situations, are difficult to evaluate. We submitted the initial simulation to sensitivity analysis with different transaction costs. The first assumed relatively low transaction costs, about US$2 per hectare (a 2% increase in costs for the NTL scenario) while the second simulated higher transaction costs of US$10 per hectare (a 10% increase in costs for the NTL scenario). Antle and Stoorvogel (2008) considered this range as possible values in Senegal. Our results are displayed in Figure 3-12. The adoption rate scale varies from 50 to 100%.

**Figure 3-12 Adoption rate sensitivity analysis with different level of transaction costs**
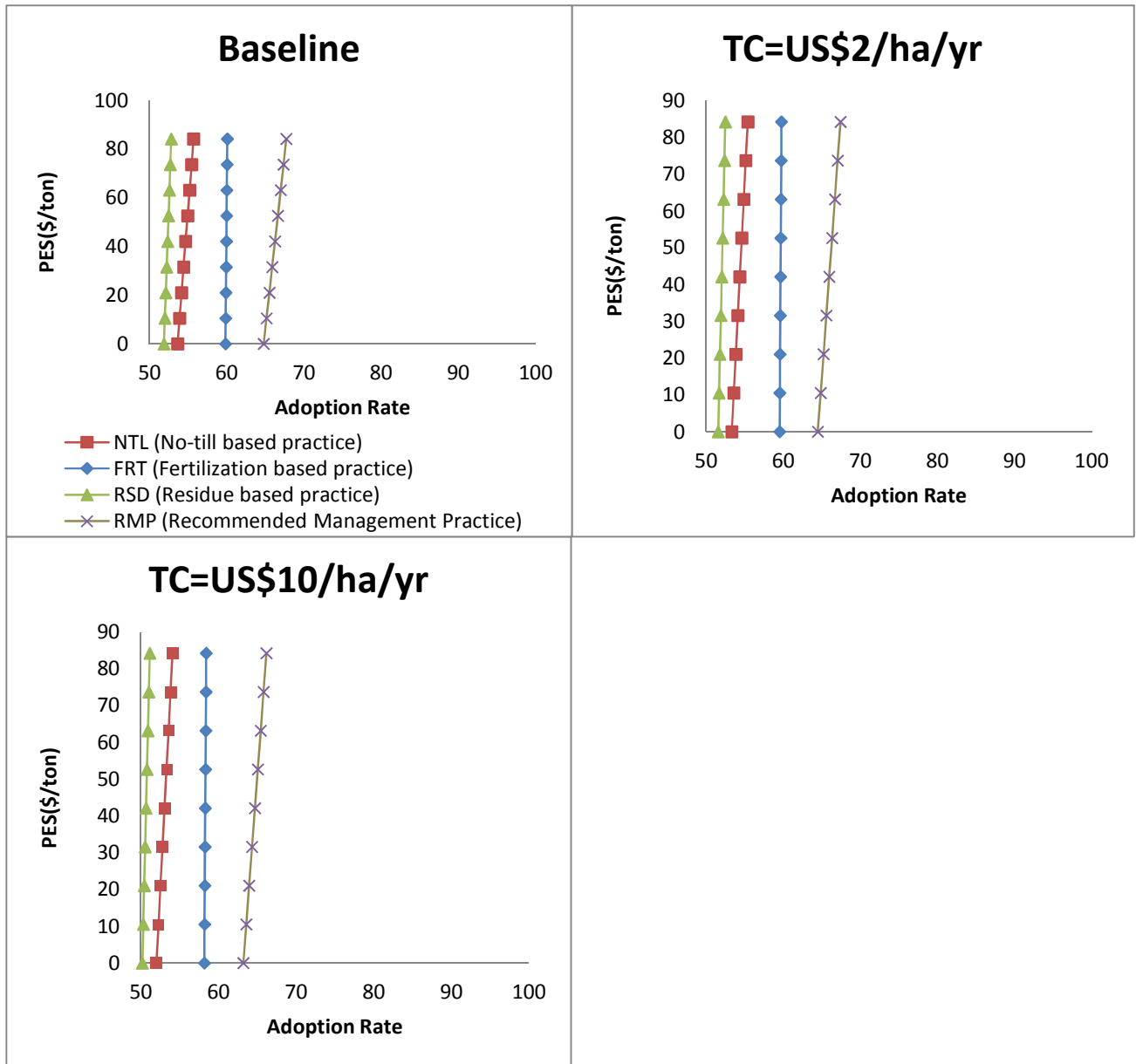


The impact of transaction costs for the four management practices was quite low. When

we introduced a transaction cost of US$2/ha, the participation rate decreased slightly. Moreover,

even when we tested a US$10/ha transaction cost, the simulated adoption rates decreased less than 5% for the management practices.

The fertilization based scenarios (FRT/RMP) differed slightly, exhibiting a small decrease in adoption rates over the two other scenarios (RSD and NTL). Fertilization based practices may be profitable enough to offset the negative impact of transaction costs. Moreover, even additional costs are higher for RSD and NTL, those practices seem to be profitable enough for 50% of farmers to participate in carbon contracts. For those four conservation agriculture production systems, the simulated yields and carbon sequestration amounts seems to be high enough to offset transaction costs, even if those costs are substantial.

## Sensitivity analysis with between system correlation coefficients

The correlation between returns in activities within system $a$ and system $b$ was set to 0.3, and the correlation between returns $\rho$ in systems $a$ and $b$ was set to 0.75 in Equation 13. Here, we found a correlation between returns in system $a$ and system $b$ of 0.6, 0.85, and 0.95. The adoption rate scale goes from 50 to 100%. These results are shown in Figure 3-13.

**Figure 3-13 Sensitivity analysis with different value of between system correlation**
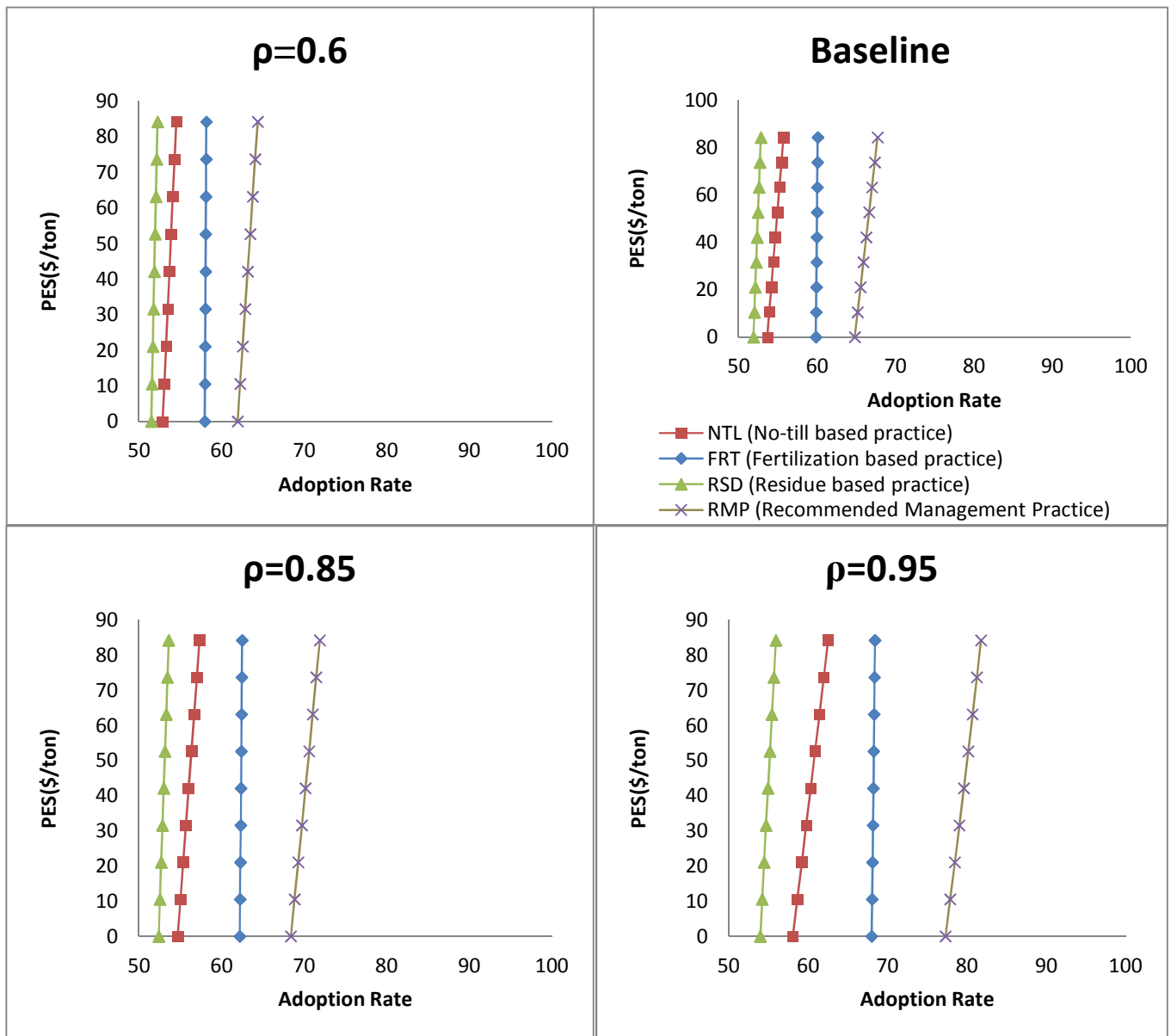


As the correlation between returns in systems increases, the simulated adoption rate increases as well. RMP saw the biggest increase: 15% when $\rho=0.95$ compared to the baseline where $\rho=0.75$. Moreover, adoption rate for the fertilization based scenario increased by 10% when $\rho=0.95$ compared to the baseline. The higher the correlation of returns between the systems, the higher the estimated adoption rates.

This assumption makes perfect sense. When farmers are asked to switch to a system that would provide returns very close to what they already have, they are willing to enter carbon contracts. That is to say, if the returns of the alternative system correlate closely to current practices, farmers are more likely to switch. The bigger difference observed for FRT and RMP proves farmers are willing to enter these types of contracts to access fertilizers.

## Sensitivity analysis with within system correlation coefficients

As explained previously, the correlation between returns in activities within system $a$ and system $b$ was set to 0.3. Here, we sought a correlation within returns $\emptyset$ in system $a$ and system $b$ of 0.1, 0.5, and 0.9. The adoption rate scale goes from 50 to 100%. These results are shown in Figure 3-14.

**Figure 3-14 Sensitivity analysis with different values of correlation within activities Ø**
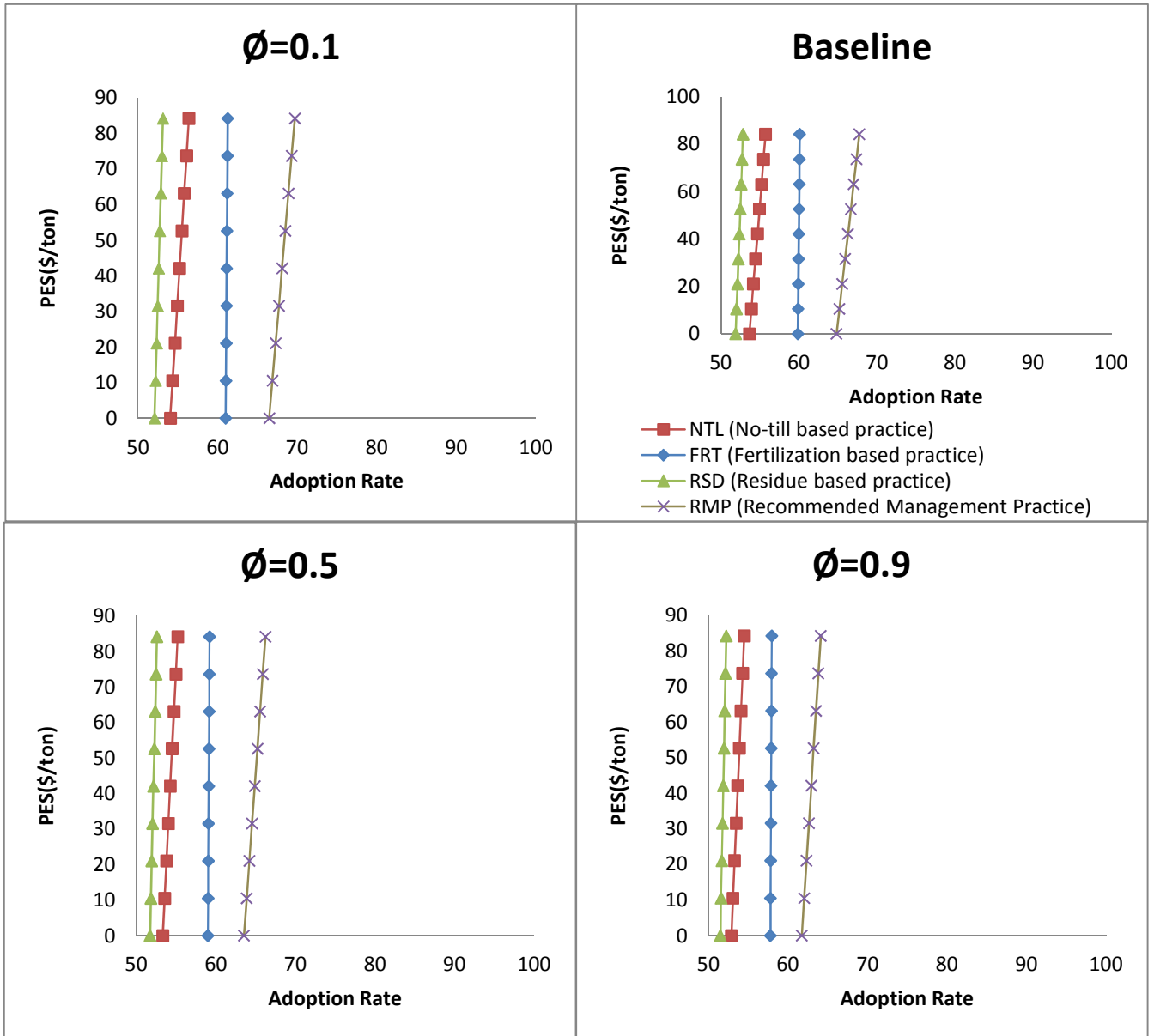
When returns within activities decreased, we did not observe any substantial evolution in adoption rates. On the other hand, when we increased the correlation between activities, we did see a slight decrease in simulated participation rates.

Considering that either increasing or decreasing this within system correlation did not cause any significant change on adoption rate, farmers seem willing to enter carbon contracts, without regard for the activities correlation. Further research may want to focus on crop diversification strategies.

# Chapter 4 - Recommendations and perspective

## Case study findings

This study evaluated the economics of carbon sequestration within Wa, Ghana. It used model processing data from both secondary sources and from a recent survey and assessed the economic feasibility of conservation systems including a payment for carbon sequestration. It derived how many farmers would participate in carbon contracts from opportunity costs calculations. We compared different crop rotations under conservation practices. The analysis showed high adoption rates. These scenarios appeared to be profitable enough for farmers to call for a change in production systems, highlighting the potential for conservation agriculture practices.

The expected increase in revenues was mainly due to improved yields. The proportion of carbon payment to total benefit appeared to be small, even if carbon prices reached substantial levels. High adoption rates were not affected by additional costs, either fixed or adjustment costs. Another simulation showed the economic potential of increasing the proportion of groundnuts in crop rotations.

Why do farmers not currently implement these practices? One possible hypothesis is that they face barriers in implementing scenario practices, such as using fertilizers of switching to no-till. Costs may also dissuade farmers from buying fertilizers, even if they are subsidized by the government. No-till practices require additional fixed costs that keep farmers from adopting no-till. In particular, no-till requires farmers to learn how to farm effectively with new equipment and how to reorganize their production systems. Hence, learning costs may place no-till practices

out of range of farmers in Wa. Last, farmers view new cropping systems as inherently risky. This may explain the current low adoption of conservation practices.

## Policy implications

Carbon payments do not represent a strong enough incentive for farmers to change their farming practices. In fact, the simulated scenarios showed higher returns mainly because of the consequent increase in yields. Policies should focus more on incentives to develop conservation practices, not payments for carbon sequestration. Nevertheless, carbon payments may represent an additional economic incentive for farmers to adopt conservation agriculture production systems. If carbon payments partly cover additional costs linked with the switch in practices, farmers may be more likely to adopt new practices.

Thus, carbon contracts may need to provide inputs that would decrease the relative costs that farmers face when switching to conservation systems. Fertilizer, herbicides, pesticides or improved seeds could be provided free to farmers to reduce this cost barrier. Considering the changing climate paradigm, providing drought tolerant seeds would be an additional incentive for farmers to switch to conservation practices, reducing the barriers they face.

The scenarios that are relatively easy to implement would not depend on fertilizers; NTL and RSD would fall into that category. Moreover, recent work shows that Ghana lacks appropriate machinery to implement no-till practices. Small-scale farmers need adapted tools at affordable prices according to Boahen et al. (2007). To develop such machinery, policies should focus on creating affordable no-till planters and other basic agricultural tools, as it has been done in other developing countries like Pakistan, India, and Brazil (Ekboir 2001).

# Limitations of the study

The results of this study rely on fertilizer prices subsidized by government. However, fertilizer costs and availability are long-term issues in Africa, the market for such inputs being very marginal.

This case study is based on ex-ante estimation of production costs and revenues. The analysis relies on sometimes estimated information and on an ex-ante situation. For example, we assessed no-till management practices considering a labor savings of 20%. The accuracy of the data is important when estimating ex-ante the economic profitability of carbon sequestration. Costs such as conservation practices learning costs (through workshops or training sessions), information costs within farm communities, or property rights issues are difficult to estimate ex-ante. Institutional costs must also be considered to implement and monitor a carbon contract system. The real level of net returns, of opportunity costs, and the derived adoption rates probably differ from the ex-ante values reported in this study.

Behavioral factors also influence farmers' willingness to switch management practices. Risk and uncertainty increase the perceived costs of making the change, and play a substantial role in adopting technology (Sunding and Zilberman 2001). Fuglie and Kascak (2001) show that in the US, geographic location and other factors affect farmers' willingness to adopt no-till practices. Consequently, the overall effect of both risk and adjustment costs vis-à-vis the baseline scenarios can be either positive or negative depending on the tradeoff range between those two factors.

A technical limitation of the present case study might be uncertainties linked to the ex-ante simulations from the DSSAT/Century models. Yields and soil organic carbon sequestration amounts have been simulated in the top 20 cm of the soil. That implies that carbon contracts

would reward farmers based on the evolution of the Soil Organic Carbon at that precise depth. The literature does not provide any information about the depth that would be considered for such contracts. Moreover, these assessed amounts may not match the actual amounts that would be observed if practices were implemented.

## Perspective

Further research should analyze more complex cropping systems, including rotations with other crops. Opportunity costs and adaptation rates could be derived with these production systems. Other types of rotations may lead to a higher carbon sequestration rate, so the carbon payment may increase revenue more.

To further validate the minimum-data approach, a more precise analysis could be conducted suing on-site specific data. Field data on yields and carbon sequestration for the different scenarios would allow the two different approaches to be compared and may highlight the accuracy of a minimum-data approach, as has been done in Antle et al. (2010).

Another area requiring research is farmers' willingness to enter carbon contracts and to adopt conservation practices, given the ex-ante economic returns. As previously explained, behavioral factors must be taken into account.

Finally, in the broader picture, recent research has focused on technical issues of adapting to climate change. Nevertheless, both a micro and macroeconomic research on the economic feasibility of adaptation to global warming may be needed. The barriers to adaptation must be understood to implement appropriate policies for developing countries to adapt to climate change.

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# Appendix A - Marginal costs and revenues analysis

| Items | Weight | Price ($/kg) | FP | NTL | FRT | RSD | RMP |
|---|---|---|---|---|---|---|---|
| Revenue | | | | | | | |
| Crop | | | | | | | |
| Maize | 0.50 | 0.38 | 1320.50 | 1327.55 | 3664.65 | 1438.00 | 3691.35 |
| Millet | 0.25 | 0.57 | 643.75 | 766.15 | 1027.30 | 840.80 | 1192.25 |
| Groundnuts | 0.25 | 0.70 | 1373.30 | 1382.20 | 1373.30 | 1393.65 | 1382.20 |
| Carbon (delta) | | 0.04 | 0.00 | 152.00 | 17.00 | 67.00 | 224.00 |
| Total Revenue w/o pmt | | | 587.26 | 607.62 | 1092.93 | 641.52 | 1123.14 |
| Total Revenue w pmt | | | 587.26 | 614.01 | 1093.64 | 644.34 | 1132.54 |
| Carbon revenue | | | 0 | 6.38 | 0.71 | 2.814 | 9.41 |
| Revenues from practices improvements | | | | 20.36 | 505.67 | 54.26 | 535.88 |
| **Total additional revenues** | | | | 26.75 | 506.38 | 57.08 | 545.29 |
| **Part of carbon revenue** | | | | 23.87% | 0.14% | 4.93% | 1.73% |
| **Part of yield improvement** | | | | 76.13% | 99.86% | 95.07% | 98.27% |
| Marginal Variable Cost | | | | | | | |
| *Biochemical* | | | | | | | |
| Seed | | | | | | | |
| Maize | | | 0 | 0 | 0 | 0 | 0 |
| Millet | | | 0 | 0 | 0 | 0 | 0 |
| Groundnuts | | | 0 | 0 | 0 | 0 | 0 |
| Fertilizer | | | | | | | |
| Maize | | | 0 | 0 | 21.53 | 0 | 21.53 |
| Millet | | | 0 | 0 | 10.76 | 0 | 10.76 |
| Groundnuts | | | 0 | 0 | 0 | 0 | 0 |
| Other chemical inputs | | | | | | | |
| Maize | | | 0 | 19.29 | 0 | 19.29 | 0 |
| Millet | | | 0 | 19.29 | 0 | 19.29 | 0 |
| Groundnuts | | | 0 | 19.29 | 0 | 19.29 | 0 |
| Marginal labor cost | | | | | | | |

| | | | | |
|---|---|---|---|---|
| Maize | -25.30 | 30 | 12 | 4.70 |
| Millet | -26.89 | 30 | 12 | 3.10 |
| Groundnuts | -22.43 | 30 | 12 | 7.56 |
| **Total marginal cost** | | | | |
| Maize | -6.01 | 51.53 | 31.29 | 26.23 |
| Millet | -7.61 | 40.76 | 31.29 | 13.86 |
| Groundnuts | -3.15 | 30 | 31.29 | 7.56 |
| **Net revenues** | 32.44 | 462.93 | 25.79 | 526.81 |