Two Papers Evaluating the Economic Impact of Agricultural Innovation

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ABSTRACT

While extensive research has been carried out to examine the yield growth brought about by innovations in agricultural technology, not enough work has been done to document the economic impacts of these innovations on areas besides yields and income. This study presents two papers which contribute to our understanding of the health and environmental impacts of agricultural innovation, “Expected economic benefits of meeting nutritional needs through biofortified cassava in Nigeria and Kenya,” and “Projected farm-level impacts on income of conservation agriculture in the Andean Region.” The first paper is motivated by the public health consequences of vitamin and mineral deficiencies, which affect more than two billion people worldwide and can lead to increased incidence of illness, disability, and mortality. Through the use of the disability adjusted life years concept (DALYs), economic surplus analysis, and benefit-cost analysis, the authors determine the economic impact of a staple crop biofortification project. The study finds that biofortified cassava in Nigeria and Kenya is a cost effective means of reducing health problems associated with vitamin A and iron deficiency. The second paper considers the significant livelihood challenges faced by rural communities in the Andes, including poverty, food insecurity, and natural resource constraints. Through the development and implementation of a linear programming model, the study analyzes the economic impact of a conservation agriculture project in central Ecuador, and finds that certain experimental cropping activities designed to decrease soil degradation may contribute to increased incomes for farm households.

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Chapter One

Introduction

An extensive body of research in agricultural economics documents the growth in yields and income brought about by technology innovations (see for example, de Janvry and Sadoulet 2002 and Binswanger and von Braun 1991). Numerous studies have considered the factors which affect technology adoption, including access to credit, risk aversion, human capacity and other farm/farmer characteristics, among other factors (Feder et al 1985). However, more research is needed on the economic impacts of technology beyond adoption and yields, which would provide a more accurate picture of the total costs and benefits of technological innovation in agriculture. Additional work must be done to document the wide-ranging effects of agricultural innovation, including the human health and environmental impacts of new farming systems and technologies. This Master's thesis is comprised of two papers which seek to deepen our understanding of the economic impact of agricultural innovation through its direct impacts on public health and the natural environment.

The first paper, "Expected economic benefits of meeting nutritional needs through biofortified cassava in Nigeria and Kenya," is motivated by the serious public health consequences of vitamin and mineral deficiencies, which affect more than two billion people worldwide. An inadequate consumption of micronutrients such as iron and vitamin A can lead to increased incidence of illness, disability, and mortality, particularly in the developing world (Micronutrient Initiative 2009). The present paper focuses on Nigeria and Kenya, where both vitamin A deficiency and iron deficiency anemia are significant concerns. Although micronutrient deficiencies have many causes, one of the primary contributing factors is diet. The most vulnerable population groups in both Nigeria and Kenya, as well as in much of the developing world, rely on one or two nutrient-poor staple food crops for much of their caloric intake.

Given the central place of cassava and other staple food crops in the diets of those suffering the most from vitamin and mineral deficiencies, biofortification—that is, plant breeding to increase nutritional content—has been identified as one potentially effective public health intervention. An ongoing study at the Danforth Plant Science Center, with funding from the Bill and Melinda Gates Foundation, aims to combat micronutrient malnutrition in Kenya and Nigeria by developing and introducing new varieties of biofortified cassava that contain adequately higher levels of iron and vitamin A to eliminate these deficiencies in those who consume it. The primary objective of the present study is to project the total economic effects of this cassava biofortification project.

The data used to complete the economic impact assessment of the new cassava varieties for Nigeria and Kenya was obtained through interviews with experts in plant science, agronomy, and human health, and from published sources. The methods of analysis entailed the following three steps:

1) Estimate the monetary value of the probable beneficial health effects—that is, reduced losses from vitamin A and iron deficiencies.

2) Estimate the economic surplus generated by the extended shelf life of cassava (a trait that accompanies vitamin A fortification) in both Nigeria and Kenya, along with the cultivar's improved disease resistance in Kenya.
3) Compare the health and economic surplus benefits to the costs of developing and disseminating the new varieties in a benefit-cost analysis.

Based on a review of the related literature, expected findings are that the cassava biofortification project will lead to a net economic gain. That is, the research and development costs will be less than the combined health and economic surplus benefits. This will lead to recommendations for increased investment in similar innovative public health projects.

The second paper comprising this thesis, "Projected farm-level impacts on income of conservation agriculture in the Andean Region," arises from the considerable livelihood challenges faced by rural communities in the Andes, including poverty, food insecurity, and natural resource constraints. The study focuses on farm households in two portions of the Chimbo River sub-watershed of central Ecuador, which rely heavily on agriculture for their livelihood. These families are confronted with low agricultural productivity caused in part by endemic environmental factors including steep topography, poor soil quality, and an erratic rainfall pattern. The farming system is characterized by a reliance on a small number of crops and the accompanying risk from environmental and economic shocks. Farmers are compelled to continually seek more farmland in order to compensate for low yields. The additional available land is of lower quality and is more susceptible to erosion, since it is located mainly on steeply-sloped mountainsides of thin, unstable topsoil. (SANREM CRSP website)

The Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM CRSP) Ecuador project aims to develop and disseminate sustainable agricultural technologies, such as water-diversion ditches, minimal tillage, and crop rotations, to improve the livelihoods of these rural households. The primary objective of the present study is to evaluate the economic impact of the practices introduced through the SANREM CRSP Ecuador project with regard to farm income to identify the optimal mix[1] of conservation agriculture technologies for farmers in the study area.

The economic evaluation of the conservation agriculture project was conducted using data obtained through interviews with farmers in the study area and with SANREM CRSP project scientists, from a 2007 baseline survey of farm households in the project area, and from published sources. The analysis proceeded through the following methods:

1) Develop two linear programming models (one for each of the two distinct watersheds in the study area) to maximize income subject to various production constraints, allowing an assessment of the likely livelihood improvements attainable through the use of innovative conservation agriculture techniques:

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[1] Optimal is defined as profit-maximizing.

    a. Determine the model activities by identifying the principal activities on a typical farm in the study area (crop production and selling, borrowing money, etc.), as well as the crop production activities introduced by SANREM CRSP (cover cropping, varying types of tillage, etc.).

    b. Determine the model constraints by identifying existing constraints on farm activity (applicable constraints on land, labor, capital, and other farm resources).

2) Populate the models with numerical values for activity coefficients and constraint levels by analyzing collected and published data.

3) Run the models, analyze their output, and conduct sensitivity analysis.

The ultimate aim of conservation agriculture is to enhance the quality of soils and of the other elements of the natural resource base in order to improve farm yields and protect the natural environment. Due to the nature of the soil erosion process, it is expected that any significant reduction in soil loss resulting from the adoption of conservation agriculture innovations will be apparent only over a long-term period—that is, after a minimum of ten years. Yet individual farmers will likely make their decisions regarding conservation agriculture based on a comparison between the possible short-term increases in net revenue on the one hand, and the risks and short-term implementation costs associated with the conservation practices on the other. This, along with the value of the long-term ecosystem services provided by an improved soil base, will raise important policy implications such as the possible benefits of incentive programs to support investment in conservation agriculture.

Together, the assessments of the biofortification project and the conservation agriculture project contribute further evidence about the significant economic impacts of agricultural innovations. The remainder of this paper is organized as follows. Chapter 2 presents the background, objectives, methods, findings, and conclusions of the paper on biofortified cassava. Likewise, Chapter 3 is comprised of the background, objectives, methods, findings, and conclusion of the paper evaluating conservation agriculture. The final chapter offers overall conclusions and recommends areas for future research.

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Chapter Two

Expected economic benefits of meeting nutritional needs through biofortified cassava in Nigeria and Kenya

2.1 Introduction

Vitamin and mineral deficiencies affect more than two billion people worldwide, contributing to considerable illness, disability, and mortality. The problem is most severe in developing countries, where a third of the children under age five suffer from vitamin A deficiency and one fifth of maternal deaths are attributed to iron deficiency anemia during pregnancy (Micronutrient Initiative 2009). The present study focuses on Nigeria and Kenya, where both vitamin A deficiency (VAD) and iron deficiency anemia are significant concerns. It is reported that 25 percent of children less than six years old in Nigeria and 70 percent in Kenya suffer from vitamin A deficiency, while 69 percent of children less than five in Nigeria have iron deficiency anemia and 60 percent in Kenya (Micronutrient Initiative (2004). Forty-seven percent of Nigerian women and 43 percent of Kenyan women aged 15 to 49 suffer from iron deficiency anemia. A study in Western Kenya of children aged one to three found that 29 percent had severe VAD and 92 percent had anemia (Nabakwe & Ngare 2004).

Vitamin A and iron deficiencies have several negative health and economic consequences, including early mortality and reduced productivity. Vitamin A deficiency leads to night blindness, corneal scarring, and blindness among children under the age of five (Rice et al. 2004; Stein et al 2005). Between 250,000 and 500,000 children are rendered blind by VAD each year, and children who have lost their vision due to VAD have a 50 percent chance of dying within a year (Caulfield et al. 2006). VAD also weakens the immune system, leaving its victims more susceptible to diseases such as measles and malaria, as well as increasing the severity of such diseases (West & Darnton-Hill 2001; Sommer & West 1996). VAD is a primary risk factor for early mortality, contributing to 630,000 deaths annually from infectious disease, and is associated with at least 20 percent of the mortality from measles, diarrhea, and malaria (Rice et al. 2004).

Iron deficiency is the principal cause of anemia, which leads to reduced levels of energy, physical activity, and productivity (Hallberg & Scrimshaw 1981; Horton & Ross 2003). Iron deficiency anemia (IDA) is also responsible for impaired mental development (Nokes & Bundy 1997) and can cause irreversible neurological damage (Grantham-McGregor and Ani 1999). Iron deficiency weakens the immune system, exacerbating the impact of infectious diseases (Caulfield et al 2006). Finally, IDA leads to increased maternal mortality, contributing to 841,000 pregnancy-related deaths annually, as well as 134,000 deaths among children under the age of five (Stoltzfus et al. 2004; Rush 2000).

While several factors contribute to micronutrient deficiencies in the developing world, including inadequate health care and sanitation, diet is the primary cause. People consume a disproportionate amount of staple food crops, which are relatively low in micronutrients, and consume an insufficient amount of the fruits, vegetables, and animal products that provide the micronutrients essential for good health (Micronutrient Initiative 2009). One such staple food is cassava, which is important in the diet for most of the populations in Nigeria and Kenya. Cassava is the most important crop, by weight and value of production, in Africa, with more than 100 million metric tons produced annually (FAOSTAT 2009). Nigeria is the largest producer, averaging more than 40 million metric tons per annum in 2005 to 2007. Kenya is also an important cassava producer. Cassava is a major source of calories, especially for the poor, and is a relatively dependable crop even in the face of erratic rain fall and poor soils. While millions of poor households rely on cassava for half of their daily energy, the crop contains only limited amounts of micronutrients such as vitamin A and iron. Approximately 20 percent of Nigerian children get more than 12.5 percent of their energy from cassava, and 11.9 percent obtain more than 25 percent of their energy from the staple crop (author estimates). In Kenya, cassava accounts for more than 50 percent of the diets of 16 percent of the population, or 7.1 million people (author estimates).

Given the central place of cassava in the diets of people suffering from vitamin and mineral deficiencies, biofortification — or genetic improvement to increase nutritional content — has been identified as a potential intervention to reduce micronutrient malnutrition. Biofortification can be carried out through field-based breeding or through transgenic modification. It is expected to be particularly effective in combating micronutrient deficiencies among poorer households, those who are unable to afford a wide variety of foods and consume a diet based on a relatively large proportion of one or two staple crops (Nestel et al. 2006), as well as among people living in remote areas that are seldom targeted by processed food fortification and vitamin supplement programs (Manyong et al. 2004).

Several studies have analyzed the probable impact of biofortified staple crops. Meenakshi et al (2007) published the results of an extensive study of staple crop biofortification that examined six crops and three micronutrients across eleven countries in Africa, Asia, and Latin America. Another comprehensive survey conducted by Qaim, Stein and Meenakshi (2007) highlighted the potential benefits of biofortification aimed at important staple food crops, specifically rice and wheat with higher pro-vitamin A and iron content for cultivation in India. Both studies found that biofortification compared favorably with fortification and supplementation in terms of cost and effectiveness.

A biofortification program, BioCassava Plus (BC+), was initiated in 2005 and was aimed at developing and distributing improved cassava varieties, one for Nigeria and one for Kenya, to reduce the incidence of the micronutrient deficiencies in those countries.[2] The BC+ varieties being developed for cultivation in those countries are designed to have significantly increased levels of beta carotene (pro-vitamin A) and iron. The variety being developed for Nigeria is based on a farmer-preferred cultivar resistant to cassava mosaic disease (CMD), and the cultivar for Kenya will be engineered for resistance to both CMD and cassava brown streak disease (CBSD).[3] An additional benefit of enhancing vitamin A content is the extension of shelf life of cassava roots. Fresh cassava roots deteriorate within a few days and shelf life may be extended for up to three weeks, although field trials are ongoing to confirm this trait. If it is, both varieties should exhibit delayed post-harvest physiological deterioration (PPD), a major cause of lost revenue in cassava production. Because bio-fortifying cassava will not increase yield, reduce production costs, or mitigate risk, the degree to which farmers adopt the new biofortified

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[2] The project, "Improving Cassava for Nutrition, Health, and Sustainable Development," is being carried out by researchers at the Donald Danforth Plant Science Center, with funding from the Bill and Melinda Gates Foundation, Global Health Program.

[3] CBSD is a devastating disease of cassava that is spreading rapidly in East and Central Africa. The disease had been an endemic problem in the East African coastal region for decades and was not causing much damage to the crop. Recently the disease moved to the higher altitude areas of the East Central region such as Western Kenya, South-western Uganda, and North Western Tanzania where it is causing as much as 50 percent yield loss.

varieties will depend on the extent to which they also reduce the per-unit cost of production. One means of lowering that cost, while potentially providing more carbohydrates and protein, is to bio-fortify and release varieties that reduce disease problems and post-harvest losses.

The purpose of this study is to present an assessment of the benefits of cassava biofortification with vitamin A and iron in Nigeria and Kenya. The assessment includes an evaluation of the likely health effects and the likely increase in economic benefits associated with the new cassava varieties. Economic benefits are combined with the costs of developing and disseminating the varieties in a benefit-cost analysis.

2.2 Methods

The economic impact assessment of the new cassava varieties for Nigeria and Kenya consists of three steps: (1) quantifying the projected health benefits from the new varieties, (2) calculating the expected economic surplus benefits from the new varieties, and (3) using benefit-cost analysis to compare the total benefits from steps 1 and 2 with the costs of developing and disseminating the new varieties.

2.2.1 Health Benefits: Reduction in DALYs Lost

Quantifying expected health benefits of biofortified cassava involves an assessment of current health effects of vitamin A and iron deficiencies in Nigeria and Kenya—including mortality, morbidity, and disability—and an assessment of the likely change in health impacts that would result from developing and adopting the BC+ cassava varieties. In addition, the analysis involves assessing the economic value of the health changes associated with the micronutrient deficiencies. Previous studies have attempted to assess these factors, using a measure called Disability-Adjusted Life Years (DALYs), which was first described by Murray and Lopez (1996) as a means of capturing health effects in a single index that combines the number of years of life lost and the number of years lived with temporary or permanent disability due to a given health problem.

Zimmerman and Qaim (2004) were the first to calculate the economic value of DALYs saved in the context of biofortification when they applied the method to project the benefits of golden rice in the Philippines. They estimated annual losses to vitamin A deficiency (VAD) without biofortified rice is $144 million for children, $50 million for pregnant women, and 84 million for lactating women for a total loss of $278 million. They projected that the total loss would be reduced by $88 million with golden rice. They also estimated the costs of developing and disseminating the biofortified rice and then calculated a rate of return on the investment of 66 to 133 percent depending on assumptions.

Subsequent studies have applied the method to vitamin A, iron, and zinc for several other crops and countries. For example, Manyong et al (2004) applied the method to estimate the benefits of vitamin A fortified cassava in Nigeria. They estimated that VAD in that country caused annual losses of $1,100 million to children, $155 million to pregnant women, and $148 million to lactating women for a total of $1,403 million. They projected that biofortified cassava would reduce those losses by $49-$175 million in children, \$26-\$62 million in pregnant women, and \$23-\$59 million in lactating women, for a total benefit of \$99-\$296 million.

The number of DALYs lost to disease are calculated as the sum of years of life lost due to preventable death (YLL) and years lived with illness or disability from a preventable disease or health condition (YLD). The calculation of DALYs lost for a particular micronutrient deficiency in a specific country requires identifying functional outcomes (e.g., night blindness, increased child mortality) associated with the deficiency as well as the affected target groups (e.g., children less than five, lactating women) and the size of those groups. DALYs are quantified using the formula

$$DALYs_{lost} = \sum_j T_j M_j \left(\frac{1 - e^{-rL_j}}{r} \right) + \sum_i \sum_j T_j I_{ij} D_{ij} \left(\frac{1 - e^{-rd_{ij}}}{r} \right)$$

where *Tj* is the total number of people in target group *j*, *Mj* is the mortality rate associated with the deficiency in target group *j*, and *Lj* is the average remaining life expectancy for target group *j*. *Iij* equals the incidence rate of each disease *i* in target group *j*, or the percent who suffer from the disease or health condition. *Dij* is the disability weight for disease *i* in target group *j*—that is, the associated degree of disability of each health outcome, which can vary from 1 for someone who dies to a small fraction for a somewhat minor disability—and *dij* equals the duration of disease *i* in target group *j* (for permanent diseases *dij* equals the average remaining life expectancy *Lj*). Finally, *r* is the discount rate for future life years, which is applied in order to account for the fact that losses that occur closer to the present are worth more than those occurring later.

The current health impacts of vitamin A deficiency and iron deficiency in Nigeria and Kenya—that is, the number of DALYS presently lost due to the deficiencies—were estimated using target group sizes, functional outcomes, incidence rates, disability weights, a discount rate, and disease durations gathered from published sources (U.S. Census Bureau 2010; Murray & Lopez 1996; Stein et al. 2005). Once the numbers of DALYs currently lost in each country were calculated, the projected reduction in DALYs lost, if the new BC+ cassava varieties are developed and adopted for cultivation, was calculated as a percentage of the current DALYs lost. This percentage depends on the assessment of new incidence rates for the nutrient deficiency-related diseases. Those new incidence rates in turn depend on the nutrient quantity and bioavailability in the new crop varieties, the effect of the added available nutrients on the functional health outcomes, and the quantity of the new cassava varieties consumed.

The new cassava varieties are fortified with bioavailable nutrients such that those individuals who receive 25 percent of their daily energy from the new varieties will obtain the minimum daily allowance of vitamin A and iron. Therefore, the health impacts of the new crops depend on the quantity consumed, which is determined by both the quantity of cassava currently consumed and the adoption rates for the new varieties. In Nigeria, approximately 25 percent of children under age 5 and 25 percent of pregnant and lactating women (the target groups for vitamin A and iron deficiencies) receive 25 percent of their daily energy from cassava and would have their incidence rate of disease and disability from vitamin A and iron deficiency reduced to zero if there were 100 percent adoption of the new variety. This 25 percent of children and pregnant women is multiplied by the maximum adoption rate of 24 percent to estimate a projected 6 percent reduction in DALYs lost per year at the point of peak adoption in Nigeria. And in Kenya, 18 percent of children under age five and 18 percent of pregnant and lactating women (target groups for vitamin A and iron deficiencies) consume adequate cassava to benefit from an incidence rate of zero for the related health outcomes. Therefore, at peak adoption, there would be a projected 3 percent overall reduction in DALYs lost per year—that is, the maximum expected adoption rate of 16 percent multiplied by 18 percent.

The difference in the number of DALYs lost with and without biofortified cassava represents the health impact of the biofortification project. There are multiple ways to assign an economic value to the DALYs saved through biofortification. Discounting (at 3 percent[4]) and summing the DALYs saved from the year of variety release until 2030, and dividing that sum by total expenditures on research and development, provides the cost per DALY saved, which can be compared to alternative means of meeting the nutrient requirements. Alternatively, each DALY saved could be assigned a subjective value such as $1,000 in order to determine the total value of lives saved and disability avoided due to the micronutrient enhanced varieties.[5]

2.2.2 Economic Surplus Analysis

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[4] The 3 percent discount rate was chosen to maintain consistency with the current literature applying the DALYs approach to staple food biofortification, allowing comparison among similar studies.

[5] Annual per capita income has been suggested as a possible value for a DALY, but that implies that a year of life for a person in Kenya and Nigeria would differ if their per capita incomes differed. Others have suggested a standard $1000 value to circumvent that problem while still being within a plausible range.

In addition to providing health benefits, the new cassava varieties are expected to provide economic benefits due to a productivity change that shifts out the supply of cassava. It is assumed that incorporating vitamin A into cassava imparts a degree of delayed PPD to the roots, resulting in a yield gain (losses saved) that is partially offset by a small increase in input costs for those who adopt the new varieties. In Nigeria, vitamin A enhancement will be incorporated in a variety resistant to CMD, although the new biofortified variety will not contribute additional CMD resistance. However, the delayed PPD trait will add value to that from biofortification and it will increase adoption. In Kenya, the biofortified varieties also add value from delayed PPD as well as from combining resistance to cassava brown streak disease (CBSD) and cassava mosaic disease (CMD). This combined disease resistance in the new BC+ (Serere) variety is new and increases yield compared to current varieties. In addition, both delayed PPD and disease resistance will bolster adoption rates in Kenya.

Economic surplus analysis was used to calculate expected economic benefits from the BC+ varieties associated with the supply shifts caused by the higher yields. A closed economy model was assumed in the analysis since little cassava is traded internationally. Change in economic surplus was projected for the 16 years after variety release The formula for the change in total economic surplus (TS) for a closed economy with linear demand and supply and a parallel research induced supply shift is: $\Delta TS = P_0 Q_0 K (1+ 0.5 Z\eta)$, where P_0 and Q_0 are initial equilibrium price and quantity, respectively; $Z = K\varepsilon/(\varepsilon+ \eta)$ is the relative reduction in price due to the supply shift; ε = supply elasticity; η = demand elasticity (absolute value), and K = shift of the supply curve as a proportion of the initial price. The latter is calculated as: K = $\left(\frac{E(Y)}{\varepsilon}\right) - \left(\frac{E(C)}{1+E(Y)}\right)$ p A (1-d), where E(Y) is the expected proportionate yield increase per hectare after adoption of the new technology, E(C) is the expected proportionate change in variable input cost per hectare, p is the probability of success with the research, A is the adoption rate for the technology, and d is the depreciation rate of the new technology (Alston et al. 1995). No depreciation was assumed in this analysis. The formulas for calculating benefits, and their net present value, were incorporated in spreadsheets for the calculations.

The added net benefits of the projected yield and cost changes were estimated using economic surplus analysis incorporating the assumptions shown in table 1. Estimates of yield and cost changes, adoption rates, and probabilities of success were obtained through interviews with scientists and from data on previous varietal adoption rates in the countries. Benefits were assumed to begin in year 13 (for Nigeria) and year 14 (for Kenya) after the research and regulatory processes are complete. They were assumed to continue for sixteen years after release. Adoption occurs gradually as cuttings are multiplied, and peak adoption of 24 percent (Nigeria) and 16 percent (Kenya) is reached in the tenth year after varietal release. The estimated peak adoption rate for Nigeria was based on a December 2009 survey of the cassava varieties under cultivation in eight of the country's primary cassava-producing states (Akoroda, 2010). The survey results indicate relatively high current adoption rates for the cassava variety serving as the base cultivar for the new biofortified BC+ variety.[6] A conservative estimate of 24 percent adoption was assumed based on the current distribution of the base cultivar throughout

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[6] Current adoption rates for the base cultivar (TME7) range from 20 to 60 percent.

Nigeria and the expected maximum adoption rate in key cassava-producing states after biofortification.[7] Adoption rates of new cassava varieties in Kenya have varied widely due to the effect of periodic outbreaks of cassava mosaic disease (CMD), with farmer's exhibiting greater willingness to adopt disease-resistant varieties following significant occurrences of CMD. For example, the Kenya Agriculture Research Institute (KARI) estimated an adoption rate as high as 50 percent in some parts of western Kenya following a CMD crisis in the 1990's. Given the wide variation in adoption rates, a conservative estimate of 16 percent was assumed, a rate applicable to a period that is unaffected by a major CMD outbreak.

It is assumed that the research has a 50 percent chance of succeeding and will result in a yield improvement (savings in losses) of 10 to 15 percent for adopters in Nigeria due to delayed PPD and 20 to 35 percent for adopters in Kenya due to delayed PPD and combined resistance to CMD and CBSD. Plant scientists indicate that current PPD losses are approximately 20 percent. The new varieties should delay PPD as long as the roots are undamaged at harvest. Approximately 95 percent of the rainy season crop and 50 percent of the dry season crop are undamaged at harvest. Eighty percent of the total crop is harvested during the rainy season and 20 percent during the dry season. Therefore, the savings in losses due to PPD were calculated as: $0.95 * 0.8 + 0.5 * 0.2 = 0.86$. With a 20 percent PPD loss currently, the final estimate PPD loss averted is $0.86 * 0.2 = 0.17$. Therefore, the new varieties will increase the net product by approximately 17 percent

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[7] The a) current percent adoption and b) projections of peak adoption after biofortification, for important cassava-growing states, are as follows: Oyo state, a) 26.63% b) 40%; Ondo state, a) 19.97% b) 30%; Benue state, a) 23.33% b) 40%; Kogi state, a) 58.42% b) 75% (Akoroda 2010 for (a) and author estimates for (b)).

due to delayed PPD. Analysis in this paper assumed a conservative gain of 10 and 15 percent in Nigeria. Yield improvement from combined CMD and CBSD resistance in Kenya was estimated by scientists to be 10 to 20 percent.[8] Thus, the total gain in Kenya from delayed PPD and from disease resistance was 10 to 15 percent plus 10 to 20 percent, or a total 20 to 35 percent.

Finally, a 5 to 10 percent increase in input costs per hectare was assumed, with the additional costs resulting from procurement of cassava cuttings for the first year of cultivation of the new varieties.

Table 1. Basic assumptions in models to estimate economic benefits of GM cassava varieties with resistance to CMD and delayed PPD in Nigeria and Kenya and resistance to CBSD in Kenya

Parameter	Nigeria	Kenya
Production (million tons)	40	0.6
Price per ton (US $)	75	95
Percent yield gain	10 – 15	20 – 35
Percent cost increase per ha.	5 – 10	5 – 10
Maximum adoption rate (%)	24	16
Years to max after first adoption	10	10
Years to first adoption	13	14
Years of benefits	16	16
Probability of success (%)	50	50
Elasticity of supply	1	1
Elasticity of demand	.43	.3
Discount rate (%)	3[9]	3
Market	No international trade	No international trade

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[8] Recent crop losses to CBSD in East Africa indicate that this estimate may be conservative.
[9] The 3 percent discount rate was chosen based on the real rate of return on investment.

2.2.3 Benefit-Cost Analysis

The final step in the analysis was to combine the health and economic surplus benefits and compare them with the research and distribution costs of the project in a benefit-cost analysis using a discount rate of 3 percent.[10] Health benefits equaled the number of DALYs saved due to the biofortified varieties, valued at $1000 per DALY. Total research and dissemination costs were estimated at $12,159,000, and were assumed to be distributed equally between Nigeria and Kenya.

2.3 Results

The estimated DALYs lost due to vitamin A deficiency and iron deficiency in Nigeria and Kenya are presented in Tables 2-5 along with the projected DALYs saved due to biofortified cassava. In Nigeria, pro-vitamin A fortified cassava is estimated to reduce total DALYs lost due to the health outcomes associated with VAD by 6 percent. Most of the DALYs saved result from a reduction in child mortality (189,000). In Kenya, cassava enhanced with pro-vitamin A is estimated to reduce DALYs lost due to VAD by about 3 percent. Again, most of the DALYs saved are due to a reduction in child mortality (12,500).

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[10] The 3 percent discount rate was chosen based on the real rate of return on investment.

Table 2. DALYs lost to Vitamin A deficiency in Nigeria and saved by biofortified cassava

Functional Outcome	Target group (million) (Tj)	Incidence rate (Iij)	Disability weight (Dij)	DALYs lost/yr before bio-fortification (thousand)	DALYs saved/yr with bio-fortified cassava at max adoption (thousand)
Night blindness	23.4	.00387	.05	4.5	0.3
Corneal scarring	23.4	.00057	.2	66.5	4.0
Blindness	23.4	.00057	.5	166.4	10.0
Measles	23.4	.012097	.35	2.7	0.2
Measles with complications	23.4	.012097	.7	10.8	0.6
Increased child mortality	23.4	.0054	1	3152.2	189.1
Total DALYS	23.4			3403.2	204.2

Sources: Target groups (Tj) obtained from U.S. Census Bureau, International Data Base (IDB) online; Mortality rates (Mj) calculated based on the DALYs Handbook (Stein et al, 2005) using WHO Mortality Country Fact Sheets online; Average remaining life expectancy (Lj) calculated based on the DALYs Handbook using average life expectancy data from the U.S. Census Bureau, IDB; Incidence rates (Iij) taken from *Global Health Statistics* (Murray and Lopez, 1996), when available. When only prevalence rates were available, incidence rates were calculated as prevalence/duration (duration from DALYs Handbook); Disability weights (Dij) taken from the DALYs Handbook; Disease duration (dij) calculated using average onset of disease from the DALYs Handbook and average life expectancy from U.S. Census Bureau, IDB.

Table 3. DALYs lost to Vitamin A deficiency in Kenya and saved by biofortified cassava

Functional Outcome	Target group (million) (Tj)	Incidence rate (Iij)	Disability weight (Dij)	DALYs lost/yr before bio-fortification (thousand)	DALYs saved/yr by bio-fortified cassava at max adoption (thousand)
Night blindness	6.6	.00387	.05	1.3	0.04
Corneal scarring	6.6	.00057	.2	20.6	0.6
Blindness	6.6	.00057	.5	51.5	1.5
Measles	6.6	.012097	.35	.8	0.02
Measles with complications	6.6	.012097	.7	3.1	0.1
Increased child mortality	6.6	.0024	1	433.6	12.5
Total DALYS	6.6			510.8	14.7

Sources: Target groups (Tj) obtained from U.S. Census Bureau, International Data Base (IDB) online; Mortality rates (Mj) calculated based on the DALYs Handbook (Stein et al, 2005) using WHO Mortality Country Fact Sheets online; Average remaining life expectancy (Lj) calculated based on the DALYs Handbook using average life expectancy data from the U.S. Census Bureau, IDB; Incidence rates (Iij) taken from *Global Health Statistics* (Murray and Lopez, 1996), when available. When only prevalence rates were available, incidence rates were calculated as prevalence/duration (duration from DALYs Handbook); Disability weights (Dij) taken from the DALYs Handbook; Disease duration (dij) calculated using average onset of disease from the DALYs Handbook and average life expectancy from U.S. Census Bureau, IDB.

Iron biofortified cassava is estimated to reduce DALYs lost due to the health outcomes associated with iron deficiency by 6 percent in Nigeria and by 3 percent in Kenya. Most of the DALYs saved result from a reduction in maternal mortality caused by IDA (187,700 for Nigeria and 89,300 for Kenya). DALYs saved due to vitamin A enhancement are significantly greater than those saved due to iron enhancement.

Table 4. DALYs lost to Iron deficiency in Nigeria and saved by biofortified cassava

Functional Outcome	Target group (million) (Tj)	Inci-dence rate (Iij)	Disability weight (Dij)	DALYs lost/yr before bio-fortification (thousand)	DALYs saved/yr with bio-fortified cassava at max adoption (thousand)
Impaired physical activity (Moderate)					
Children < five	23.4	.057444	.011	62.2	3.7
Women 15+	42.9	.003137	.011	30.5	1.8
Impaired physical activity (Severe)					
Children < five	23.4	.003578	.087	30.7	1.8
Women 15+	42.9	.000372	.09	29.6	1.8
Impaired mental (moderate)					
Children < 5	23.4	.00347	.006	11.6	0.7
Impaired mental (severe)					
Children < 5	23.4	.00207	.024	27.8	1.7
Maternal mortality due to IDA					
Women 15-49	35.2	.0004[a]	1	187.7	11.3
Stillbirth accompanying maternal mortality due to IDA	.0141[b]	.3[c]	1	106.5	6.4
Child mortality accompanying maternal mortality due to IDA	.0141[b]	.0396[d]	1	13.9	0.8
Total DALYS				500.5	30

Sources: Target groups (Tj) obtained from U.S. Census Bureau, International Data Base (IDB) online; Mortality rates (Mj) calculated based on DALYs Handbook (Stein et al, 2005) using WHO Mortality Country Fact Sheets online; Average remaining life expectancy (Lj) calculated based on the DALYs Handbook using average life expectancy from the U.S. Census Bureau, IDB; Incidence rates (Iij) taken from *Global Health Statistics* (Murray and Lopez, 1996), when available. When only prevalence rates were available, incidence rates were calculated as prevalence/duration (duration from DALYs Handbook); Disability weights (Dij) taken from the DALYs Handbook; Disease duration (dij) calculated using average onset of disease from the DALYs Handbook and average life expectancy from U.S. Census Bureau, IDB.

[a] IDA causes 5% of maternal mortality. Maternal mortality is 0.8% in Nigeria. Therefore Iij = 0.05 *0.008 = 0.0004. [b] The target group for stillbirths, and for child mortality that accompany maternal mortality caused by IDA, is childbearing women who die in childbirth due to IDA; 35.2 * 0.0004 = 0.0141. [c] 30% of maternal mortality results in still births. [d] The share of exclusively bread fed infants (22%) times the under five mortality rate (18%) = 0.0396.

Table 5. DALYs lost to Iron deficiency in Kenya and saved by biofortified cassava

Functional Outcome	Target group (million) (Tj)	Inci-dence rate (Iij)	Disability weight (Dij)	DALYs lost/yr before bio-fortification (thousand)	DALYs saved/yr with bio-fortified cassava at max adoption (thousand)
Impaired physical activity (Moderate)					
Children < five	6.6	.057444	.011	17.6	0.5
Women 15+	11.3	.003137	.011	9.4	0.3
Impaired physical activity (Severe)					
Children < five	6.6	.003578	.087	8.7	0.3
Women 15+	11.3	.000372	.09	9.1	0.3
Impaired mental (moderate)					
Children < 5	6.6	.00347	.006	3.7	0.1
Impaired mental (severe)					
Children < 5	6.6	.00207	.024	8.7	0.3
Maternal mortality due to IDA					
Women 15-49	9.4	.0005[a]	1	89.3	2.6
Stillbirth accompanying maternal mortality caused by IDA	.0047[b]	.3[c]	1	38.7	1.1
Child mortality accompanying maternal mortality due to IDA	.0047[b]	.0216	1	2.8	0.1
Total DALYS				188.0	5.4

Sources: Target groups (Tj) obtained from U.S. Census Bureau, International Data Base (IDB) online; Mortality rates (Mj) calculated based on DALYs Handbook (Stein et al, 2005) using WHO Mortality Country Fact Sheets online; Average remaining life expectancy (Lj) calculated based on the DALYs Handbook using average life expectancy from the U.S. Census Bureau, IDB; Incidence rates (Iij) taken from *Global Health Statistics* (Murray and Lopez, 1996), when available. When only prevalence rates were available, incidence rates were calculated as prevalence/duration (duration from DALYs Handbook); Disability weights (Dij) taken from the DALYs Handbook; Disease duration (dij) calculated using average onset of disease from the DALYs Handbook and average life expectancy from U.S. Census Bureau, IDB.

[a] IDA causes 5% of maternal mortality. Maternal mortality is 1% in Kenya. Therefore Iij = 0.05 *0.01 = 0.0005. [b] The target group for stillbirths, and for child mortality that accompany maternal mortality caused by IDA, is childbearing women who died during childbirth due to IDA; 9.4 * 0.0005 = 0.0047. [c] 30% of maternal mortality results in still births. [d] Share of exclusively bread fed infants (18%) times the under five mortality rate (12%) = 0.0216.

The cost per DALY saved is found by dividing the total cost of developing and disseminating the biofortified varieties by the discounted (at 3 percent) sum of the DALYs saved from the year of variety release until 2030. In Nigeria, the cost per DALY saved of vitamin A enhanced cassava is estimated at $5, while a variety biofortified with both vitamin A and iron costs about $4 per DALY saved. In Kenya, a variety biofortified with vitamin A alone is estimated to cost about $77 per DALY saved, while cassava enhanced with both vitamin A and iron is estimated to cost $56 per DALY saved. These estimates are comparable to those in previous studies on biofortified crops. Meenakshi et al (2007, 2010) applied a similar method to estimate the benefits of vitamin A fortified cassava in Nigeria, DR Congo, and northeast Brazil; vitamin A fortified maize in Ethiopia and Kenya; vitamin A fortified sweet potato in Uganda; and iron and zinc fortified beans in Honduras, Nicaragua, and northeast Brazil; rice in Bangladesh and India; and wheat in India and Pakistan. Their estimated ranges were wide due to varying assumptions, but for cassava in Nigeria they estimated the costs per DALY saved through biofortification at $8-$137 and for maize in Kenya, $18-$113. They note that the World Health Organization (WHO) (2010) estimated the cost per DALY saved in Africa through vitamin A fortification at $41 and for supplementation at $52.

Meenakshi et al (2007) estimated that the cost per DALY saved by reducing iron deficiency in South Asia through biofortified rice and wheat was $1-$18. Baltussen et al (2004) estimated it at $27 for Africa. Meenakshi et al (2007) estimated that the cost per DALY saved to reduce zinc deficiency in South Asia through biofortified rice and wheat was less than $11, and noted that WHO estimated the cost per DALY saved in Africa at $82 for crop biofortification as compared to $120 for supplementation.

The benefits of rice and wheat biofortified with iron and zinc and of rice biofortified with vitamin A in India were projected by Qaim, Stein, and others in a series of papers (Qaim et al 2007; Stein et al 2005; Stein et al 2006a; Stein et al. 2006b; Stein et al 2007). They projected the cost per DALY saved due to iron biofortification in rice and wheat to be $1-$5 and for zinc biofortification to be $1-$9. They projected the cost per DALY saved due to vitamin A biofortification in rice to be $3-$19.

Attaching a value of $1000 per DALY saved to the numbers in tables 2-5, the annual DALYs saved through biofortification are worth $204 million for vitamin A alone and $234 million for both vitamin A and iron in Nigeria (table 6). This number is about the mid-point of the range estimated by Manyong et al (2004). For Kenya, annual DALYs saved for vitamin A and iron biofortification together is estimated at $20 million, with $14.7 million due to vitamin A.

The annual undiscounted value of the delayed PPD in Nigeria after full adoption is estimated at $3.3 million for the 10 percent yield loss reduction and a 10 percent increase in input costs. The numbers for a 15 percent yield loss reduction and a 5 percent increase in input costs is $38.4 million. For Kenya, the annual undiscounted value for the delayed PPD in combination with resistance to CMD and CBSD is $0.53 million under the assumption of a 20 percent yield gain and a 10 percent increase in input costs. With a 35 percent yield gain and a 5 percent increase in input costs, the value is $1.4 million. The total discounted benefits minus costs from the time period when research costs were first incurred through the first 16 years of adoption are $14 to 221 million in Nigeria and zero and $2.3 million in Kenya.

The numbers in Table 6 underestimate the real value of the delayed PPD and the CBSD resistance because those traits are important drivers in the adoption of the biofortified cassava. Adoption would be lower without the visible yield effects. However once adoption does occur, the majority of the economic benefits are derived from the biofortification as opposed to the yield change. If we add the value of vitamin A enhanced cassava to the value of the yield changes, the total annual undiscounted value is $207 to $242 million in Nigeria and $15 to $16 million in Kenya. For cassava enhanced with both vitamin A and iron, the total annual undiscounted value is $237 to $272 million in Nigeria and $20 to $21.5 million in Kenya. The discounted net benefits minus costs from the year when research costs were first incurred through the first 16 years of adoption for the combined yield changes and biofortification with vitamin A are $1,200 to $1,400 million in Nigeria and $76 to $81 million in Kenya. The corresponding values are $1,400 to $1,600 million in Nigeria and $105 to $110 million in Kenya when both vitamin A and iron enhancement are included.

Table 6. Projected economic benefits of biofortified and disease resistant cassava in Kenya and Nigeria (million $)

	Nigeria	Kenya
Annual undiscounted benefit of cassava with delayed PPD after maximum adoption	3.3-38.4	
Annual undiscounted benefit of cassava after full adoption with delayed PPD and with CMD and CBSD resistance		0.5-1.4
Net present value of benefits minus costs of cassava with delayed PPD from first research through 16 years after adoption begins	14-221	
Net present value of benefits minus costs cassava with delayed PPD and CBSD resistance from first research through 16 years after adoption begins		0-2.3
Annual undiscounted benefit of cassava with delayed PPD and bio-fortification with Vitamin A after maximum adoption	207-242	
Annual undiscounted benefit of cassava with delayed PPD and bio-fortification with Vitamin A and Iron after maximum adoption	237-272	
Annual undiscounted benefit of cassava after full adoption with delayed PPD, CMD and CBSD resistance, and bio-fortification with Vitamin A		15-16
Annual undiscounted benefit of cassava after full adoption with delayed PPD, CMD and CBSD resistance, and biofortification with Vitamin A and Iron		20-21.5
Net present value of benefits minus costs of cassava with delayed PPD and biofortification with Vitamin A from first research through 16 years after adoption begins	1,200-1,400	
Net present value of benefits minus costs of cassava with delayed PPD and biofortification with Vitamin A and Iron from first research through 16 years after adoption begins	1,400-1,600	
Net present value of benefits minus costs of cassava with delayed PPD, CBSD resistance and bio-fortification with Vitamin A from first research through 16 years after adoption begins		76-81
Net present value of benefits minus costs of cassava with delayed PPD, CBSD resistance and bio-fortification with Vitamin A and Iron from first research through 16 years after adoption begins		105-110

The benefits of disease resistance in table 6 may appear low because we assume that the counterfactual is a set of cassava varieties with some added resistance to CMD and CBSD that will be released by other institutions (using conventional or marker-assisted breeding). Hence the yield advantage over those other varieties is relatively small.

2.4 Conclusions

Biofortified cassava in Nigeria and Kenya is a cost effective means of reducing health problems associated vitamin A and iron deficiency. The $4 to $77 estimated cost per DALY is low compared to alternative means for addressing these problems. The World Development Report for 1993 reviewed many public health interventions and found that interventions costing less than $150 per DALY averted were highly cost effective. The World Health Organization (2010) estimates the cost per DALY saved in Africa through Vitamin A fortification to be $41 and for supplementation to be $52. Most of the benefits from vitamin A biofortification result from reduced mortality of children under 5 years old, while most of the benefits from iron biofortification are derived from reductions in maternal mortality.

Economic returns from biofortification are high, in fact higher than the benefits from the yield improvements due to delays in post-harvest physiological deterioration and to CBSD resistance. However, without the addition of at least one of these traits, the benefits of biofortification would likely be significantly lower due to a lower rate of varietal adoption by farmers.

The potential benefits of biofortification have now been documented in numerous studies examining a variety of crops, nutrients, and regions. Further research is needed to confirm these findings as well as to consider the factors that will determine the relative long-term effectiveness of biofortification as compared to other approaches to combating malnutrition. One area for future research is to assess the acceptance of biofortified crops by consumers. There has been some resistance in Africa to genetically modified crops. Understanding the nature and extent of this resistance will be vital if biofortification is to have a real impact on micronutrient deficiencies and the related health outcomes.

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Chapter Three

Projected farm-level impacts on income of conservation agriculture in the Andean Region

3.1 Introduction

Rural communities in the Andean region are confronted with a number of significant livelihood challenges, including low incomes, food insecurity, and a poor natural resource base. Such difficulties figure prominently in the lives of subsistence farming households in the Bolivar province of central Ecuador, where 77% of families lack the resources to fulfill their basic needs. Bolivar is ranked lowest among Ecuador's 24 provinces in its poverty index (Andrade). The present study is focused on two sections of the province's Chimbo River watershed, which are geographically, culturally, and socio-economically distinct: the higher-elevation Illangama watershed and the lower-elevation Alumbre watershed. The two watersheds are characterized by their differing cropping systems, which are determined by their altitude above sea level, with the lower watershed ranging in elevation from 600 to 2400 meters, and the upper from 2400 to 4500 meters (Gibson et al). The average farm size is between 3 and 5 hectares in the upper watershed and between 1 and 4 hectares in the lower watershed (Alwang et al, 2005).

Rural Andean households, including those in the Illangama and Alumbre watersheds, are heavily dependent on agriculture, yet farm production is limited by such ecological factors as steep topography and erratic rainfall. Although the area's volcanic soil is naturally rich in nutrients, landslides have created an increasing number of dead zones with virtually no vegetation cover. Moreover, farmers' exposure to risk from climatic and economic shocks is heightened by dependence on a limited number of staple food crops. The principal crops in the upper watershed are potatoes and fava beans, while corn and beans dominant the agricultural landscape of the lower watershed. Additional crops in the upper watershed include onions, pasture for dairy cattle and sheep, and local tubers. In the lower watershed, farmers grow some cassava and various garden vegetables. Food insecurity in both watersheds is compounded by decreased nutrient levels in staple food crops, which is linked to poor soil quality (SANREM CRSP).

Ecuadorian farmers endeavor to compensate for poor soil quality and low yields by expanding production, yet this often means cultivating land that is of lower quality and located on steeper slopes, making it more susceptible to erosion. Thus develops a persistent cycle of low yields, expansion of croplands, and soil erosion. This pattern is accompanied by other forms of environmental degradation, including the increased sedimentation in rivers and streams that has resulted in reduced fish populations downstream. Guaranteeing the continued food security of the households caught up in this cycle will require efforts to conserve the soil on which they depend (SANREM CRSP).

Conservation agriculture has been identified as a potential solution to the area’s environmental degradation and associated decline in agricultural yields. This environment-focused approach to agriculture is defined as a collection of farming practices aimed at conserving, improving, and more efficiently utilizing the available natural resource base. The three main principles comprising the majority of conservation agriculture systems are the use of reduced or minimal soil tillage, the maintenance of an organic soil cover (food crop or cover crop) at all times, and the implementation of purposeful crop rotations (Alwang et al, 2009). In essence, conservation agriculture differs from conventional agriculture in its additional focus on environmental and long-term economic benefits, rather than uniquely agricultural and short-term economic benefits (Dumanski et al).

Numerous studies have examined the potential economic and environmental benefits of conservation agriculture. Research has been focused primarily on the associated changes in yields and farm income, the impacts on the environment and the natural resource base, the components of conservation agriculture, and the various factors affecting the adoption of conservation agriculture systems and practices. For an overview of the spread and implications of conservation agriculture in North and South America, see Derpsch (2006). Additionally, Anderson and Thampapillai provide a summary of cost-benefit analyses carried out on soil erosion reduction projects, a key focus of conservation agriculture (1990).

One of the primary goals of conservation agriculture is to increase the percentage of organic matter, especially carbon, in agricultural soils. The focus on soil carbon content is due to the fact that soils contain more of the world’s organic carbon than the atmosphere and the land biota—that is, flora and fauna—combined (Lal and Kimble, 1997). A higher organic content is linked to greater soil productivity, which increases the profitability and thus the livelihoods of individual farm households. Moreover, an improved natural resource base can be beneficial to future generations of farmers as well as to consumers, in the form of higher-nutrient food crops. Increased levels of organic matter in the soil also represent an environmental improvement, in that the farming techniques associated with conservation agriculture, including reduced tillage, cover crops, and crop rotations, have been shown to contribute to carbon sequestration and thus to decrease the rate of global warming (West and Post, 2002).

Drawing on the potential, if yet unconfirmed, benefits offered by conservation agriculture, and given the need for innovative approaches to combating the challenges faced by farming communities in the Andes and throughout the developing world, the U.S. Agency for International Development is funding an ongoing, research-based agricultural development program focused on improving the livelihoods of the rural poor. This program, the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM CRSP), has operated in Ecuador since 2004. The immediate goals of SANREM CRSP-Ecuador are to develop and disseminate sustainable agricultural technologies, such as soil conservation techniques, to increase incomes and conserve the natural resource base. Several techniques have been developed, or identified and adapted to the local context, including water-diversion ditches, organic fertilizer, minimal tillage, crop rotation, and terraced cropping (SANREM CRSP website). The objectives of the SANREM CRSP Andean Regional Project for the current five-year phase (2010-2014) include the identification, evaluation, and dissemination of the most suitable conservation agriculture production systems (CAPS) for the region, the identification and promotion of mechanisms to improve the profitability of CAPS, and capacity-building to increase CAPS dissemination.

The present study assesses the economic benefits of conservation agriculture practices in the Andean region developed on the SANREM CRSP project in Ecuador. The objective of this assessment is to evaluate the impact of conservation agriculture innovations on farm income and to identify the optimal mix of practices for farmers in the study area, where optimal is defined as profit-maximizing. Two farm-level linear programming models—one for the Illangama watershed and one for the Alumbre watershed—are presented. The models maximize net revenue[11] subject to farm resource and production constraints, allowing an assessment of the likely livelihood improvements attainable through the diffusion and adoption of conservation agriculture innovations.

3.2 Methods

The economic evaluation of the SANREM CRSP Ecuador project entails three steps: (1) developing a linear programming model designed to maximize net revenue subject to constraints on available inputs, (2) populating the model with numerical values for activity coefficients and resource constraint levels by analyzing collected and published data for two sub-watersheds of the Chimbo watershed in Bolivar province, and (3) running the model for each subwatershed, analyzing the solutions, and conducting sensitivity analyses.

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[11] The author defines net revenue as profits—that is, the returns above costs to fixed factors and farm management (farmers' labor and entrepreneurship).

3.2.1 Model Development

A separate linear programming model was constructed for each of the two sub-watersheds in the study area—the higher elevation Illangama and the lower elevation Alumbre sub-watershed. The models were designed to maximize net revenue, subject to farm resource and production constraints, allowing an assessment of the potential economic benefits offered by conservation agriculture. Since the study approaches the analysis of conservation agriculture by specifically examining the innovative agricultural practices being developed and tested through the SANREM CRSP Ecuador project, the model design is a direct function of SANREM agricultural experiments. Thus each sub-watershed model is a two-year model encompassing four approximately six-month cycles, corresponding directly to the series of experimental crop rotations developed by SANREM scientists, which are made up of four approximately six-month cycles each.

The basic elements of both models are activities and constraints. The model solutions consist of levels, or amounts, of the model activities that should be implemented in order to maximize net revenue subject to the constraints. More precisely, the model is used to determine the number of square meters that should be devoted to each experimental crop rotation. The range of possible solutions is limited by the model constraints. For example, the model allocates the limited (constrained) amount of available agricultural land among the different innovative crop rotations.

The aggregated linear programming tableau for the Illangama and Alumbre sub-watersheds is presented in Table 1. The model activities are combined into four categories—production, selling, cash transfer, and revenue—which appear as columns in the aggregated tableaus. The model constraints are likewise aggregated into categories, which appear as rows in the two tables, and are labeled in the left-hand column (Land Constraint, Labor Constraints, etc.).

The elements under the activity columns represent the model coefficients, which are multiplied by the activity levels (i.e. amounts) selected by the model to determine each activity's impact on the available farm household resource or other constraint. Positive coefficients generally denote that the activity requires labor, cash, or other inputs, while negative coefficients signify that the activity contributes cash or another input. For example, the coefficient for the Production Activities column on the cash constraint row is positive (A), indicating that these activities require, rather than contribute, cash, while the corresponding coefficient under the Selling Activities column is negative (-P), since these activities contribute cash.

Table 1: Aggregated tableau for the upper and lower watershed models

	Production Activities	Selling Activities	Cash Transfer Activities	Revenue Activities	RHS
Objective Function				1	Max
Land Constraint	1				≤ C
Labor Constraints	L				≤ C
Rotational Constraints	±1				= 0
Yield Transfer Rows	-Y	1			= 0
Cash Constraints	A	-P	±1	1	≤ C
End of Period Cash		-P	-1	1	= 0

L = Monthly labor requirements for each production activity (hours/m2)
Y = Yield for each production activity (kg/m2)
A = Costs for each production activity (dollars/m2)
P = Price for each production activity crop (dollars/kg)
C = Model constraint values

Model activities

The model activities were determined by identifying the principal crop-related activities on a typical farm in the study area, as well as the experimental crop production activities introduced by the SANREM CRSP Ecuador project. The experimental SANREM activities include the construction of diversion ditches to reduce soil loss from rainwater runoff, reduced tillage to protect soil, crop rotations, herbicides and manual weed removal, and the use of cover crops as organic mulch and to reduce soil erosion and increase organic matter in the soil.

The Illangama watershed model contains nine sets of cropping activities, corresponding to the experimental control—that is, the traditional farming system—and eight experimental treatments. These nine cropping activities are presented in Table 2.

Table 2: Cropping activities in the Illangama watershed

Treatment Number	Diversion Ditches	Tillage Regime	Cover Crop Treatment	Crop Rotation
Control	No	Conventional	No Cover Crop	Potatoes, Fallow, Fava Beans, Potatoes
One	Yes	Conventional	Remove	Potatoes, Oats-Vetch, Barley, Fava Beans
Two	Yes	Conventional	Till into Soil	Potatoes, Oats-Vetch, Barley, Oats-Vetch
Three	Yes	Reduced	Remove	Potatoes, Oats-Vetch, Barley, Fava Beans
Four	Yes	Reduced	Till into Soil	Potatoes, Oats-Vetch, Barley, Oats-Vetch
Five	No	Conventional	Remove	Potatoes, Oats-Vetch, Barley, Fava Beans
Six	No	Conventional	Till into Soil	Potatoes, Oats-Vetch, Barley, Oats-Vetch
Seven	No	Reduced	Remove	Potatoes, Oats-Vetch, Barley, Fava Beans
Eight	No	Reduced	Till into Soil	Potatoes, Oats-Vetch, Barley, Oats-Vetch

In the Alumbre watershed, four experimental cropping treatments were introduced, along with the experimental control of traditional practices. These five treatments are represented in Table 3.

Table 3: Cropping activities in the Alumbre watershed

Treatment Number	Weed Control	Tillage Regime	Cover Crop Treatment	Crop Rotation
Control	Weeding and Herbicide	Conventional	No Cover Crop	Corn, Fallow, Beans, Fallow
One	Manual weeding	Conventional	Remove	Corn, Oats, Beans, Oats
Two	Herbicide	Conventional	Till into Soil	Corn, Oats, Beans, Oats
Three	Manual weeding	Reduced	Remove	Corn, Oats, Beans, Oats
Four	Herbicide	Reduced	Till into Soil	Corn, Oats, Beans, Oats

Additional model activities were included in each watershed model to account for the selling of crops and the transfer of cash from one six-month period to another, as well as from the end of the final six-month period into a net revenue account. Credit borrowing and labor selling/hiring activities were excluded from the models based on their minimal significance to farm households in the study area and their negligible impact on the conservation agriculture experiments which are the subject of this study.[12] The Illangama watershed model is comprised of a total of 47 activities, while the Alumbre

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[12] The author observed that there is a significant amount of labor hiring in the Alumbre watershed. However, during sensitivity analysis, the author determined that including labor hiring in the model would not affect the study results.

watershed model encompasses 27 activities. The entire set of model activities for the upper and lower watersheds are presented in Appendix A.

Model constraints

The farm production-related constraints were determined by identifying existing constraints on farm activity—that is, constraints on land, labor, and available cash. Additional constraints were developed to account for traditional and experimental crop rotations in the model, as well as to link crop yields with selling activities. Given the fact that men and women work side by side within family groups to carry out the work required for the traditional and experimental cropping activities comprising the model, constraints on labor use by gender group were not included in the model.[13] The Illangama watershed model includes a total of 64 constraints and the Alumbre watershed model contains 48 constraints.[14]

3.2.2 Data Collection and Population of the Model

The data required to populate the activity coefficients and constraints of the programming model included the production costs (labor requirements and other inputs) of current agricultural practices in the study area, the production costs of implementing the experimental practices, current yields and prices, expected or actual yield changes associated with the new practices, and resources available to the average farm household in the study area.

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[13] The author acknowledges that more research is needed to determine whether and to what extent the impacts of conservation agriculture in Ecuador differ by gender.

[14] The full model with all activities and constraints is available by contacting the author.

Model activity coefficients

Interviews with project economists, agronomists, and soil scientists between June 2010 and July 2011 provided data on the experimental conservation agriculture practices which constitute the SANREM CRSP Ecuador project, along with associated costs and yields for the various practices. Data was also obtained through a survey of farmers in the study area conducted between June 9 and June 22, 2011. A total of 45 survey participants in the Illangama watershed, and 43 participants in the Alumbre watershed, were selected randomly among the heads of farm households. Participants included both those practicing conventional agriculture and those implementing the experimental production practices introduced by the SANREM project.

The data gathered through these expert and farmer interviews were used to construct crop budgets for the SANREM control and treatment activities analyzed. Labor required for each cropping activity was compiled on a monthly basis, covering the twenty-four months of the model period. Likewise, input requirements for each crop production activity were combined into a cash costs figure. Finally, the budgets were completed with yield amounts for each production activity. Since the SANREM experiments are ongoing, complete yield information for all cropping activities is not yet available. Therefore, yields used to populate the models were either actual or expected, depending on data availability. Assumptions about expected yields for the various experimental crop production activities were determined through interviews with agronomists involved in SANREM project implementation as described below.

For the upper sub-watershed, Illangama, actual yield data were available for oats-vetch. Since the role of this crop in the SANREM experiment was a cover crop incorporated into the soil to enrich it, the yield data consisted of total vegetation produced—including both edible and non-edible portions of the crop. Based on a comparison with average production yields for the crop in Ecuador obtained from the Statistics Division of the United Nations Food and Agriculture Organization (FAOSTAT, 2011), it was assumed that 5% of the total vegetation produced was edible, and thus saleable at the market price included in the model. Thus the marketable yield coefficients for oats-vetch used for model population were 5% of the measured experimental yields. The same assumption was applied to oats-vetch yields for the Alumbre subwatershed model.

In the Illangama model, yield data for potatoes under current practices (the control treatment) were obtained through farmer interviews. The use of diversion ditches was assumed to have no impact on yields[15], while reduced tillage was assumed to provide a 15% smaller potato yield than conventional tillage, based on initial observations of the experimental plots. For barley, yield under current practices was determined through farmer interviews, and yield was assumed to be 10% greater for barley planted in fields following the tilling under of the oats-vetch cover crop (treatments 2, 4, 6, and 8). The tillage regime was expected to have no effect on barley yield. Finally, for fava beans, data on yield under current practices were acquired through farm household surveys, and the experimental treatment yields were expected to be equivalent to that for the control treatment.

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[15] All assumptions on yield variations among treatments were determined through consultation with the implementing scientists.

For the lower elevation Alumbre sub-watershed, actual yield outcomes were available for all the corn and oats-vetch treatments. (Again, saleable yields of oats-vetch were assumed to be 5% of actual experimental yields.) For beans, information on yields under current practices (conventional tillage, no cover crop) was obtained through interviews with farmers. Based on initial observations of the experimental plots at a pre-harvest stage, it was assumed that yield would be highest under the conventional tillage regime preceded by the tilling into the soil of the oats-vetch cover crop. Compared to this scenario, reduced tillage combined with the incorporated cover crop was assumed to provide 10% less yield, while the removal (rather than tilling in) of the oats-vetch cover crop, combined with either conventional or reduced tillage, was assumed to provide 20% less yield than the first scenario (conventional tillage combined with incorporated cover crop).[16]

Model constraints

The constraint levels on available land were obtained from a 2007 baseline survey of 207 households in the study area, carried out by the National Agricultural Research Institute of Ecuador (INIAP). According to the survey, the average amount of farmland available per family in the upper watershed is 13,108 square meters, while the corresponding figure for the lower watershed is 34,999 square meters. The labor constraint—that is, the amount of available labor for the average farm family—was assumed to be 400 hours per month in both the Illangama and Alumbre watersheds. This amount was determined

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[16] Complete crop budgets for the upper and lower watersheds are available by contacting the author.

based on an average rural family size of two adults and four children, with each adult providing 100 hours of labor per month, and each child supplying 50 hours of labor per month.[17] Thus total available labor per family was calculated to be 400 hours per month. Based on interviews with project scientists familiar with the study area, available cash at the beginning of a six-month period was assumed to be 400 dollars.

3.2.3 Model Implementation and Sensitivity Analysis

The linear programming model was run using Excel Solver software. The model solution for each watershed indicated the optimal mix of production activity levels for the various experimental cropping treatments, which were selected by the Solver program along with the other model activities in order to maximize farm household revenue. The results were analyzed by considering the impact of the model constraint levels on the results, as well as the implications of the shadow prices associated with the constraints, including labor and cash resources (capital). Additional analysis consisted of an examination of the profit reductions that would be brought about by implementing those model activities which were not selected as part of the optimal solution. Finally, sensitivity analysis was conducted to determine the impact of altering the assumptions used in this study as to the expected yield changes from the implementation of conservation agriculture practices.

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[17] The author assumed 25 working days per month, with 4 hours of crop-related labor per day for adults (with the other 4 work hours per day devoted to other farm household activities), and 2 hours of crop-related labor per day for children (with the rest of their time spent at school or on other farm household activities).

3.3 Results

Optimal solutions

The implementation of the Illangama watershed model produced an optimal solution which satisfied the model constraints. The model indicated that 1,180 square meters of land should be planted according to the model's control scenario—that is, the current farm practices of a potatoes, fallow land, fava beans, and fallow land rotation, sown under conventional tillage and without diversion ditches or a cover crop. Additionally, 1,078 square meters should be devoted to experimental cropping activity 5, which calls for a rotation of potatoes, oats-vetch, barley, and fava beans, with conventional tillage, no diversion ditches, and the removal, rather than incorporation into the soil, of the cover crop. Finally, experimental cropping activity 6 should be implemented on 864 square meters of land. Treatment 6 consists of growing the crop rotation potatoes, oats-vetch, barley, oats-vetch, without the use of diversion ditches, under conventional tillage, and with the incorporation into the soil of the oats-vetch cover crop. Taken together, the three sets of cropping activities chosen by the model indicate that diversion ditches are not profitable, given both their high costs and their lack of contribution to yields, and conventional tillage proved to be more economically beneficial than did reduced tillage. Results were mixed as to the profitability of the conservation agriculture treatment of tilling the oats-vetch cover crop into the soil, as well as with regard to which crop rotation is ideal, since the model allocated cropland to three different crop rotations.

The resulting total 3,122 square meters of land planted in the Illangama model would produce 2,926 kg of potatoes in cycle one and 1,106 in cycle four, 447 kg of saleable oats-vetch in cycle two and 184 kg in cycle four, 298 kg of barley, and 123 kg of fava beans in cycle three and 112 kg in cycle four. All crops produced would be sold, resulting in net revenue of 2,283.18 dollars.

The implementation of the Alumbre watershed model also resulted in an optimal solution satisfying all model constraints. This run indicated that cropping activity 3 should be undertaken on 8,286 square meters of land and that no other cropping activities should be implemented. Treatment 3 consists of growing the crop rotation corn, oats-vetch, beans, and oats-vetch, under reduced tillage and manual weeding, and without the incorporation of the oats-vetch cover crop into the soil. Unlike in the upper watershed solution, reduced tillage proved more revenue-optimizing than did conventional tillage. Incorporation of the cover crop was not part of the optimal solution, while in the upper watershed the opposite was true. Manual weeding proved to be more profitable than the use of herbicide. The 8,286 square meters of land would yield 2,897 kg of corn, 2,159 kg of saleable oats-vetch in both cycles two and four, and 2,173 kg of beans. All crops would be sold to yield 7,710.88 dollars in net revenue.

Analysis of the Results and Sensitivity analysis

The model output was analyzed to determine the role of the constraint levels in determining the optimal solutions, as well as the projected impact on revenue that would result from the implementation of those experimental activities not selected as part of the revenue-maximizing cropping system. Seven constraints were binding in the Illangama model: available labor for the months of January (Year 2) and July (Year 2), and available cash—that is, capital—in each of the four six-month model periods. The high labor requirement in January and July of Year 2 results from planting the labor-intensive fava in both current practices and experimental treatment 5. The shadow prices for labor in January and July of Year 2 are $0.57 and $0.16 respectively, indicating that an additional hour of labor in the corresponding months would contribute those dollar amounts to total revenue. In other words, a farmer would be willing to pay up to only $0.57 and $0.16 per hour to hire labor in those periods, which is well below the current wage rate for agricultural labor of approximately $1.00 per hour. There is in fact little labor market activity in the upper watershed. In the Alumbre model, none of the labor constraints are binding.

In the Illangama model, the shadow price for available cash in the second, third, and fourth six-month model periods is $1.00, which suggests that an additional dollar of capital investment for those periods would be rewarded in proportional increases in net revenue. The same is true for the final three available cash constraints in the Alumbre model. This indicates that increased credit availability could improve outcomes for small farmers in the study area. Indeed, the shadow price for available cash in the Illangama model’s first period is about $2.00, and for the Alumbre in the same period it is $16.00, indicating that additional capital at the beginning of the planting cycle would be highly profitable. It is noted that the credit market in both watersheds is minimal to nonexistent.

As indicated in Table 4, the implementation of certain cropping activities that were not selected as part of the optimal solutions in both the Illangama and Alumbre models would lead to reductions in profits.[18] These results indicate that forcing these activities into the model—in other words, choosing to implement cropping activities not determined to be part of the revenue-maximizing solution—would reduce revenue.

Table 4: Profit reduction from implementing non-optimal activities		
Model	**Activity**	**Profit reduction per square meter**
Illangama	Fava beans Treatment 1	-$0.46
	Oats-vetch Treatment 2	-$0.46
	Fava beans Treatment 3	-$0.44
	Oats-vetch Treatment 4	-$0.52
	Fava beans Treatment 7	-$0.04
	Oats-vetch Treatment 8	-$0.06
Alumbre	Beans Current Practices	-$0.26
	Oats-vetch Treatment 1	-$0.08
	Oats-vetch Treatment 2	-$0.05
	Oats-vetch Treatment 4	-$0.04

For the Illangama watershed, a typical farm planting 3,122 square meters of land—as selected by the optimal model solution—would be faced with the reduced profits from implementing non-optimal activities presented in Table 5. A typical farm in the Alumbre watershed, planting 8,286 square meters of land as selected by the linear programming model, would face the profit reductions for each non-optimal model farm activity indicated in Table 6.[19]

Table 5: Profit reduction from implementing non-optimal activities for a typical farm in the upper (Illangama) watershed		
Model	**Activity**	**Reduced Cost for 3,122 square meters**
Illangama	Fava beans Treatment 1	-$1,436.12
	Oats-vetch Treatment 2	-$1,436.12
	Fava beans Treatment 3	-$1,373.68
	Oats-vetch Treatment 4	-$1,623.44
	Fava beans Treatment 7	-$124.88
	Oats-vetch Treatment 8	-$187.32

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[18] All non-selected model activities not listed in Table 4 induce profit reduction of $0.00.

[19] It is important to note that the values in Tables 5 and 6 are high-end estimations, and represent the highest possible reduction in profit that might result from the implementation of the cropping activities not selected by the model.

Table 6: Profit reduction from implementing non-optimal activities for a typical farm in the lower (Alumbre) watershed		
Model	**Activity**	**Reduced Cost for 8,286 square meters**
Alumbre	Beans Current Practices	-$2,154.36
	Oats-vetch Treatment 1	-$662.88
	Oats-vetch Treatment 2	-$414.30
	Oats-vetch Treatment 4	-$331.44

Sensitivity analysis was conducted to determine the impact on the model results of the assumptions used to estimate the yield changes that would result from the implementation of the experimental conservation agriculture practices.[20] In order to test the sensitivity of the results, additional model runs were carried out using more conservative assumptions about the benefits of conservation agriculture. As described under the heading Model Activity Coefficients in section 3.2.2, actual yield data was available for oats-vetch in both the Illangama and Alumbre watersheds, as well as for corn in the Alumbre watershed. Therefore, the model coefficients for these two crops were not altered during the sensitivity analysis, as they were for the other crops. For example, in the case of potatoes in the upper watershed, the original assumption held that reduced tillage (a conservation agriculture treatment) would reduce yields by 15% as compared to conventional tillage. For the purposes of this step in the analysis, reduced tillage was assumed to reduce yields by 30%, or double the original assumptions. Table 7 shows the assumptions used in the original model run, as well as those used for the sensitivity analysis, for the four crops that were subject to sensitivity analysis.

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[20] Sensitivity analysis was not carried out on the labor requirements or cash costs used to populate the model, since these elements of the model were determined using actual, rather than estimated, data.

Table 7: Altered yield assumptions for sensitivity analysis		
Crop (Watershed)	**Original Assumptions**	**Revised Assumptions**
Potatoes (Illangama)	Reduced tillage reduces yield by 15 percent compared to conventional tillage	Reduced tillage reduces yield by 30 percent compared to conventional tillage
Barley (Illangama)	Previous incorporation of oats-vetch cover crop into the soil increases barley yield by 10 percent	Previous incorporation of oats-vetch cover crop into the soil increases barley yield by 5 percent
Fava (Illangama)	Yields are equal under reduced and conventional tillage	Reduced tillage decreases yield by 10 percent
Beans (Alumbre)	Previous incorporation of oats-vetch cover crop into the soil increases bean yield by 20 percent	Previous incorporation of oats-vetch cover crop into the soil increases bean yield by 10 percent

Four additional model runs were implemented for the Illangama watershed: a separate run for each of the crops targeted by the sensitivity analysis (potatoes, barley, and fava), as well as one run incorporating the changed assumptions for all three crops. Under the new barley yield scenario, assuming a smaller yield increase from the incorporation of the oats-vetch cover crop into the soil ahead of the barley planting—that is, a 5 % rather than a 10 % greater barley yield—the results indicated that less barley should be planted. This resulted in the production and sale of 292 kg of barley instead of 298 kg as in the original solution. All other crop production amounts remained the same, resulting in a net revenue of 2,280.79 dollars, compared to 2,283.18 dollars in the original solution. The same solution resulted from the new run of the model incorporating the revised assumptions for potatoes and fava along with barley. When applied individually, the changed assumptions about potatoes and fava beans did not affect the original results. This was expected, since the initial model run indicated that only conventional tillage should be implemented, not reduced tillage, so assuming that reduced tillage would decrease yields even more would surely not bring that conservation agriculture practice into the optimal solution. Likewise, for the Alumbre watershed model, the results were unchanged given the new assumptions about bean yields under conservation agriculture. This makes sense—given that the optimal solution did not include tilling in the oats-vetch cover crop ahead of bean planting, it would certainly not indicate that this activity should be implemented under the new assumptions in which the practice is even less beneficial to yields.

3.4 Conclusions

Based on the findings of this study, it is clear that innovative conservation agriculture practices have the potential to improve the livelihood of the rural poor in Ecuador, and perhaps throughout the Andean region, since experimental SANREM activities were included in the revenue-optimizing solution for both watershed models. For both the higher-elevation Illangama watershed and the lower-elevation Alumbre watershed, the results produced by the linear programming model developed for this study indicate that innovative cropping practices—either alone or in combination with current practices, depending on the watershed—can provide higher net revenue than do current practices alone.

This study makes a significant contribution to the literature concerning the impact of conservation agriculture by examining the profitability of this still-evolving approach to agriculture in a controlled, experimental setting. The cropping systems being tested as part of the SANREM CRSP research and development program in Ecuador allow a systematic analysis of the benefits and costs of conservation agriculture.

Recommendations for further research

The primary shortcoming of this study was the absence of a soil quality constraint in the programming model. Indeed, one of the main objectives of conservation agriculture research and programs is to develop innovative approaches to conserving the soil and the other ecological resources on which the long-term productivity of agriculture depends. The inclusion of a soil quality constraint in each model would facilitate the analysis of the impact of conservation agriculture on the natural resource base. The magnitude of the soil loss constraint—that is, the amount of soil loss permitted by the model, represented by the right hand side of the soil loss constraint in the model—would be determined by an analysis of both current erosion levels and optimal soil conditions under conservation agriculture systems, as determined by soil scientists. The soil quality coefficients in the model would represent the changes in soil quality brought about by the various conservation agriculture treatments, and could be estimated using data on soil organic content (organic carbon), water runoff, or another relevant soil quality indicator Furthermore, the right hand side value for the soil loss constraint—that is, the combined amount of soil degradation (i.e. soil runoff, reduced organic content, etc.) brought about by the crop production activities could be adjusted to assess the impact of altering the targeted level of soil quality to be attained by the implementation of conservation agriculture practices. The implementation of this analysis would require the ongoing collection of soil quality data specifically linked to the experimental crop production treatments under consideration, for a period of time adequate to capture accumulated impacts on soil quality—that is, a minimum of three, and as many as ten, years. In fact, the current phase of the SANREM CRSP project in Ecuador includes a research component focusing on soil carbon content. Experiments are underway to collect and analyze soil samples from the various experimental conservation agriculture farm plots. Thus, the data needed to complete the current study with an analysis of the impact of conservation agriculture techniques on soil quality will be available within the next three years.

References – Chapter Three

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Chapter Four

Conclusions

The two papers comprising this thesis, “Expected economic benefits of meeting nutritional needs through biofortified cassava in Nigeria and Kenya,” and “Projected farm-level impacts on income of conservation agriculture in the Andean Region,” serve to broaden the base of economic understanding about the wide-ranging effects of agricultural innovation. It is clear from the findings of each paper that technological advances in agricultural can make real contributions to overall societal well-being, whether in the area of public health or the environment. As presented in Chapter Two, the cassava biofortification project in Nigeria and Kenya is likely to improve public health outcomes by combating micronutrient deficiencies, and to do so at a lower cost than alternative interventions such as supplements and conventional fortification. Likewise, the findings of Chapter Three suggest that the experimental conservation agriculture technologies currently being implemented in Ecuador have the potential to increase yields and income for rural Andean farmers, as well as enhancing soil organic content over time, leading to greater environmental quality.

Given the current difficulties in the world economy and the increasing competition among worthwhile projects for the limited available funds, well-executed economic impact assessments will continue to be an essential component of project evaluation in a variety of fields, including agriculture, public health, the environment, and education, among others. The author hopes that this thesis will serve as a template for carrying out economic impact assessments on diverse projects in various geographic regions.

Appendix A: Model Activities for the Upper and Lower Watersheds

Model Activities: Illangama (Upper) Watershed									
#	**Category**	**Activity**	**Crop**	**Diversion Ditches**	**Tillage Regime**	**Rotation**	**Cover Crop Treatment**	**Planting Cycle**	**Model Label**
1	Production Activities	See Crop, Diversion Ditches, Tillage Regime, Rotation, Cover Crop Treatment, and Planting Cycle Columns	Potatoes	No ditches	Conventional	Conv	-	1	PoNdCC1
2			Potatoes	Ditches	Conventional	1	-	-	PoDC1
3			Potatoes	Ditches	Conventional	2	-	-	PoDC2
4			Potatoes	Ditches	Reduced	3	-	-	PoDR3
5			Potatoes	Ditches	Reduced	4	-	-	PoDR4
6			Potatoes	No ditches	Conventional	5	-	-	PoNdC5
7			Potatoes	No ditches	Conventional	6	-	-	PoNdC6
8			Potatoes	No ditches	Reduced	7	-	-	PoNdR7
9			Potatoes	No ditches	Reduced	8	-	-	PoNdR8
10			Potatoes	No ditches	Conventional	Conv	-	4	PoNdCC4
11			Oats-vetch	Ditches	Conventional	1	Remove	2	OaDC1cr2
12			Oats-vetch	Ditches	Conventional	2	Do not remove	2	OaDC2sr2
13			Oats-vetch	Ditches	Reduced	3	Remove	2	OaDR3cr2
14			Oats-vetch	Ditches	Reduced	4	Do not remove	2	OaDR4sr2
15			Oats-vetch	No ditches	Conventional	5	Remove	2	OaNdC5cr2
16			Oats-vetch	No ditches	Conventional	6	Do not remove	2	OaNdC6sr2
17			Oats-vetch	No ditches	Reduced	7	Remove	2	OaNdR7cr2
18			Oats-vetch	No ditches	Reduced	8	Do not remove	2	OaNdR8sr2

19			Barley	Ditches	Conventional	1	-	-	BaDC1
20			Barley	Ditches	Conventional	2	-	-	BaDC2
21			Barley	Ditches	Reduced	3	-	-	BaDR3
22			Barley	Ditches	Reduced	4	-	-	BaDR4
23			Barley	No ditches	Conventional	5	-	-	BaNdC5
24			Barley	No ditches	Conventional	6	-	-	BaNdC6
25			Barley	No ditches	Reduced	7	-	-	BaNdR7
26			Barley	No ditches	Reduced	8	-	-	BaNdR8
27			Fava Beans	No ditches	Conventional	Conv	-	-	FaNdCC
28			Fava Beans	Ditches	Conventional	1	-	-	FaDC1
29			Fava Beans	Ditches	Reduced	3	-	-	FaDR3
30			Fava Beans	No ditches	Conventional	5	-	-	FaNdC5
31			Fava Beans	No ditches	Reduced	7	-	-	FaNdR7
32			Oats-vetch	Ditches	Conventional	2	Do not remove	4	OaDC2sr4
33			Oats-vetch	Ditches	Reduced	4	Do not remove	4	OaDR4sr4
34			Oats-vetch	No ditches	Conventional	6	Do not remove	4	OaNdC6sr4
35			Oats-vetch	No ditches	Reduced	8	Do not remove	4	OaNdR8sr4
36	Selling Activities		Potatoes	-	-	-	-	1	SPoCyc1
37			Oats-vetch	-	-	-	-	2	SOaCyc2
38			Fava beans	-	-	-	-	3	SFaCyc3

39		See Crop and Planting Cycle Columns	Barley	-	-	-	-	3	SBa3
40			Potatoes	-	-	-	-	4	SPoCyc4
41			Fava beans	-	-	-	-	4	SFaCyc4
42			Oats-vetch	-	-	-	-	4	SOaCyc4
43	Cash Transfer Activities	Cash Transfer 1	-		-	-			CTR1
44		Cash Transfer 2	-		-	-			CTR2
45		Cash Transfer 3	-		-	-			CTR3
46		Cash Transfer 4	-		-	-			CTR4
47	Revenue Activities	Net Revenue	-		-	-			REV

Model Activities: Alumbre (Lower) Watershed

#	Category	Activity	Crop	Tillage Regime	Rotation	Weed Control	Cover Crop Treatment	Planting Cycle	Model Label
1			Corn	Conventional	Conv		-	-	CoCC
2			Corn	Conventional	1	Weed	-	-	CoCW1
3			Corn	Conventional	2	Herbicide	-	-	CoCH2
4			Corn	Reduced	3	Weed	-	-	CoRW3
5			Corn	Reduced	4	Herbicide	-	-	CoRH4

6	Production Activities	See Crop, Tillage Regime, Rotation, Weed Control, Cover Crop Treatment, and Cycle Columns	Oats-vetch	Conventional	1	-	Remove	2	OaC1cr2
7			Oats-vetch	Conventional	2	-	Do not remove	2	OaC2sr2
8			Oats-vetch	Reduced	3	-	Remove	2	OaR3cr2
9			Oats-vetch	Reduced	4	-	Do not remove	2	OaR4sr2
10			Beans	Conventional	Conv	-	-	-	BeCC
11			Beans	Conventional	1	-	-	-	BeC1
12			Beans	Conventional	2	-	-	-	BeC2
13			Beans	Reduced	3	-	-	-	BeR3
14			Beans	Reduced	4	-	-	-	BeR4
15			Oats-vetch	Conventional	1	-	Remove	4	OaC1cr4
16			Oats-vetch	Conventional	2	-	Do not remove	4	OaC2sr4
17			Oats-vetch	Reduced	3	-	Remove	4	OaR3cr4
18			Oats-vetch	Reduced	4	-	Do not remove	4	OaR4sr4
19	Selling Activities	See Crop and Cycle Columns	Corn	-	-	-	-	-	SCo
20			Oats-vetch	-	-	-	-	2	SOa2
21			Beans	-	-	-	-	-	SBe
22			Oats-vetch	-	-	-	-	4	SOa4
23	Cash Transfer	Cash Transfer 1	-	-	-	-	-	-	CTR1
24		Cash Transfer 2	-	-	-	-	-	-	CTR2

25	Activities	Cash Transfer 3	-	-	-	-	-	-	CTR3
26		Cash Transfer 4	-	-	-	-	-	-	CTR4
27	Revenue Activities	Net Revenue	-	-	-	-	-	-	REV