Impact Methods to Predict and Assess Contributions of Technology (IMPACT)

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Final Report

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Submitted By

Impact Assessment Group
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In Collaboration with

Kenyan Minister of Agriculture
Kenya Agricultural Research Institute
International Livestock Research Institute
Institute of Rural Economy
Institute of Sahel

Foreword

This is the final report for Grant #PCE-G-00-97-00051-00 which was initiated October 1, 1997 and completed December 31, 1999. Quarterly reports were submitted, along with interim progress reports, for major milestone events during the course of the grant. This report completes the work called for under the grant.

The research is being continued under the SANREM CRSP Global Project under the title of Global Decision Support System. In this ongoing research, the aim is to continue to develop and apply the models developed under this effort at national, regional, and global levels to assess the impact of options for technology and policy to improve sustainable use of natural resources to achieve improved food security in the new century. The overall effort under this grant has been, and continues to be, augmented by funding from the U.N. Food and Agriculture Organization and the Africa Bureau of USAID. Research is being continued in Kenya and Mali.

The research done under this grant involved collaboration with a number of institutions supported by USAID. In developing these methods for impact assessment, we selected technology developed by both the CRSPs and the IARCs. We collaborated with these organizations and their national and regional partners. In West Africa, collaboration was established with the INTSORMIL CRSP including U.S. University and national partners in Mali, Senegal, and Burkina Faso. We also collaborated with the Peanut CRSP in this region. In East Africa, we collaborated with the International Livestock Research Institute (ILRI) and their partners, the Kenya Agricultural Research Institute and the Ministry of Agriculture and Rural Development in the Government of Kenya. We also worked with ILRI's research and government partners in Uganda and Tanzania. Through these relationships, we were able to acquire and evaluate experimental results for the technologies that were used as platforms for developing our methods. We benefitted greatly from the knowledge and wisdom of colleagues and farmers operating in these parts of Africa. We wish to express our thanks to both the institutions and people in these settings that enabled the success of our model development and validation.

To ensure technology transfer of the results of this grant, we conducted two workshops in Mali. One was in December 1999 and the second in July 2000. These workshops involved senior decision makers and analysts in the Government of Mali as well as colleagues in the Mali Institute of Rural Economy(IER). We established and are continuing Memoranda of Understanding with the Institut du Sahel as well as IER in West Africa. These enable collaboration at both the national level in Mali and at the regional level with the CILSS countries. In Kenya, we held two workshops on the Smallholder Dairy Technology assessment, one in October 1998 and one in September 2000. A planning workshop was also held in September 2000 to continue the development and application of these models for use by the Government of Kenya (GOK) in assessments of options to enhance food security through the sustainable use of critical natural resources. In both East and West Africa, an important emerging analytic capacity is being provided for use in risk assessment and aversion in longer term planning.

In July 2000, the USAID Office of Agriculture and Food Security organized a national workshop in Washington on Impact Assessment. This provided a major opportunity to present and discuss the IMPACT methods with decision makers and scientists from USAID, World Bank, all of the CRSPs and the International Agricultural Research Centers. We express gratitude to the sponsor for organizing this workshop and for their support of this research.

We were very fortunate to have the active collaboration of two key individuals from national research organizations. Dr. Robert Kaitho, a KARI scientist has been a key collaborator throughout these studies. We would also like to recognize the contribution of Mr. Alpha Kergna of IER in Mali for his continuing contributions as our principal coordinator of the collaborations in that country. As part of the follow-on effort under SANREM, long term training at Texas A&M was provided for Dr. Kaitho and the same training is planned for Mr. Kergna.

The Texas A&M collaborators who were responsible for research conducted under this grant were members of the Impact Assessment Group(IAG). This is an interdisciplinary group from the fields of agricultural economics, environmental sciences, ecology and geography. We are part of the Agriculture Program of the Texas A&M University System. As described in the report, the major thrust of this research was to develop a holistic and integrated approach to impact assessment of technology or policy options for food security and natural resources management. This team brought together the several existing capacities for impact assessment. They extended the methods and developed new approaches for integrating these into IMPACT. The members of this group that contributed to IMPACT are shown in the following table.

The members of the IAG wish to express their appreciation to Ms. Penny Banks of the Department of Agricultural Communications at Texas A&M for serving technical editor for the preparation of this report. We also express thanks to Ms. Toni Bland, Administrative Assistant to the Office of the IAG for her contributions in administration of the grant and the Group.

Members of the IAG also express their appreciation to Dr. Edward A. Hiler, Vice Chancellor for Agriculture at Texas A&M for his moral and fiscal support of the Group and for the cost sharing that was done for this project.

As coordinator for the Impact Assessment Group, I would like to add my personal thanks to all the members of The Impact Assessment Group. The product of our effort is clearly greater than the sum of the parts and the willingness and efforts of the members of this group to make the pieces fit together are a major part of the total contribution.

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Abstract

This report covers research done for the USAID Office of Agriculture and Food Security of the Center for Economic Growth and Agriculture (Global Bureau). The overall objective was to develop and evaluate methods to assess the impact of the introduction and use of technology resulting from USAID investments in agriculture and natural resources for developing countries. A suite of integrated, interactive models was created for use in developing countries to assess the economic, environmental, and societal impact of such technologies. The research, conducted in East and West Africa, involved acquiring relevant databases and expert opinions through collaboration with national and regional partners; establishing a spatial framework using GIS methods to organize and analyze spatially explicit information; developing biophysical models to estimate production and environmental consequences of new technology; and adapting and using economic sector and farm-level models to estimate their economic consequences. Environmental consequences were estimated at field, area, and watershed levels. Methods were developed and evaluated to estimate the adaptation of new technology to geographically similar zones in areas that were both contiguous and non-contiguous to the locations where the technology was developed. The approach involved using research sponsored by USAID as case studies for developing and evaluating methodology. This provided both new methodologies and illustrative examples of the utility of the products. The project has proven the concept for the approach and, while the resulting products are judged to be imperfect, they are usable for the stated purposes. Further development is being continued under the Global Project of the SANREM CRSP.

Acronymns

AFS	USAID Office of Agriculture and Food Security
CGIAR	Consultative Group for International Agricultural Research
CMDT	Campagnie Malienne pour le Diveloppement des Textiles
CRSPs	USAID Collaborative Research Support Program
DANIDA	Danish Development Assistance
ENSO	El Niño Southern Oscillation
ICRISAT	International Center for Research in the Semiarid and Arid Tropics
IER	The Malian Institute of Rural Economy (Institut Economique Rurale)
IMPACT	Impact Methods to Predict and Assess Contributions of Technology
INTSORMIL CRSP	International Sorghum and Millet Collaborative Research Support Program
MOA	Memorandum of Understanding
MOA	Ministry of Agriculture
NCGIA	National Center for Geographic Information and Analysis
NDVI	Normalized Difference Vegetation Index
NOAA RFE	National Oceanic and Atmospheric Agency Russian Far East
PNVA	Programme National de la Vulgarisation Agricole
SANREM CRSP	Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program
UNDP	United Nations Development Program
USAID	U.S. Agency for International Development
USGS	United States Geological Survey
WxGEN	Weather Generator for EPIC

Units

KSH	Kenya Schilling
USH	Uganda Schilling
MT	Metric Ton
FCFA	Central African Francs

Section 1: Overview and Summary

1.1 Introduction

In the post-cold war era, there is growing competition for funds for international development and increasing pressure to wisely select, justify, and demonstrate the utility of these investments. Similarly, decision makers in developing countries are faced with the need to make choices among options for investing very scarce resources to sustainably enhance the efficiency of food production. Methods such as those developed in this project are needed to assist the decision-making process by providing quantitative estimates of the economic, environmental, and societal consequences of the options to be considered, including investment in research and technology development. There is also need to provide national decision makers improved capability to monitor progress toward achieving their goals relative to various international agreements and conventions.

1.2 Roles of Impact Assessment in International Development

USAID and the World Bank sponsored a workshop at the University of Georgia at Athens in October 1995 to define a set of variables (indicators) that could be used to measure progress toward achieving stated goals in agricultural research and development for the agency. A hierarchical set of six goals and objectives was defined to broadly represent the combined investment strategy of USAID and the CGIAR. The product of the workshop was a tiered set of indicators judged to be useful in defining progress toward meeting these goals. The intent was to contribute to the broader process of impact assessment and evaluation that is underway in the CGIAR while addressing the specific needs of the agency. This was viewed as a first step in a development process leading ultimately to a framework and methodologies for assessing the impact of international agricultural research and development. It was intended that this would build on and enhance the existing methodologies used by the IARCs and donor agencies.

At the Athens workshop, specific indicators were proposed that would define progress toward achieving the six management level goals. Table 1.2.1 shows the management goals and related indicators from the workshop. It was recognized that the management goals and indicators are highly interrelated in practice. Production practices have environmental consequences. The availability of natural resources paces the capacity to produce food. These relationships illustrate why a complete assessment of impact requires an integrated suite of models.

The third column in Table 1.2.1 lists the primary models or methods developed or adapted in this project to evaluate progress toward achieving the goals. The integrated suite of models for IMPACT (Impact Methods to Predict and Assess Contributions of Technology) assists decision makers to maintain the broader perspective in judging the merits of alternative strategies for international development directed at enhancing the sustainable production of food.

Table 1.2.1 Goals, indicators, and primary models and methods used for IMPACT

Management Goal	**Management Level Indicators**	**Primary Models and Methods from IMPACT**
Productivity Increase	Index of international prices of major staple food commodities Total annual food production in developing countries	Ag Sector model Farm-level models Biophysical models
Marketing/Utilization Improvement	Value added to raw agricultural products	Input / Output models Global Ag Sector Model
Policy Reform	Equity distribution of benefits of development	Ag Sector Model Farm-level models Biophysical models
Management and Conservation of Natural Resources	Land area under improved natural resource management	Biophysical models Watershed models Economic models
Ecoregional / Global Integration of Results	Common goals and indicators across nations for regional and global affairs	Global Ag Sector Model Watershed Models Common GIS Frame-work
Institutional Capacity Building	NARS institutional capacity Adequacy of national policy environments	Graduate fellows Workshops Mentoring

The conceptual framework for IMPACT is shown in Figure 1.2-1. The distinguishing aspect of this methodology is the interactive linkage of models that assess environmental, economic, and societal consequences of the introduction of new technology. The suite of models may be used together or in parts, depending on the nature of the assessment. The geographic and institutional scales at which the methods have been developed and tested include farm or household, watershed, sub-national (provincial), and national levels. As the methods evolve, there is ongoing effort to provide better means of relating the output of models at these various levels of scale.

Another important feature of IMPACT is developing a spatial framework and analysis capacity for related data and information that are linked to the suite of models. This provides a means of organizing and processing related databases into a geographically coherent manner. The processed data is referred to in this method as foundation data, which can be used repeatedly for similar analyses.

Spatially explicit analysis of related geographic variables provides a basis for establishing areas of similar agro-environmental characteristics. This offers a more precise mechanism for establishing appropriate sampling frames for the assessment and is used in estimating areas of geographic equivalence where a technology package or policy option developed for one site might be adaptable to another. The methods have been used to predict the adaptability of technology developed in one country to geographically equivalent regions in adjacent countries.

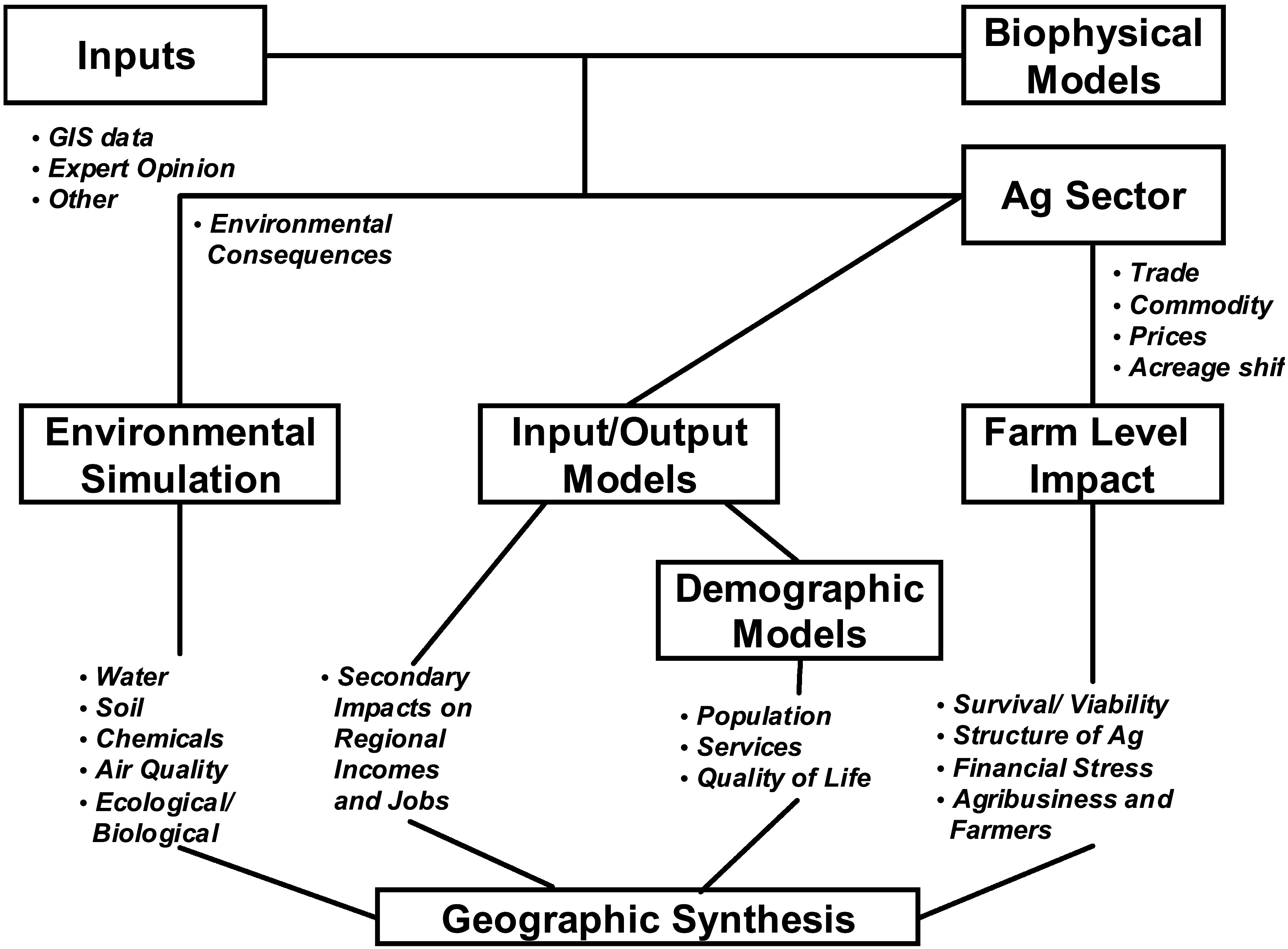


Figure 1.3-1. Impact Assessment Relationship and Outcomes

Ensuring usability of the products is a major challenge for this project. Workshops and longer-term training will be limited in this effort but continued in subsequent activities. Packaging the data and models into usable forms for counterparts in developing countries is part of the overall effort. Potential users of IMPACT in developing country locations will have full access to both methods and information.

1.3 Defining the Dimensions of Assessment

Careful consideration at the outset of the dimensions of the assessment to be undertaken with clear definition of the information and data requirements improves the efficiency and sharpens the focus of the analysis. While these principles and guidelines may appear to be recognized features of standard practice, they became even more important as IMPACT dealt with the interface problems and issues associated with the diversity of disciplinary backgrounds and model formats that were integrated in the overall methodology. The dimensions of the assessment could best be defined by dealing with a set of "what and where" questions. These questions are summarized in Table 1.3.1.

Table 1.3.1. Dimensions of the Assessment.

Subject Matter "What" Questions	Spatially Linked "Where" Questions
Initial Conditions	**Initial Conditions**
Terms of the technology or policy to be assessed	Definition of the geographic area in which the assessment will occur
Baseline conditions into which the technology or policy will be introduced	Economic and statistical data defined by political boundary
Definition of missing data and plans for acquiring or estimating them	Historical data on representative farms
Assumptions about adoption and factors affecting it	Experimental and demonstration data for the technology package being assessed
Externalities affecting adoption	Natural resource, environmental, and meteorological data (georeferenced)
Historical data and information needed for stochastic analysis	Relevant agro-environmental zones (geographically equivalent)
Products and outputs resulting from change	**Locations of outcomes of technology or policy adoption**
Economic outcomes	Commodity shifts along economic and risk-based gradients
Environmental outcomes	Intensification vs extensification
Societal outcomes	Prediction of adaptation using geographic equivalence
	Adaptation vs Adoption

1.3.1 The "What Questions"

The "what" or subject matter questions are of two types: (a) what are the initial conditions to be defined for the assessment and (b) what are the products of the assessment. The "where" questions deal with spatially explicit components of initial conditions and products.

1.3.1.1 Initial Conditions for the Assessment:

- What is the precise operational definition of the technology or policy option to be evaluated? What is the technology, what change will occur, how will it be measured?

- What is the baseline situation into which the technology or policy option will be introduced? What variables must be defined to state the baseline condition and estimate the effects of introducing the option? Examples at varying levels of scale include:

  - Cost of production
  - Changes in yield
  - Risk (economic and biophysical)
  - Current land use and related practices
  - Natural resource and environmental threats
  - Natural resource availability and competition (water and land) for expansion
  - Local, regional, national, and international (global) markets
  - Sociologic factors affecting change

- What data critical to the assessment are not available and what alternative modeling methods can be used to estimate the missing inputs?

- What variables are critical to the assessment but not modeled and which must be acquired in other ways and how will this occur (e.g., adoption rates)?

- What assumptions about adoption of technology or policy must be made or understood?

- What externalities will affect adoption of technology or policy change and how will they affect it? Examples include:

  - Population growth
  - Markets
  - Weather
  - Capital availability

- What historical data are necessary to model states of nature, markets, and other stochastic variables that affect the estimate of outcomes and the risk associated with various practices? How will these data be acquired or estimated?

1.3.1.2 Examples of Products or Outputs of Models:

- Assuming decisions are driven by economic and risk aversion strategies at the farm level, what changes result from introduction of new technology or policy? Examples include:

  - Changes in quantities, prices, and location of food
  - Changes in producer and consumer benefits - Who will benefit and who will be disadvantaged by adoption of the technology or policy?
  - Defining change at national, provincial, farm or household and other levels of institutional scale
  - Shifts in land use among and between commodities
  - Intensification and extensification to meet changing demand and their effects

- What will be the long-term environmental and natural resource consequences?
  - Soil
  - Water
  - Downstream consequences of upstream practices

1.3.2 The "Where" Questions:

Defining the dimensions of assessment also involved developing and answering the "where" or spatially linked questions. The use of GIS methods and spatially explicit analysis is a critical part of the methodology of IMPACT both for geographically framing the initial conditions (locations) into which the options will be placed and for projecting the possible locations where outcomes of technology or policy will be manifest.

1.3.2.1 Initial Conditions

Bringing together answers to the "where" questions is made difficult in IMPACT because much of the needed primary and secondary statistical data is stratified by political boundaries under which it was collected while utility of the technology or outcome of policy options is based on biophysical and geographic variables that transcend these boundaries. Politically defined boundaries do not conform to biologically defined areas for agricultural production. A substantial part of developing IMPACT was providing methods to link data and results from politically and agro-environmentally defined areas of land use. This method moves past the previous use of arbitrarily drawn contiguous agro-ecological zones to use GIS methods for more precisely defining the biologically significant differences within and between politically defined land areas.

- Statistical data collected within politically defined boundaries (e.g., district, province, national) provide critical "where" inputs to both economic and environmental models. Examples include:

  - Land use by commodity
  - Quantity and quality of commodity produced
  - Income and purchasing power
  - Distances to markets, roads, and infrastructure relevant to production, processing, and distribution
  - Distribution of population

- Historical data on farms or households that are representative of the regional agriculture and agro-environmental areas under study.

- Georeferenced experimental and demonstration data relevant to the performance of farming systems using technology being assessed.

- Natural resource, environmental, and meteorological data are often collected using methods that transcend politically defined boundaries with distributions that can be georeferenced. Examples are:

  - Meteorological data collected at weather stations or estimated from satellite imagery (including methods to compute meteorologic surfaces from point sources of measurement)
  - Soils
  - Elevation
  - Biological constraints to production of given commodities such as disease, insects, and other pests

1.3.2.2 Locations of Outcomes of Adopting Technology or Policy Options

The "where" questions are also critical in projecting the location(s) where the technology or policy option could be or has been manifest. Two principal outcomes were modeled that produced answers to the where questions: (a) what land areas are involved when commodities are displaced to achieve an improved economically driven equilibrium within the agriculture sector and (b) does the displacement involve intensification or extensification.

Where use of a practice, technology, or policy option was modeled, we defined two generic ways in which this could occur. Intensification involves exercising the option on land areas currently used in production of the relevant commodity(s) - creating more product with the same land area in the same location. For purposes of our analysis, we defined intensification to include the displacement of one commodity by another within existing land areas suitable for production of both commodities. Displacement in these models occurs when the technology or policy option causes a more favorable economic outcome relative to current land use. Extensification is the process of introducing production into land areas that were previously unused or used for less intensive purposes. In practice, to meet the demands for food imposed by increasing population, extensification has often involved exploiting marginal lands with resultant degradation and/or desertification. These terms define the limits of a continuum of land use change resulting from outcomes driven by technology or policy options.

The concept of geographic equivalence was employed as a means of defining land areas which are geographically similar to sites where technology has been developed or adopted. What constitutes geographic equivalence was determined experimentally. For instance, one of the most important variables across large land areas was found to be minimum and maximum temperatures and the ratio of precipitation to evapotranspiration. Other variables include soil type and elevation. We used these variables in cluster analyses to estimate contiguous and noncontiguous land areas to which the technology or policy option under assessment could be adapted. This was the first of several steps in predicting the use of technology at other locations.

Other georeferenced factors or constraints were introduced to refine or "trim" the area of possible adaptation. One can define the area to varying levels of scale, depending on the need for the assessment and the computational capacity available. At this point, it was possible to compare the estimates derived from the geographic equivalence analysis with the reported distribution of the commodity in question. This contributes to verification of the model output and points the way toward estimating whether adoption in this area would involve intensification or extensification. The term adoption was used where evidence indicated the technology or policy option would actually be used. Adaptation reflects geographic equivalence and adoption, to reflect the sum of all factors, including geographic ones that drive the use of technology or effect of policy.

In situations where farm-level assessments are done, defining agro-environmental zones with geographic equivalence provides a quantitative and statistically valid method of establishing adequate and sufficient sampling frames for further site specific experimentation – i.e. the location of individual farms that are average or modal farms representative of the area under study.

A similar method was developed to interface biophysical models that estimate outputs such as yield and erosion with economic models that produce output at the level of politically defined boundaries. Polygons representing geographic conditions or agro-environmental zones were created using the almanac characterization tool (ACT) which includes foundation databases relevant to agricultural production. Within each agro-environmental zone, the EPIC model was used to estimate yields and environmental consequences for each of the major commodities in the agricultural sector of the country involved. The ACT was used to aggregate polygons within politically bounded land areas to create estimates of yields. These estimates were compared with statistical data, where available, at the district or province level as a means of verification of the methods used. The assessment of the economic impact of introducing new technology at the politically bounded areas was done by comparing baseline and changed conditions. Explanations of the models will follow in another section.

Assessment of the impact of technology or policy options at the watershed level is both ecologically and politically relevant. The consequences of changes in farming practices at the field level are integrated at the watershed level and the downstream consequences of upstream practices are estimated. We used a combination of field, area, and watershed models to estimate the consequences of erosion and use of chemicals on water quality and quantity in a watershed representative of a diversity of the agriculture, as in Kenya where we had studied at farm and province levels. The same methods of determining baseline conditions and estimating effects of introducing new technology at field and province level were employed to develop inputs for watershed models. Results were correlated with measured streamflow data.

Summary Generic Approach
The discussion of the general approach described above is summarized here. The details of the methods are contained in subsequent sections of the report or in appendices. · Define the Dimensions of Assessment · Establish a baseline scenario against which effects of change will be estimated · Define explicit scenarios to be modeled · Establish a spatial framework for the analysis · Identify sources of expert opinion or knowledge at the appropriate level of scale · Define information needs, acquire information, estimate missing data · Parameterize and modify or develop models · Define linkages between models for input-output and iterative relationships · Acquire or estimate inputs to models · Conduct iterative analyses and evaluation of model outputs - separate and aggregate · Interpret · Focus on capacity building and transfer to user(s) · Clearly define goals and procedures in a multidisciplinary operational environment · Meet the needs of different decision makers

1.4 The IMPACT Toolkit

The basic framework of models, data management methods, and display techniques offers a variety of capacities from which to develop specific assessment methods. Choosing the suite of models and data requires consideration of a number of specific factors that define the analysis. It was also important to understand the resolution and extent of impact that will be studied and the analytical capability of in-country collaborators who will use the system after the analysis is completed. Is the focus economic only? If so, should analyses be confined to the national level, sub-national (provincial), and/or household level? Should spatial analysis be confined to administrative reporting entities or should the analysis be stratified based on geographic equivalence, agro-ecological zones or bio-market clusters? Should stochastic response of crops, livestock, and markets be considered in the analysis? If so, at what level should probabilistic response be applied? Can probability distributions be assigned from secondary or primary data? If not, which biophysical model(s) should be applied to the situation? Are the necessary support data readily available to conduct biophysical analyses? If sparse, is it possible to use an array of data estimation tools to project the data spatially and through time? Can rapid survey and data acquisitions methods be used to generate the data in a timely manner? If environmental impact is called for, which attributes will be studied? At what scale and level of resolution will landscape components and processes be represented in the analysis? Will spatial extrapolation be required for adjacent countries? Is socio-demographic impact analysis required?

The current set of tools that are actively used in the impact assessment process are listed below. Descriptions of these models can be found in the Web sites and references listed.

Spatial Characterization Tool (SCT)/Almanac Characterization Tool (ACT) – required to establish the spatial extent of the technologies and/or policies, extract socio-environmental data to classify socio-environmental zones and conduct geographical equivalence analysis for regional extrapolation. http://www.brc.tamus.edu/char/index.html

Agricultural Sector Model (ASM) – equilibrium sectoral economics model used to conduct national and sub-national level analyses of price, production, consumption, and foreign trade responses to technology and policy by state of nature across multiple regions, farm produced commodities, and processed products.

Global Agricultural Sector Model (Global-ASM)- extension of ASM used to look at multi-country and trade impacts of technology and policy in terms of production, consumption, and trade impacts across 28 regions of the world.

Farm Level Income and Policy Simulation Model (FLIPSIM) – establishes the household level response to technologies and subsequent response in terms of income, net worth, and household survival (income, nutrition). http://www.afpc.tamu.edu/models/

Erosion Productivity Impact Calculator (EPIC) – georeferenced, hydrologic-based crop production and environmental response simulation model needed for determining variability of crop yields, erosion, nutrient loss (N, P), and pesticide loading in response to management input and weather dynamics. http://www.brc.tamus.edu/epic/

Phytomas Growth Model (PHYGROW) – georeferenced hydrologic-based multiple plant/animal species simulation model capable of reflecting complex grazing land environments in terms of plant response, animal selective grazing, animal response (stocking, performance), and complete water balance. This tool was developed by the Center for Natural Resource Information Technology at Texas A&M University. http://cnrit.tamu.edu/rsg/phygrow

Soil and Water Assessment Tool (SWAT) – spatially explicit, basin-scale hydrology model capable of generating, routing, and assessing dynamics of runoff, erosion, and agricultural chemicals in large multiple sub-basin systems. http://www.brc.tamus.edu/swat/

Nutritional Balance Analyzer (NUTBAL PRO) – protein and energy balance simulation model for cattle, sheep, goats, and horses with ability to predict gain/loss, milk yield, and optimum feedstuff mediation. This tool was developed by the Ranching Systems Group in the Center for Natural Resource Information Technology at Texas A&M University.
http://cnrit.tamu.edu/ganlab/Pages/nutbal.htm

Statistical Analysis System (SAS) – a statistical analysis package used to generate critical coefficients for the weather generators and establish adjustments to coefficients due to the ENSO effects.

MINITAB Statistical Analysis Package – a statistical analysis package used to conduct multivariant analysis for principle component cluster analysis in support of defining production system types (household level) and associated socio-environmental zones from household surveys.

Climate Generator (WxGEN) - weather generator used to produce variation in weather for each of the representative farms and associated virtual landscapes for each of the socio-environmental zones, regionally synchronized with southern oscillation index stage sequences.
http://www.brc.tamus.edu/epic/

World Meteorological Organization's Weather Station Database CD - the data from 1973 to 1997 are set up on a CD with all missing values of minimum/maximum temperature, precipitation, and radiation are filled via the WxGEN program. Weather generator coefficients for the WxGEN program are provide for more than 7,000 weather stations worldwide.

Mapping Unit Utility Function (MUUF) - a comprehensive program that allow estimation of soil physical, chemical, and hydrological attributes for use in biophysical models.
http://www.brc.tamus.edu/epic/

Soil Parameter Generator (SPG) – program that translates traditional soils profile data and generates and stores in database format critical soil parameters for the hydrologic-based biophysical models. This is a spreadsheet and Web-based program developed by Washington State University.
http://www.brc.tamus.edu/epic/

ArcView GIS – a commercial GIS tool needed to create shape files of survey data, weather stations, and other support data used in the analysis in the Spatial Characterization Tool and Almanac Characterization Tool.

Land Demand – a spreadsheet-template that allows computation of land area required to support forage demand of a specified population of livestock considering intake requirements and forage production capacity of the land supporting them. This tool was developed by the Center for Natural Resource Information Technology at Texas A&M University.

WINDISP3 Satellite Imagery Analysis Tool – a software package for displaying and analyzing time-series satellite images. The software is tailored specifically for monitoring vegetation and weather via satellite images for early warning of droughts, crop failures, and fire danger. Other related data sets, such as maps and tables, can be displayed and analyzed in the context of the satellite images.

NOAA RFE Precipitation Extraction System - a Web-based software tool developed by the Center for Natural Resource Information Technology at Texas A&M University that allows input of longitude and latitude and retrieval of NOAA RFE daily precipitation estimates in 16 countries.
http://cnrit.tamu.edu/rsg/rainfall.

FAO Plants and Soils Databases - these online databases (e.g. ECOCROP) were used to assist in parameterization of biophysical models.

Common Modeling Environment (CME) - this tool is designed to allow models to be placed online or on local hosts without altering those models. A special 'middleware' translator language links with a JAVA interface that the model developer can define access to model inputs and model location to use the system, either remotely or on the user's machine. Currently, PHYGROW and EPIC have middleware translators available and can share a common soils database. Because the interface is written in JAVA, the system allows delivery of models over the Internet via a Web browser. This tool was developed by the Center for Natural Resource Information Technology at Texas A&M University. http://cnrit.tamu.edu/CME

CurveExpert - this shareware tool is used to fit data points to a mathematical formula that can be used in computing response variables from point or sample data such as NDVI-forage quality estimates, point yield values converted to continuous functions, or animal performance/requirements scaled to an annual basis.

1.5 Design Matrix For This Study

The objective of this project was to develop methodologies to assess impact. The approach involved using "real world" case studies as a platform for development. The focus of the initial application was the USAID Office of Agriculture and Food Security portfolio. Case studies were chosen to be representative of this portfolio and reflect geographic and commodity diversity, thereby adding robustness to the product. The following design matrix for the project shows how these variables were reflected in the study (Table 1.5.1).

Table 1.5.1. The Design Matrix for Development of IMPACT

Location	East Africa	West Africa
USAID Grantee	International Livestock Research Institute and national collaborators	INTSORMIL and Peanut CRSPs and national collaborators
Initial Evaluation	Kenya	Mali
Commodity	Smallholder Dairy	Sorghum
Technology	Evolution of dairy technology	Sorghum production system
Regional Extrapolation	Uganda, Tanzania	Senegal, Burkina Faso

In addition to representing a cross section of the AFS portfolio, these case studies were chosen because there were existing collaborations between their scientists and those at Texas A&M, and there was a substantial data base that had already been acquired by these collaborators. In addition, the collaboration included access to and involvement with national and regional partners that were critically important for this study. We recognized that similar evaluations were being conducted at ILRI for smallholder dairy and were interested in comparing methods and results.

It is important to note that, while this design matrix provided an explicit platform for study, the methods that emerged are generic in their application. That is, they may be used to study other commodities and policy options. To the extent possible, the design of models involved providing a generic framework that is highly adaptable with the necessary specificity derived from the inputs to the model (dimensions of analysis).

Each of the case studies involved a two-step process. First, the selected technology platform was evaluated in the country where a substantial amount of experimental data and background experience existed and could be acquired from collaborators. Second, models were extended to develop the capability of extrapolating the results from locations where experimental data and experience were developed to geographically similar regions in adjacent countries. One of the goals was to develop a workable assessment methodology for ex ante analysis that allows an estimate of the broader application of results past the sites where they were developed.

IMPACT is useful for both ex ante and ex poste analysis of the impact of technology or policy options. In practice here and elsewhere, however, the analysis often falls somewhere in between; it occurs after research has been initiated and before adoption is complete. There are often experimental data on which to base expectations, but factors affecting ultimate adoption may not have been fully manifest at the time of the analysis.

The approach involved an iterative process of methodological development. Experience defined the availability of information and the cost of acquiring or estimating it. Processes were streamlined as experience was gained. We discovered things that worked and things that did not. While protocols were generally the same for the East and West Africa studies, there were differences. These provided a basis for useful comparison. Some parts of the methodologies were previously developed and there was a substantial experience in using them. Other methods were created de novo and experience is still being acquired using them.

One of the major challenges involved in developing the integrated suite of models was the development of effective and efficient interfaces between models for inputs and outputs and for iterative engagement to seek optimal solutions. The same need exists for a framework into which georeferenced information can be placed or linked for ready access and use.

An area of ongoing research is the definition of errors of estimation. While many of the procedures adopted and developed have sound statistical bases, there is need for further work to define the estimation errors for some components models and certainly for the overall suite of models. The quality of input data from developing countries is recognized as being variable and often limited. In these studies, methods were developed and extended to estimate through models the values for needed input data. The bringing together of biophysical and economic models has challenged the group in this respect. The final outcomes of introducing new technology or policy are influenced by factors that are often not fully understood and certainly not well modeled. However, despite a substantial overall uncertainty, there are a number of instances where modeled and observed results can be compared and this has provided a useful method of verification that model outputs are generally consistent with the real world.

A very positive feature of the modeling approach, as noted elsewhere, is the capacity to estimate outcomes that are highly relevant to key indicators of progress toward achieving stated goals that are either too difficult or too costly to measure. Model outputs can, in this sense, serve as effective proxies for such indicators as long as appropriate caveats are clearly stated.

A critical factor in the design and development of these methods has been consideration of how they can and will be applied by various users. While initially directed to the evaluation of the USAID portfolio, the sponsor clearly wants to make these methods available to national and regional partners in developing countries. Thus the balance between creating a new generation of more precise and general methods had to be weighed against the need to ensure that methods are useful to customers with varying levels of capacity.

We continue to seek the best balance. Among other things, it has been critical to have national partners directly involved in the research and development of the impact assessment methods. Workshops have provided some capacity building, but it will be necessary to continue this process past the end of the current project and into the next generation of development. We will discuss several concepts for packaging and using these methods later in the report.

Summary **The Design Matrix For This Study**
The main components of the specific experimental design used to develop methods in the two case studies includes the following: · Chose case studies with existing data and related background · Used national collaborators as experts and users · Modeled missing input data · Developed model interfaces · Constructed sector models at country/province levels · Defined zones of agro-environmental equivalence · Conducted rapid appraisal and in depth interviews as needed · Introduced non-modeled variables as constraints on adoption · Evaluated intensification and extensification strategies · Predicted adaptation and adoption at locations other than site of origin of data · Conducted evaluative workshops

1.6 Organization of the Report

The remaining sections of this report will present a detailed account of the development of IMPACT and its testing in real-world situations. Case studies were initiated in East and West Africa. In each example, the report will address how individual models were developed as well as how models were interfaced and interrelated. The usefulness of both individual models and the suite of models will be evaluated. The report concludes by offering lessons learned during the research that might affect the continuing development of impact assessment.

Section 2: Assessment of the Impact of Technology on Smallholder Dairies in Kenya

The evolution of smallholder dairy technology in Kenya and East Africa was chosen as the first of two case studies in the IMPACT project to develop and evaluate a suite of models to assess the impact of technology. A collaboration was established with the International Livestock Research Institute (ILRI), as a representative of the International Agricultural Research Centers (IARCs). In turn, this provided a link with the ongoing partnership among ILRI, the Kenyan Agricultural Research Institute (KARI), and the Kenyan Ministry of Agriculture (MOA). These collaborators participated by providing data, information, insight, and "ground-truth" on smallholder dairy research and development. Texas A&M benefitted substantially from the participatory research process used by this team, both in acquiring needed information, data, and advice and in national capacity building through participation. The effectiveness of this effort was enhanced very substantially by a KARI scientist, Dr. Robert Kaitho, who was seconded to ILRI and was an active collaborator as well as facilitator for the overall effort. Two workshops were held with national and regional collaborators to evaluate results and build capacity in the use of the models.

The smallholder dairy industry in Kenya is evolving from a traditional range-based operation with unimproved zebu cattle towards a more intensive system using dairy breeds and improved forages and other practices. All levels of technology are in current practice. The level of evolution varies with the geographic location of dairies, with most intensification occurring in peri-urban areas. First a baseline situtation was established in which all dairy production came from zebu cattle with unimproved forage and minimal use of modern technology. Then, the baseline situation was compared to varying levels of evolution of the industry. Once the first generation of models had been established in Kenya, researchers found geographically similar areas in Uganda and Tanzania and tested the models there.

Summary of Methods and Outputs

Activity	***Purpose***
2.1 Summary of Smallholder Dairy Industry in Kenya	Background for the analysis of the impact of technology
2.2 Technologies Contributing to Improvements	Description of the multiple components of the production system
2.3 Production Systems Evaluated	Description of the six production systems currently in practice in Kenya
2.4-2.5 Geographic Distribution of Dairies in Kenya	Initial stratification for economic modeling followed by more detailed description of currently used agro-ecological zones and then use of spatially explicit analysis to develop sampling frames for individual household analysis within these zones. Provide a basis for establishing a geographic basis for projecting the use of this technology in adjacent countries.
2.6 Biophysical Inputs for Agricultural Sector Model (ASM)	Use of PHYGROW and NUTBAL as forage and animal nutrition models to estimate inputs not otherwise available for the ASM
2.7 Development and Use of the Kenya ASM	Estimates prices, quantities, land use, consumer and producer benefits and other outputs for varying technology packages used in Kenya -- later, an output with demand driven by projected population increases in 2015
2.8 Economic Impact of Smallholder Dairy Technology Options	FLIPSIM analysis on representative modal farms for the major agro-ecological regions of Kenya to project net worth, survivability, on a stochastic basis
2.9 Environmental Impact of Smallholder Dairy Technologies in Kenya	Use of EPIC and related models to predict erosion, runoff and chemical residues
2.10 River Basin level Environmental Analysis of Impact -- The Sondu River	Use of a suite of models, including SWAT and others to predict the impact of Smallholder Dairy Technology at the watershed level
2.11 Conclusions	Summary of Kenyan smallholder dairy case study and comments of effectiveness of models

2.1 Summary of Smallholder Dairy Industry in Kenya

In 1996, an estimated 3,152 million kg of milk were produced in Kenya (Peeler and Ormore, 1996). Milk production involves 9.8 million animals of which 7.7% are dairy breeds (principally Friesian and Aryshire), and 10.3% are zebu x dairy crosses. Dairy breeds consume 11.8% of the forage used to support milk production while dairy x zebu crossbreeds consume 14.7%. The remainder of the dairy population is comprised of a variety of zebu breeds, e.g. East African zebu, sahiwal, boran, etc.

Approximately, 25.9% of milk is produced from purebred dairy breeds while an additional 16.7% is produced by dairy x zebu crossbreeds. The remainder, or 57.4%, of the milk produced in Kenya is produced by zebu breeds. Most of the milk produced for public consumption originates in the Central, Coast, Eastern, Nyanza, Rift Valley, and Western provinces of Kenya (see Figure 2.1-1, provincial map). A very small amount occurs in the periphery of some towns in the North-Eastern province, characteristic of arid and semi-arid rangelands of northern Kenya. Tables 2.1.1, 2.1.2, and 2.1.3 provide a provincial view of herd inventories by breedtype, annual milk yields by breedtype, and numbers of lactating cows producing milk each year, respectively.

Table 2.1.1 Inventory of cattle used in small holder dairy production in Kenya.

Province	Dairy	Dairy x Zebu	Zebu	Total
Central	396,245	412,755	77,530	886,530
Coast	20,104	25,296	1,073,930	119,330
Eastern	117,364	155,576	1,152,330	1,425,270
Nyanza	0	149,110	2,089,200	2,238,310
Rift Valley	211,350	253,620	4,396,130	4,818,890
Western	10,038	15,056	301,416	326,510

Table 2.1.2. Estimated total annual milk yield (kg) by region and breedtype based on the assignment of dairy, dairy x zebu, and zebu breedtypes to production systems by region in DFID survey (Peeler and Omore, 1997). Total milk yields can be contrasted to estimates provided in the DFID national survey.

Province	Dairy	Dairy x Zebu	Zebu	Total	DFID Total
Central	450,933,170	226,980,874	22,431,459	700,345,503	699,466,161
Coast	13,066,607	7,944,496	132,789,286	153,800,390	99,515,675
Eastern	95,245,056	61,009,456	178,879,555	325,074,727	335,134,067
Nyanza	0	47,677,980	264,435,537	229,550,412	312,113,517
Rift Valley	232,225,969	134,660,538	1,228,073,143	1,571,423,260	1,594,959,651
Western	11,846,025	8,586,422	90,437,452	125,673,062	110,869,899

Table 2.1.3 Estimated number of lactating cows in each province by breedtype

Province	Dairy	Dairy x Zebu	Zebu
Central	155,978	162,477	30,519
Coast	4,520	5,687	241,435
Eastern	32,945	43,672	323,471
Nyanza	0	34,129	478,184
Rift Valley	80,327	96,393	1,670,848
Western	4,098	6,146	123,044

The number of dairy animals per household varies considerably but is often less than two on average. Women are typically the principle mangers of the smaller dairy enterprises. Milk is both consumed in the household where it is produced and sold either directly or through marketing cooperatives. Larger enterprises are emerging in the peri-urban areas. The dairy enterprise is one of the few agricultural systems that produces a consistent cash flow over most of the year.

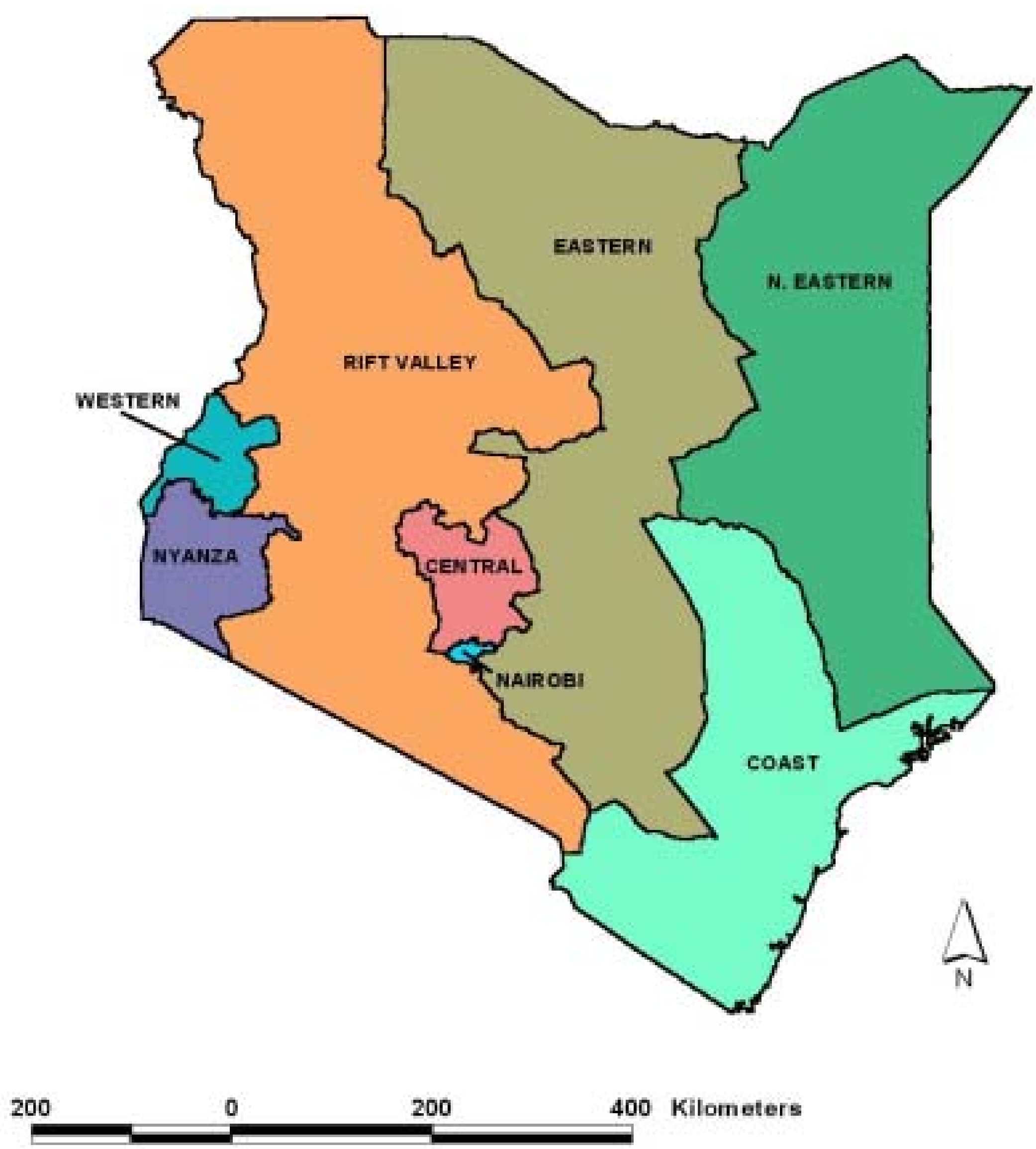


Figure 2.1-1. Provinces of Kenya.

2.2 Technologies Contributing to Improvement in Productivity

As demand for milk has increased and markets improved over the last 20 years, there has been an evolution of dairying in Kenya. Dairy breeds have been introduced and used as cross or pure breeds, and improved forage varieties have been introduced. Several management and marketing practices have been made available including improved animal health and the use of fertilizers to enhance forage production. However, the evolution of dairying has not been uniform across the country but has tended to emerge first in peri-urban areas of higher populations. National research and extension programs in KARI and the Ministry of Agriculture, in collaboration with ILRI, have contributed to the development and adoption of improved technology. The following is a partial list of the technologies which have been adopted to varying levels depending on size of operation, location, and market demand:

- Improved animal genetics by introducing dairy breeds, principally Friesan and Aryshire, and crossbreeding them with local zebu cattle, primarily East African Zebu.

- Improved forages, including Napier grass, with multiple fertilizer levels. Application of up to 50 kg N/ha has been recommended.

- Use of feedstuff/minerals, primarily corn bran, and commercial concentrate feeds and mineral sources, primarily phosphorus.

- Improved animal health programs especially for the introduced dairy breeds to minimize the impact of external and internal parasites and disease such as East Coast Fever, through spraying and vaccination.

- Intensification of production system through part time confinement of the animals (semi-zero grazing) or complete confinement (zero-based grazing) with adoption of various stall management technologies (shedding, floor construction, bedding techniques, composting, manure/urine management, etc).

- Rearing of male calves up to 24 months of age for sale, primarily in extensive dairying situations.

2.3 Dairy (Meat and Milk) Production Systems Evaluated in this Assessment

Drawing in these technologies for smallholder dairy production, national experts defined four milk production systems (Table 2.3.1) and two growing animal rearing systems that generate milk and meat within the dairy industry. These systems are described by Stotz (1983) and include:

1. **Zebu cattle - Grazing Only**: Grazing-only environments supporting zebu cattle of improved and unimproved breeding for milk production supported by native forages, introduced species growing on roadsides, and grasses/weeds available in adjacent plantations or woodland clearings. Little or no inputs are made in these systems in terms of supplement, disease control, or fertilizer.

2. **Dairy-Zebu Crossbreeds Grazing Only:** Grazing-only environments supporting dairy x zebu cross cattle for milk production supported by native forages, introduced species growing on roadsides, and grasses/weeds available in adjacent plantations or woodland clearings. Inputs are generally confined to some minerals and dipping for external parasite control.

3. **Dairy Breeds -Semi-zero Grazing:** Semi-zero grazing by pure dairy breeds where animals are stall fed and allowed tethered grazing in selected areas. Animals are hand fed harvested forage or provided access to native forages, introduced species growing on roadsides, and grasses/weeds available in adjacent plantations or woodland clearings as well as provided improved forages in stalls primarily from Napiergrass and in some cases Rhodesgrass. Use of minerals and treatment for internal and external parasites is practiced. Limited use is made of concentrates in periods of high need and low forage quality.

4. **Dairy Breeds - Zero-Grazing:** Grazing by pure dairy breeds where animals are stall fed their entire diet from both forages and concentrates. Animals are hand fed forages that are hand harvested from nearby native forages, introduced species growing on roadsides, grasses/weeds available in adjacent plantations/ woodland clearings and purchased fodder as well as provided improved forages in stalls primarily from Napiergrass and in some cases Rhodesgrass. Use of minerals is widely practiced as is treatment for internal and external parasites. Substantial use of concentrates throughout the lactation cycle of the animals is practiced throughout the year.

5. **Steer Fattening:** Extensive steer fattening with zebu x dairy cross animals up to 24 months of age. Castrated males are retained or in some instances purchased to be fattened on forages and concentrates for added revenue in the dairy operation. Animals are grazed on native forages, introduced species growing on roadsides, and grasses/weeds available in adjacent plantations or woodland clearings. Few inputs are provided to the animals.

6. **Intensive Confined Steer Feeding:** Intensive confined feeding of castrated dairy calves up to 24 months of age. Animals are hand fed improved forages, primarily Napiergrass, and provided internal/ external parasite control, minerals, and strategic use of concentrates.

Table 2.3.1 Brief description of the four major small holder dairy milk production systems in Kenya

Component	Zebu Cattle Grazing Native/Roadside/ Plantation Forage	Dairy x Zebu Cattle Grazing Native/Roadside/ Plantation Forage	Dairy Breed Cattle Grazing in Semi-Zero Grazing	Dairy breed cattle With Zero-Grazing
Forage System	Kikuyu, Stargrass, *Panicum maximum*, Themeda, Other Natives, Weeds, etc	Kikuyu, Stargrass, *Panicum maximum*, Themeda, Other Natives, Weeds, etc	Kikuyu, Stargrass *Panicum maximum*, Themeda, Other Natives, Weeds, etc Plus Napiergrass or Rhodesgrass	Napiergrass or Rhodesgrass
Feeding System	Free or herded grazing	Free or herded grazing	Corral fed with some limited tethered grazing or herded	Hand cut fodder in a corral/shed
Supplement	None	Minerals – 15 kg	Minerals – 25 kg Concentrates – 450 kg	Minerals – 25 kg Concentrates – 1000 kg
Disease Control	None	Dipping	Dip and Drench	Dip and Drench
Calf Rearing Method	3-7 month suckling	3-7 month suckling	16 wk whole milk bucket feeding	16 wk whole milk bucket feeding

2.4 Establishing the Geographic Distribution of Smallholder Dairies

The location of smallholder dairies is generally a function of location of market demand, access to market, suitable production potential of the land, absence of serious disease, access to veterinary services, access to adapted dairy breeds, and availability of supplemental feeds. Traditionally, smallholder dairying has been represented by the number of cattle used for milk production reported in each administrative district with little agro-ecological specificity or association with markets noted.

Kenya has generally accepted ecological stratification through the use of broadly defined agro-ecological zones largely defined by precipitation and elevation.

To develop a more robust spatial stratification of the environmental production zones associated with smallholder dairying, areas were defined where dairy farmers face similar biophysical and economic constraints. These contraints influence both the priorities for (ex-ante analysis) and the outcome (ex-poste) of technology adoption. Once established, the spatial sampling frame helps characterize target adoption areas and identify areas from which representative farms can be selected. Data from the representative farms subsequently provides inputs into farm simulation models. As technologies are developed and transferred to the smallholder dairies, characterization evolves to identify not only areas of adoption but also to target similar biophysical regions where the technology could be adapted.

2.4.1 Rapid Appraisal to Characterize Dairies in Agro-ecological Zones

GPS technology was used to physically locate a sample of 77 smallholder dairies selected by regional experts in KARI as representing a cross section of dairies spanning different agro-ecological zones and economic status (Figure 2.4.1-1). These farms were located across six of the common agro-ecological zones in Kenya as identified by Jaetzold and Schmidt (1984) (Figure 2.4.1-2). They were used to set the sampling frame in this research for two reasons: to ensure that a range of environments was sampled and to use a system that would allow traditional spatial resources to connect with a digital spatial information system, the Almanac Characterization Tool (ACT). An underlying objective of this process was to establish how ACT could be used to establish spatial sampling frames and display results of subsequent analyses of the overall IMPACT assessment.

From this sample of geo-referenced smallholder dairy farms, biophysical characteristics were attached to each environment from data contained in the foundation data in the ACT. A principle component analysis was run, and similar dairies were organized into environmentally coherent groups. The following commodity-oriented, agro-ecological zones were identified to contain smallholder dairying activities: Coast, Horticulture, Coffee, Tea, Wheat, and Sheep zones. A more detailed description of the methods follows in sections 2.4.2 and 2.4.3.

Using the spatial data in the ACT, descriptions of the dairy groups were recorded and geographical equivalency analysis was used to locate areas throughout Kenya with similar characteristics, thus converting a point description into a spatial characterization. Creating a digitally referenced characterization of smallholder dairies sets the stage for significant efficiencies in subsequent analyzes of zones of potential adaptation.

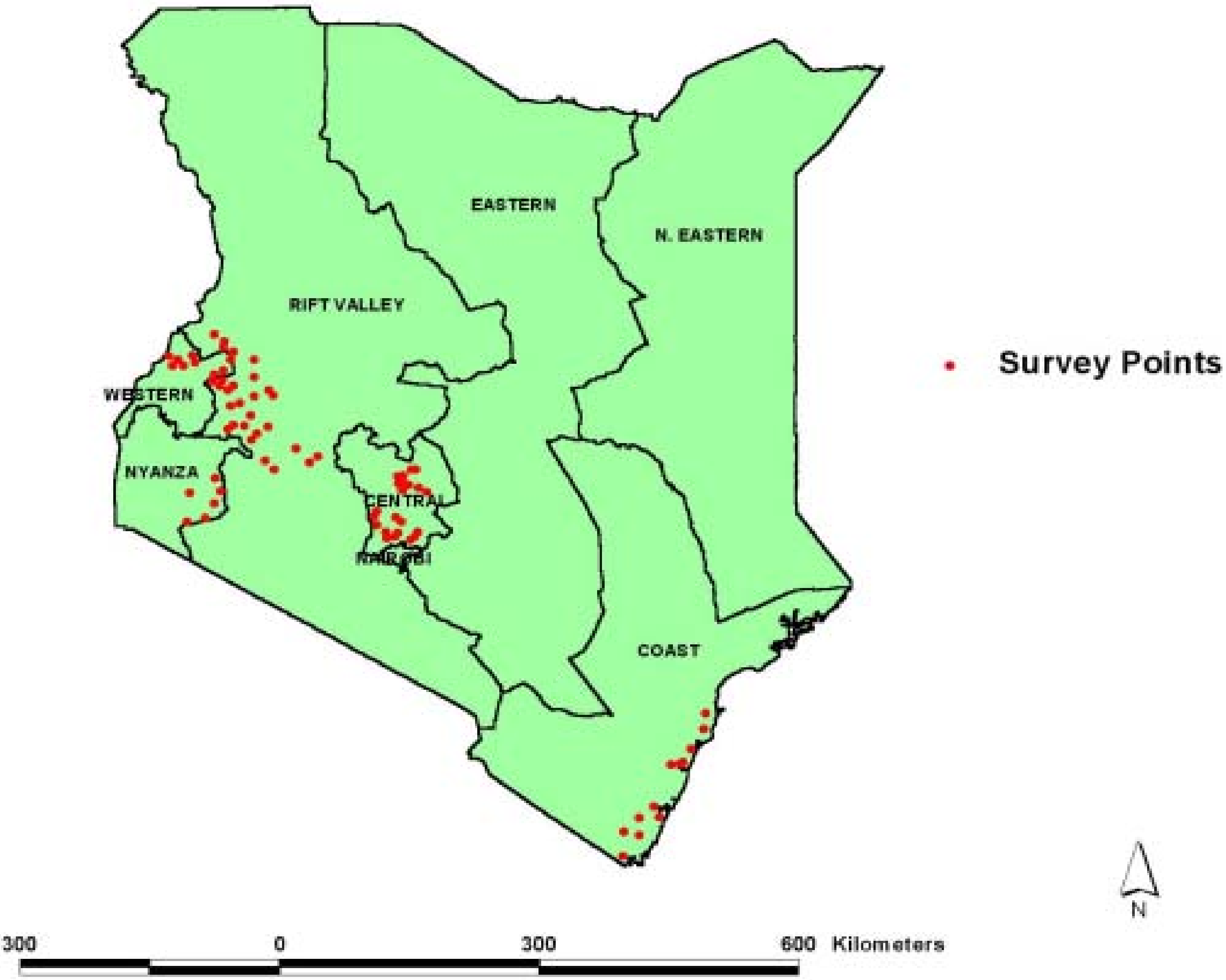


Figure 2.4.1-1. Location of sample points used to classify small holder dairy environments in Kenya.

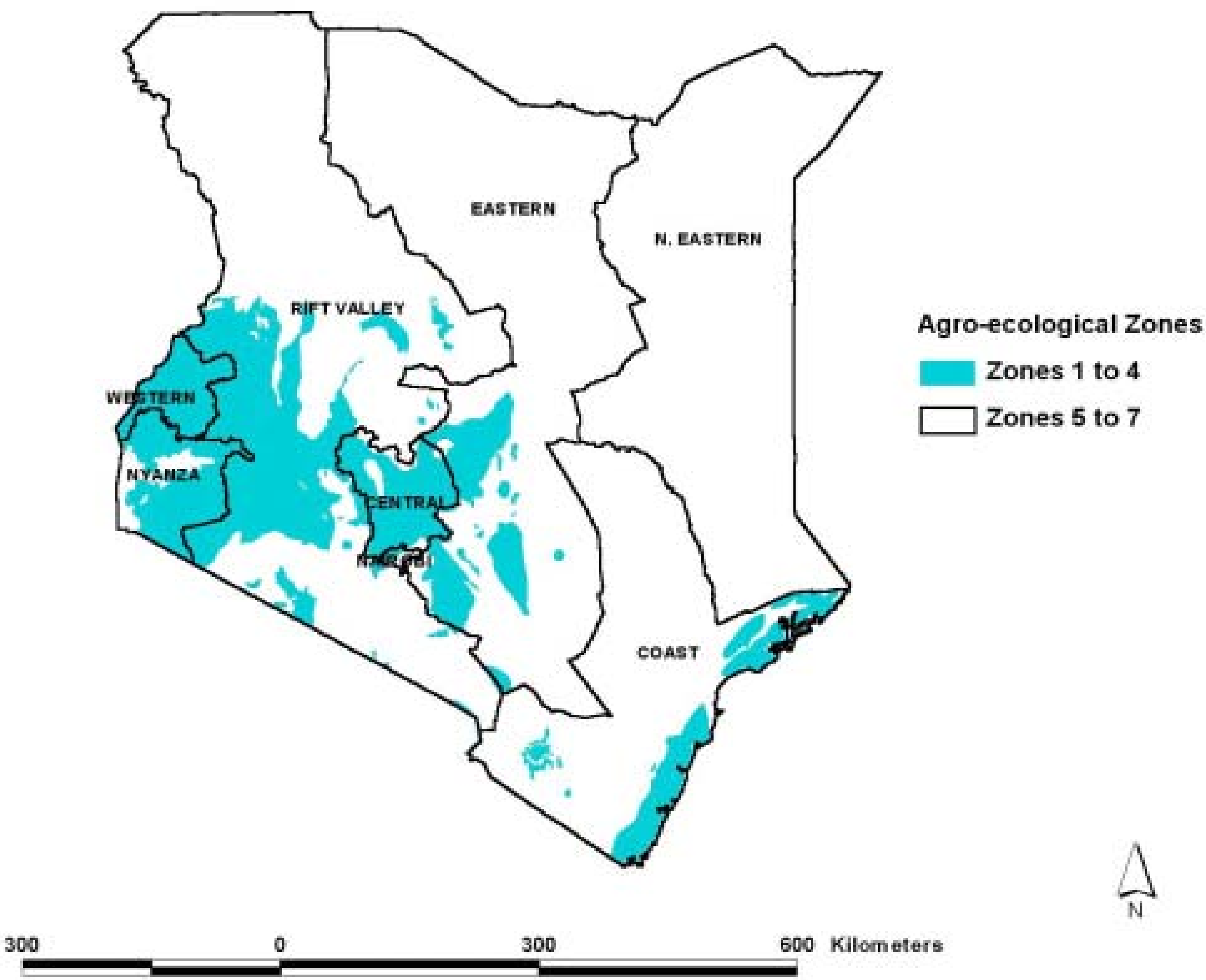


Figure 2.4.1-2. Agro-ecological zones of Kenya.

2.4.2 Methods for Characterization: Use of ACT Model to Establish Site-Specific Climatic Variables for Existing Dairy Sites

After a sample of 77 known dairy sites were identified in Kenya's traditional agro-ecological zones, the ACT was used to determine site-specific annual climatic variables for each dairy site. The variables included annual maximum and minimum temperature, extreme maximum and minimum temperature, precipitation, potential evapo-transpiration, and the precipitation/potential evapo-transpiration ratio [P/PE]. These variables were then subjected to principal components analysis to determine which climatic variables explained the most variability in the distribution of sites across Kenya.

Principal components analysis indicated that the first two principal components explained 92% of the variability among the selected smallholder dairy sites. Annual maximum and minimum temperatures were highly correlated to the first principal component, whereas precipitation and the P/PE ratio were correlated with the second principal component.

2.4.3 Cluster Analysis: Defining Climatic Production Zones

A plot of the first two principal component scores revealed two major clusters of smallholder dairy sites (Figure 2.4.3-1). The main differences between the two clusters were average maximum and minimum annual temperatures. The first cluster contained sites having higher average minimum and maximum annual temperatures (Table 2.4.3.1); these sites were located in the coastal areas of the Kwale and Kilifi districts. The second cluster contained sites having cooler average annual minimum and maximum temperatures (Table 2.4.3.1) when compared to sites in the first cluster. Sites in the second cluster were generally located in the highlands of Central and Western Kenya.

To determine the geographic extent of areas having similar environmental characteristics to the sites in each cluster, means and standard deviations of the climatic variables for each cluster were determined. Climatic variable ranges (mean ± 2 standard deviations; Table 2.4.3.1) were then placed into the site characterization module in ACT and the geographic extent of the two clusters were mapped (Figure 2.4.3-2). In the first cluster, defined as the Coast Zone, approximately 748,410 hectares were identified that had climatic environments similar to the rapid appraisal sites. In the second cluster, defined as the Highlands Zone, approximately 6,441,760 hectares were identified that had climatic environments similar to those sampled.

To further refine the characterization of sites, a cluster analysis was conducted using the annual maximum and minimum temperatures and the P/PE ratios for each of the rapid appraisal sites. The cluster analysis used Ward's linkage method with Euclidean distances and identified six major clusters (Figure 2.4.3-3). For identification purposes, clusters were named based on the major crop produced in the zone. These zones, which were previously listed in section 2.4.1, are Coast, Horticulture, Coffee, Tea, Wheat, and Sheep zones.

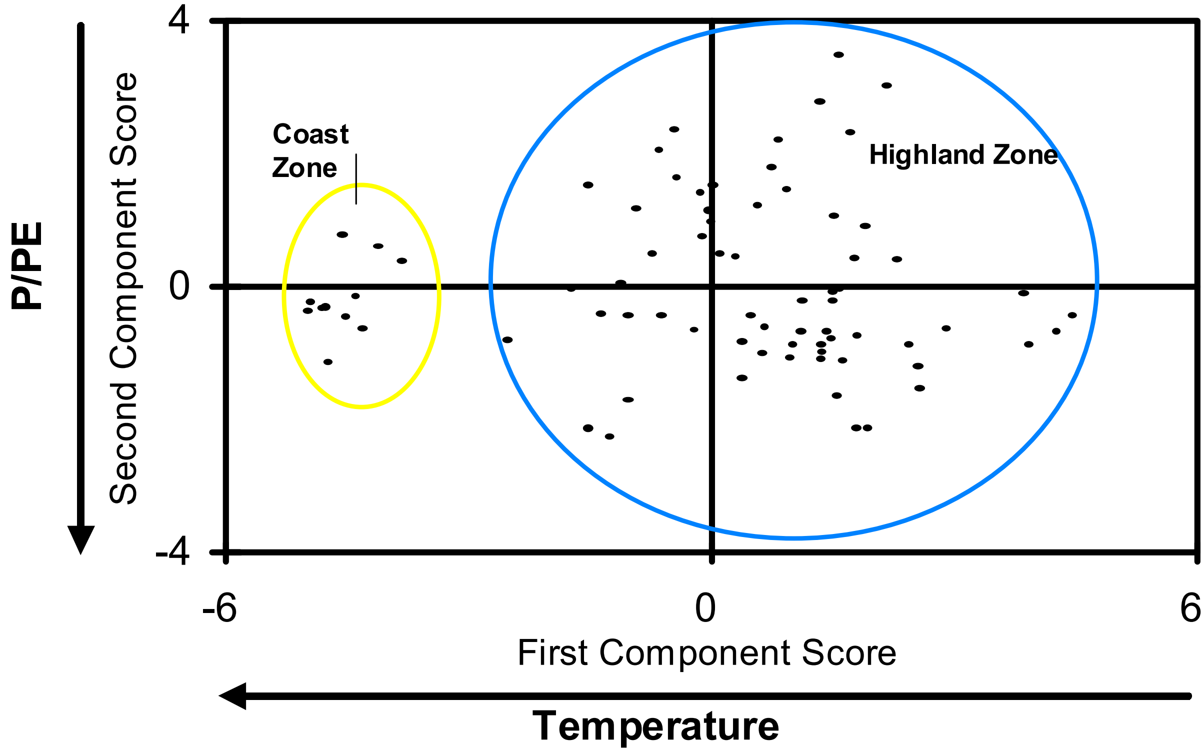


Figure 2.4.3-1. Results of principal components analysis of rapid appraisal sites sampled in Kenya. Clusters of similar sites were designated as Coast Zone and Highland Zone.

Table 2.4.3.1 Climatic variable statistics for principal component analysis clusters used in the Almanac Characterization Tool to determine geographic extent of similar smallholder dairy environments in Kenya

Variable/Statistic	Cluster 1 **Coast (n=12)**	Cluster 2 **Highland (n=65)**
Minimum Temperature		
Mean	21.87	11.19
Standard Deviation	0.69	1.71
-2 Standard Deviations	20.48	7.76
+2 Standard Deviations	23.25	14.61
Precipitation/Potential Evaporation		
Mean	0.67	0.88
Standard Deviation	0.07	0.16
-2 Standard Deviations	0.54	0.56
+2 Standard Deviations	0.81	1.20
Maximum Temperature		
Mean	29.95	24.56
Standard Deviation	0.42	2.16
-2 Standard Deviations	29.11	20.24
+2 Standard Deviations	30.80	28.89

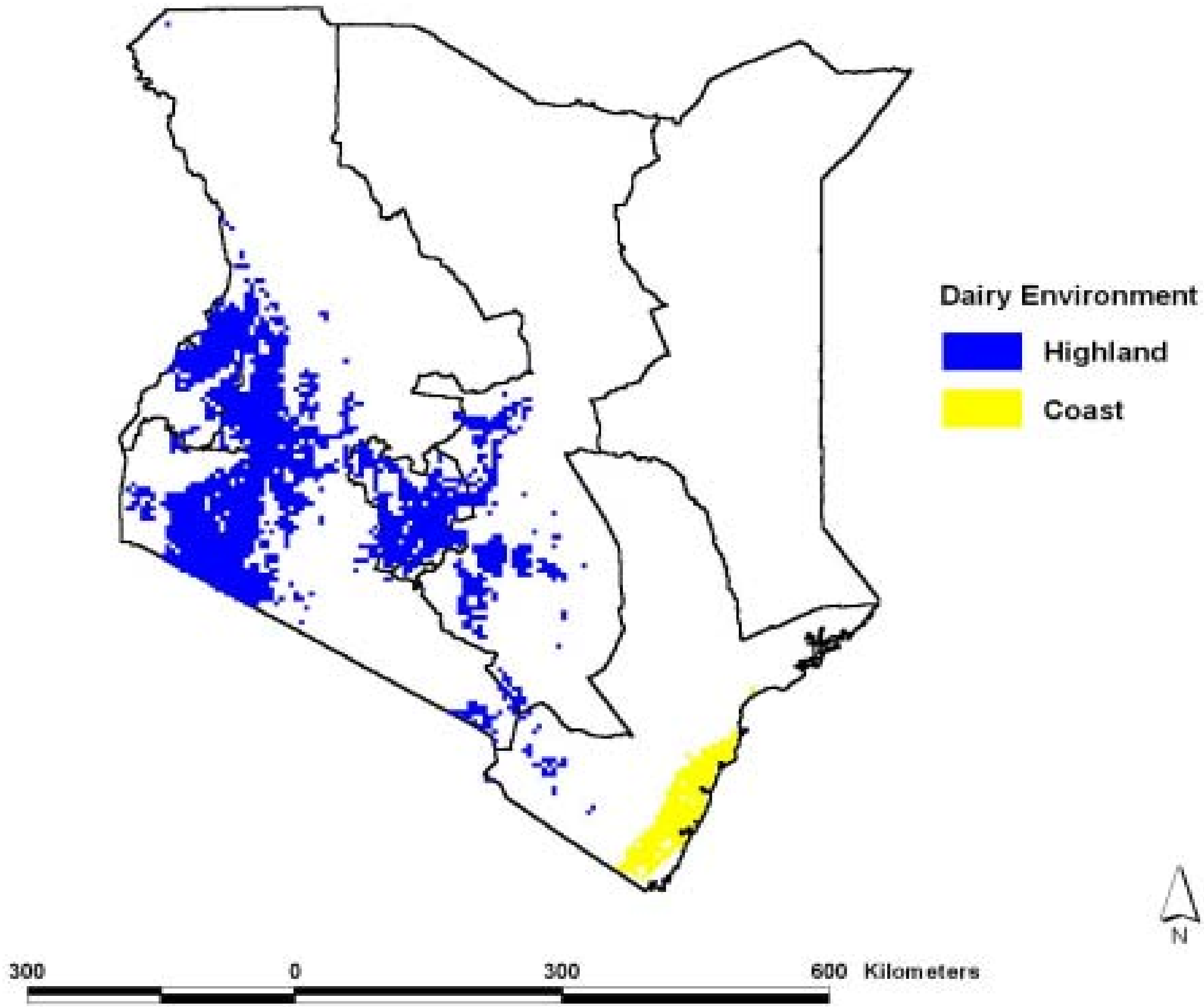


Figure 2.4.3-2. . Almanac Characterization Tool (ACT) output of geographic extent of small holder
environments identified as clusters in the principal component analysis of rapid appraisal sites in Ke

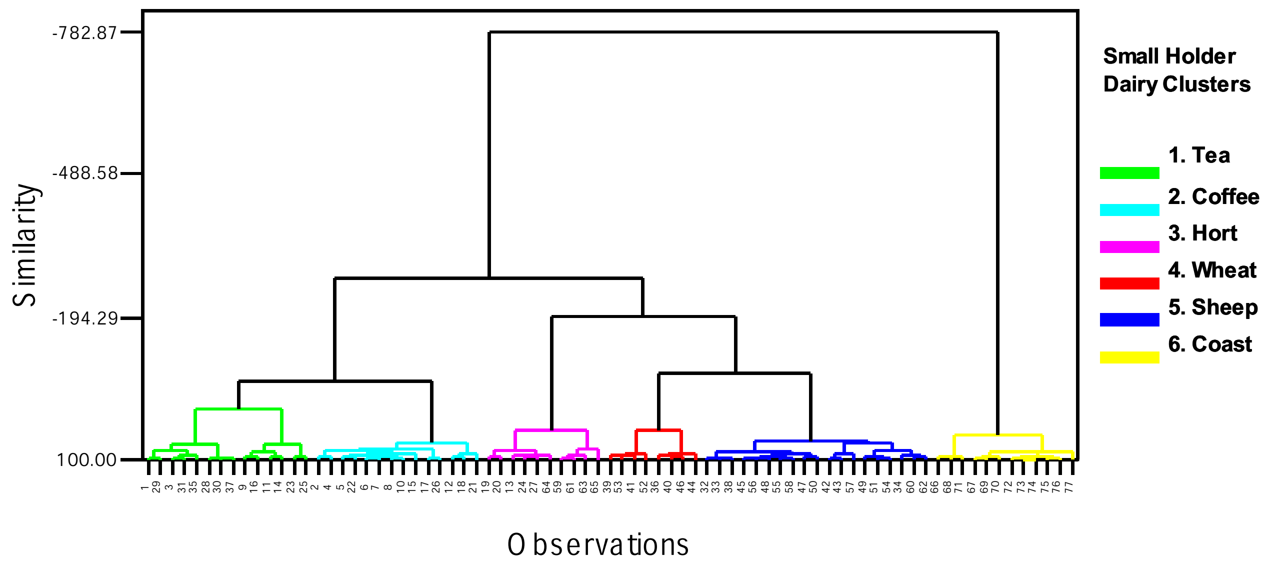


Figure 2.4.3-3. Results of the cluster analysis conducted on climatic data from the rapid appraisal sites. Clusters are identified by major activity occurring in the representative cluster (e.g., tea = tea production is main production activity within this dairy production environment).

2.4.4 ACT Analysis: Defining Dairy Production Zones

After the six climatic production zones had been defined, another ACT analysis was performed to define land area in Kenya with similar geographic characteristics. Because of the similar characteristics, these sites indicate a potential for sustaining a smallholder dairy industry.

For each of the six clusters, means and standard deviations were determined, and as before, climatic variable ranges (mean ±2 standard deviations; Table 2.4.4.1) were introduced into ACT's site characterization module. The characterization resulted in the mapping of five zones (Figure 2.4.4-1) that encompassed much of the Highland Zone from the initial characterization and a sixth zone that encompassed the same area as that of the coast zone in the initial characterization (Figure 2.4.3-2).

ACT analysis identified approximately 6,365,190 ha of land area in Kenya having similar climate to that of the representative smallholder dairy sites, encompassing approximately 11% of Kenya's total land area (Table 2.4.4.2). The Horticulture zone occupied the largest amount of land area with approximately 2,300,000 hectares identified, followed by the Sheep, Coffee, and Tea zones with each having approximately 900,000 hectares identified (Table 2.4.4.2). The Coast and Wheat zones had the lowest amount of hectares with each having approximately 600,000 hectares (Table 2.4.4.2).

On a provincial scale, the Rift Valley Province had the greatest amount of land area (approximately 2,900,000 hectares) having climatic conditions similar to the representative sites (Table 2.4.4.2). The Central, Coast, Eastern, and Nyanza provinces had similar areas with each having approximately 800,000 hectares of potential smallholder dairy land.

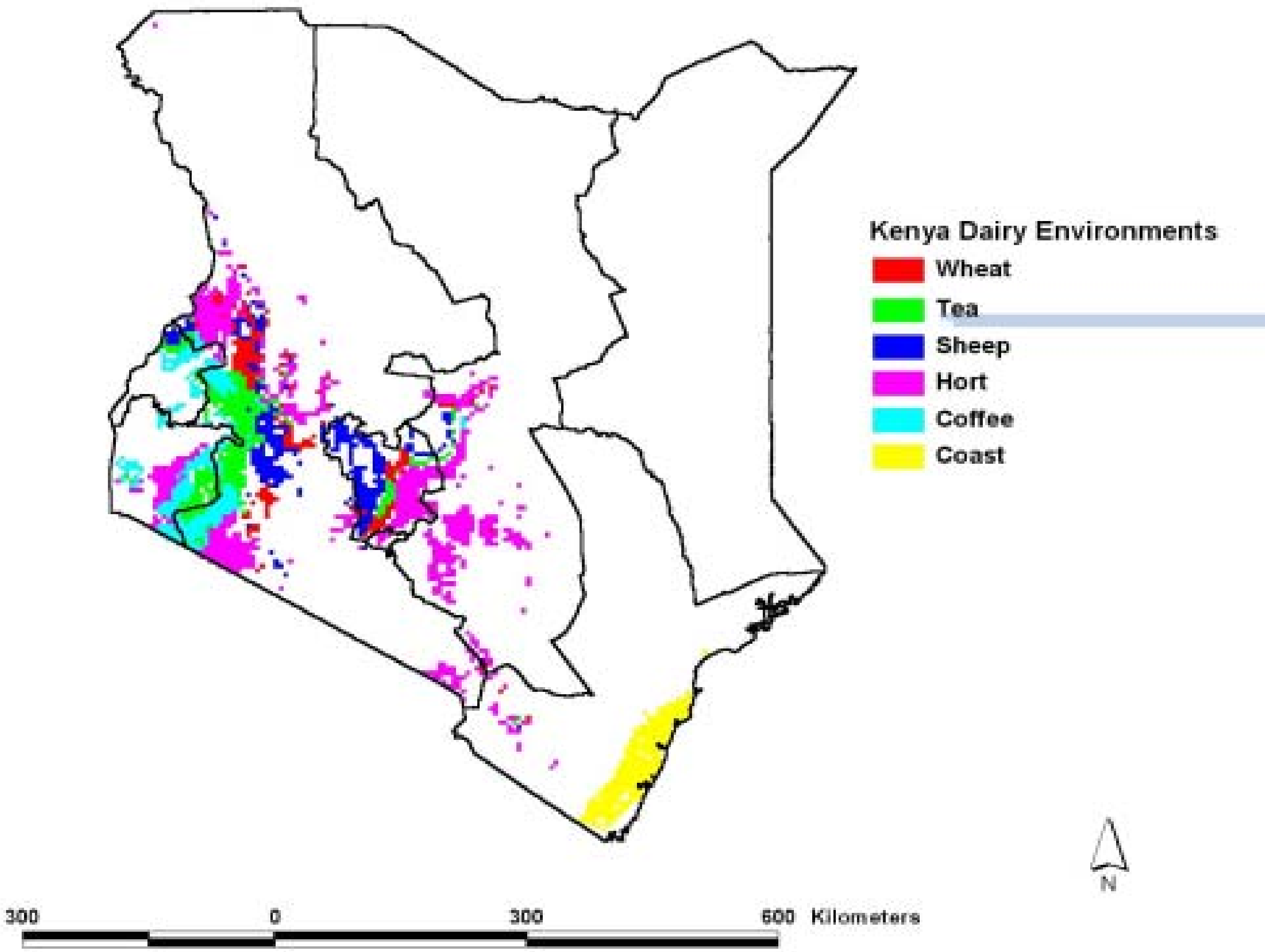


Figure 2.4.4-1. Almanac Characterization Tool (ACT) output of geographic extent of small holder dairy environments identified in the cluster analysis of rapid appraisal sites.

Table 2.4.4.1 Climatic variable statistics for clusters derived from a cluster analysis of smallholder dairy sites in Kenya. Climatic variables were used in the Almanac Characterization Tool to determine geographic extent of similar smallholder dairy environments in Kenya

Environment Zone Classification Variable/'Statistic	Cluster 1 Temperate/ Moist Coffee Dairy (n=14)	Cluster 2 Temperate/ Dry Hort Dairy (n=14)	Cluster 3 Dry/Cool Sheep Dairy (n=10)	Cluster 4 Moist / Cool Tea Dairy (n=8)	Cluster 5 Cold Wheat Dairy (n=19)	Cluster 6 Coastal Coast Dairy (n=12)
Minimum Temperature						
Mean	12.54	13.15	10.56	10.90	8.35	21.87
Standard Deviation	0.95	1.08	1.03	0.59	0.80	0.69
-2 Standard Deviations	10.65	10.99	8.49	9.72	6.75	20.48
+2 Standard Deviations	14.43	15.31	12.62	12.09	9.96	23.25
Precipitation/Potential Evaporation						
Mean	0.93	0.67	0.79	1.07	0.96	0.67
Standard Deviation	0.05	0.09	0.05	0.12	0.10	0.07
-2 Standard Deviations	0.82	0.48	0.70	0.83	0.76	0.54
+2 Standard Deviations	1.04	0.85	0.89	1.32	1.17	0.81
Maximum Temperature						
Mean	26.80	26.61	23.41	24.62	20.73	29.95
Standard Deviation	0.80	0.91	0.57	1.11	0.99	0.42
-2 Standard Deviations	25.21	24.79	22.27	22.41	18.76	29.11
+2 Standard Deviations	28.39	28.44	24.55	26.83	22.70	30.80

Table 2.4.4.2 Total area (ha) for provinces in Kenya and approximate area of zones having climatic conditions similar to small holder dairy sites sampled in Kenya

		Smallholder Dairy Zones						
Province	**Total Area**	**Coast**	**Coffee**	**Hort**	**Sheep**	**Tea**	**Wheat**	**Zone Totals**
Central	1,310,335	0	0	282,815	396,435	80,275	106,210	865,735
Coast	8,316,490	690,365	0	53,105	6,175	0	6,175	755,820
Eastern	15,766,010	0	0	710,125	25,935	12,350	33,345	781,755
N. Eastern	12,643,930	0	0	0	0	0	0	0
Nairobi	74,100	0	0	19,760	0	0	0	19,760
Nyanza	1,646,255	0	322,335	227,240	0	166,725	0	716,300
Rift Valley	17,623,450	0	416,195	1,079,390	470,535	542,165	416,195	2,924,480
Western	866,970	0	180,310	19,760	27,170	74,100	0	301,340
Grand Total	**58,247,540**	**690,365**	**918,840**	**2,392,195**	**926,250**	**875,615**	**561,925**	**6,365,190**
Percent Of Total Area		**1.2**	**1.6**	**4.1**	**1.6**	**1.5**	**1.0**	**10.9**

2.4.5 Comparing Projected Dairy Production Zones to Actual Dairy Locations

To test the validity of the ACT analysis, the projected dairy production zones were compared to the actual known location of dairies. The projections of smallholder dairy zones in Kenya were similar to small-scale dairy cattle densities (Peeler and Omore, 1997) at the district/provincial scale (Figure 2.4.5-1).

For the majority of areas where small-scale dairy cattle densities were greater than zero, ACT identified zones having climatic conditions similar to the smallholder dairy sites characterized during the rapid appraisal. For two districts (Busia and portions of Samburu), ACT did not project any areas of similar climatic conditions even though small-scale cattle densities were greater than one animal per square kilometer. For these districts, factors other than climate, such as human population density and local raw milk markets, may be important driving variables.

2.5 Selecting Representative Households and Herd Structures

To support the Agricultural Sector Model analysis and on-farm economic analysis (Figure 2.5-1), representative households had to be defined for each of the identified climatic production zones. The differences within the same dairy farming system make it necessary to identify a representative farm for each dairy system by zone. These differences can include farm resource endowment, resource use, spatial distribution, and management between households. To develop suitable methodology to identify representative farms, data were used from the ILRI/KARI smallholder dairy characterization survey conducted from Kiambu, Nairobi, Maragua, Muranga, Kirinyaga, Machakos, Nyandarua, Nakuru, and Narok districts in Kenya. About 1,700 households had been surveyed.

2.5.1 Characterization of Dairy Farms from Survey Data (principle component analysis)

Within this survey data set, a series of variables was selected as criteria to help select representative farms by climatic production zone. The variables used were: dairy farming system, farm size (acres), land ownership, Napiergrass acreage, maize acreage, number of cattle, number of dairy animals, number of indigenous cattle, predominant genotype/breeds, feeding/grazing system (%), distance from trading centre/market, household size, concentrate purchased, fodder purchased, milk production per day per cow, soil type, rainfall, altitude, mean daily temperature, and household income.

Principle component analysis was conducted on several sets of original farm/household variables to identify key factors which characterize each farming system. A multiple regression equation was established between dairy farming system and the other farm variables using the stepwise method (SAS, 1987). The variable entry criterion was set at 0.15 probability level of significance, and elimination of certain early entry variables was allowed in the equation if they were made redundant by new variables. The variables which contributed significantly in characterizing the systems (principle components) were: farm size, Napiergrass acreage, number of dairy animals, feeding/grazing system, distance from trading centre/market, rainfall, altitude, and household income.

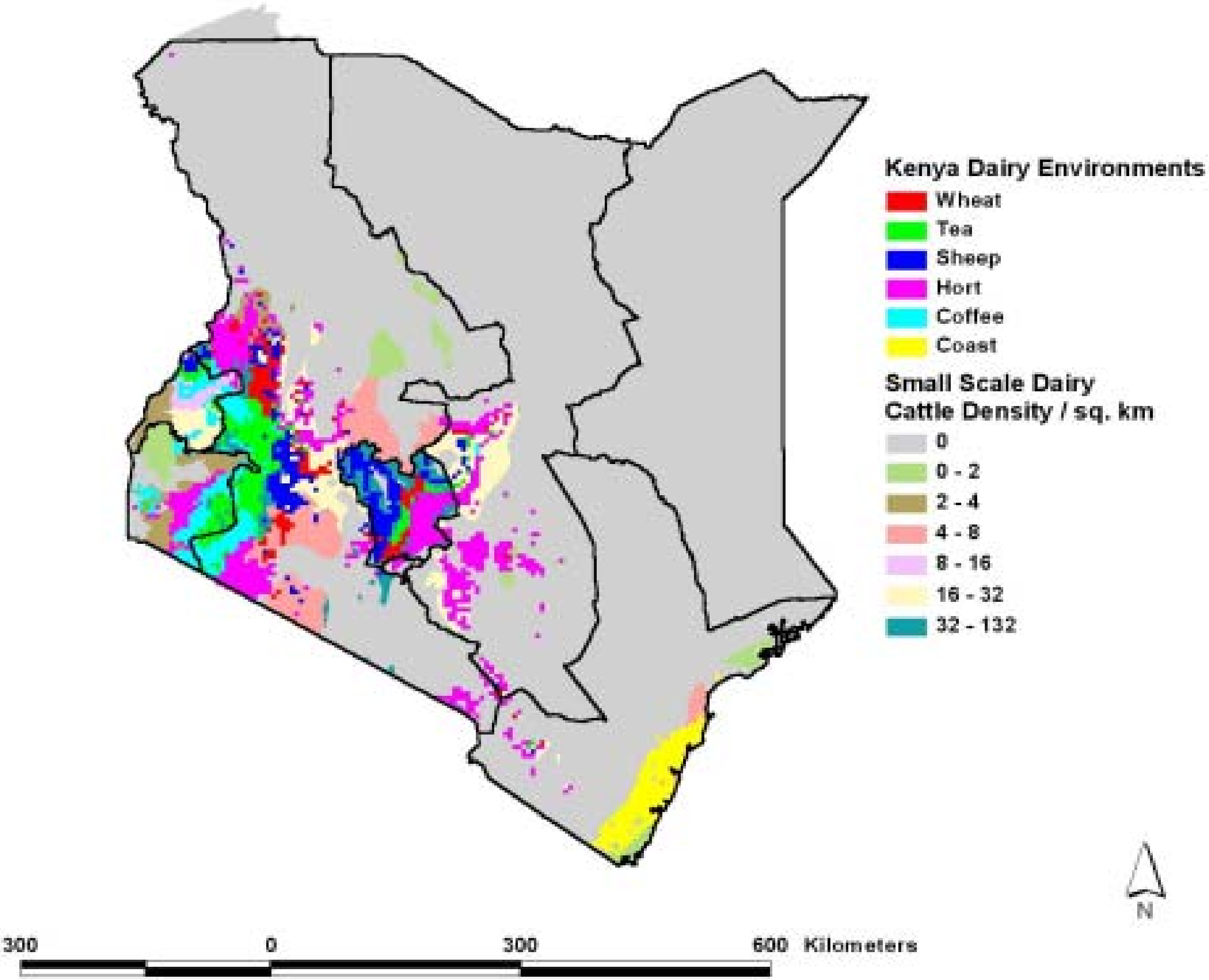


Figure 2.4.5-1. Comparison of Almanac Characterization Tool (ACT) derived small holder dairy environments with small scale dairy cattle densities at the district level in Kenya. Cattle densities were derived from district counts (Peeler and Omore, 1997).

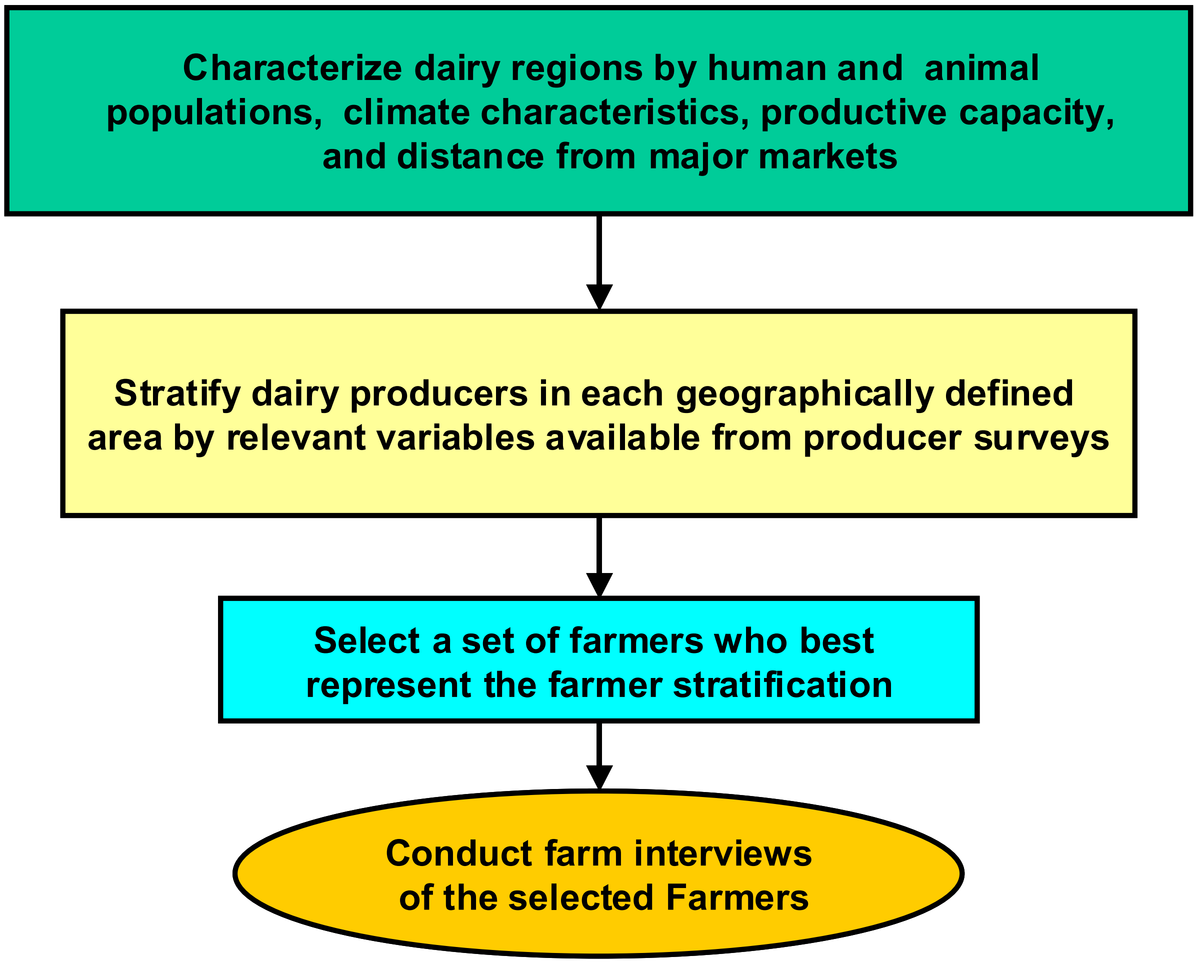


Figure 2.5-1. Process for selection of representative small holder dairies in East Africa

The CHART procedure (SAS, 1987) was then used on each of the principle components with uniform classes by farming system. Histograms were developed which also gave information such as frequency and percentage for each class. The midpoint (class) percentages were noted, and households with a value of the variable within the class were assigned the midpoint percentage and a sum of all the percentages of variables made. The representative farm selected (median farm) was the one with the highest total percentage score from all the variables derived from the principle components.

2.5.2 Survey of Representative Farms for Dairy Production Zones

Once the representative farm was selected, a detailed location of the farm was sought and the enumerator involved in the data collection was contacted. Then, the representative farm was visited and surveyed by the enumerator and an extension team. The median farms selected represented each of the six environmental production zones.

2.6. Computing Biophysical Inputs for Agricultural Sector Models

Once the spatial frame had been set and the representative farms had been selected, the next step was to begin an economic analysis using the Agricultural Sector Models (ASM) to assess the impact of the production systems at various levels of scale. However, some biophysical inputs to the ASM were needed before the ASM analysis could be done. The ASM model requires definition of the categories of animals within production systems, average annual yields of crops and supporting forage sources, annual nutrient requirements in terms of protein and energy, annual milk production, and annual nutrient requirement of cow-units (protein, energy, intake). Sections 2.6.1 through 2.6.4 explain how the needed inputs were determined.

2.6.1 Determining "area weighted mean" for administrative boundaries

Representing a composite or average view of the various production systems by administrative boundary proved challenging, given the constraints of data reporting for Kenya's livestock industry. It was decided to use seven provincial regions in Kenya (Figure 2.1-1) for which economic and biophysical data must be applied. The North Eastern region was dropped from the anaylsis because it represented neither an agricultural production nor a demand region.

The challenge was to provide animal and forage responses that reflected the "area weighted mean" of an administrative district. This was accomplished by running biophysical models for each of the repesentative farms to represent an average zonal response, and then based on hectares of that zone in each of the seven provincial regions, a weighted mean response was computed for use in the ASM analysis.

2.6.2 Definition of Typical Herd Structure Within Provinces (animal classes, breed typees, herd size)

To derive mean requirements and milk yield by livestock production system in each Kenyan province, first a "typical herd structure" of each of the production systems in each province had to be determined and then the requirements of the herd per cow unit in that herd had to be derived. The weighted herd structure for smallholder dairy households in each province based on the composition of the production types delineated in the study was used to define the animal classes and breedtypes for each province.

Each farm's herd structure was weighted according to the proportion of each production zone in a province (Table 2.6.2.1) to create an average herd structure by province (Table 2.6.2.2). The resulting herd structures were subsequently used as inputs for the Agricultural Sector Model.

2.6.3 Definition of Annual Requirements for Crude Protein, Net Energy, and Intake Demand

The NUTBAL PRO Nutritional Balance Analyzer model (Stuth et al. 1999) was used to compute the annual requirements for crude protein, net energy of maintenance, and intake demand of the animals by breedtype, class, and production system. Several breed attributes had to be evaluated to reflect differences in frame size, net basal metabolism, peak milk yield, and potential intake. Table 2.6.3.1 provides a more comprehensive view of breed attributes used in NUTBAL.

Table 2.6.2.1 Percent of each environmental production zone within each province of Kenya

Province	Coast	Coffee	Horticulture	Sheep	Tea	Wheat
Central	0.0	0.0	32.7	45.8	9.3	12.3
Coast	91.3	0.0	7.0	0.8	0.0	0.8
Eastern	0.0	0.0	90.8	3.3	1.6	4.3
N.Eastern	0.0	0.0	0.0	0.0	0.0	0.0
Nairobi	0.0	0.0	100.0	0.0	0.0	0.0
Nyanza	0.0	45.0	31.7	0.0	23.3	0.0
Rift Valley	0.0	14.2	36.9	16.1	18.5	14.2
Western	0.0	59.8	6.6	9.0	24.6	0.0

Table 2.6.2.2 Average annual herd structure and characteristics of each of the primary smallholder dairy production regions of Kenya. Values are weighted based on the composition of environmental production types in each region derived from averaged household survey

Class	Central	Coast	Eastern	Nyanza	Rift Valley	Western
Cow	2.400	3.000	1.953	2.451	2.400	2.400
Heifer (3-12 mo)	0.369	2.000	0.370	0.481	0.369	0.369
Heifer (13-24 mo)	0.434	0.000	0.412	0.609	0.434	0.434
Heifer (25-36 mo)	1.121	0.100	1.045	1.323	1.121	1.121
Male (3-12 mo)	0.197	0.000	0.191	0.323	0.197	0.197
Male (13-24 mo)	0.225	1.000	0.191	0.203	0.225	0.225
Male (25-36 mo)	0.225	2.000	0.195	0.203	0.225	0.225
Oxen	0.000	0.300	0.000	0.000	0.000	0.000
Bull	0.255	0.028	0.278	0.248	0.255	0.255
Total No. Head	5.226	8.428	4.637	5.841	5.226	5.226
Dairy Breed Ratio						
Dairy	0.49	0.44	0.43	0.00	0.50	0.40
Dairy x Zebu	0.51	0.56	0.57	1.00	0.50	0.60
Calving Interval (mo)	14.0	19.0	18.0	22.0	14.5	13.5
Lactating Cows/yr	2.057	1.895	1.302	1.339	1.986	2.133

Table 2.6.3.1 Critical NUTBAL breedtype parameters used to characterize smallholder dairy animals.

Breedtype	Friesian	Friesian x Zebu	Improved Zebu	Local Dairy Zebu	Rangeland Zebu
Framescore	2.6	2.9	-2.1	-3.2	-2.5
Intake Adj. Factor	1.01	1.00	1.00	1.00	1.00
Energy Adj. Factor	0.20	0.00	-0.20	-0.20	-.20
Hide Factor	Thin	Thin	Thin	Thin	Thin
Peak Milk Yield (kg/d)	15.1	7.4	4.0	3.8	2.2
Max. Coat Length (cm)	3.0	3.0	3.0	3.0	3.0
Avg. Birth Weight (kg)	32.0	30.0	30.0	30.0	35
Fiber Production (kg)	0.0	0.0	0.0	0.0	0
ADG Adj. Factor	1.0	1.0	1.0	1.0	1.0
Avg. Age Puberty (days)	365	365	365	365	365
Avg. Gestation (days)	270	270	270	270	270

2.6.4 Monthly Profiles for Each Combination of Production System and Production Zone to Estimate Nutrient Requirements, Intake, Milk Yield, and Meat Sales

Once location and numbers for each of the breeds had been established, average monthly profiles were derived for each production system based on environmental conditions (derived from the ACT analysis), average nutritional values, terrain conditions, feed inputs, use of metabolic modifiers, and potential intake restrictions. The average monthly values were run as a case for each class of animal for an entire year. The resulting monthly values were placed in an ACCESS database and assigned weighted values based on the mean herd structure for each province and production system. The weighted monthly values were then summed into annual requirements for crude protein (kg), net energy of maintenance (mcal), and intake (kg).

Values for the milk cow component were on a cow unit basis. A cow unit was derived by determining the fraction of other classes of animals supporting the cow herd per mature cow. This is sometimes referred to the mature breeding unit concept. To reflect the steer fattening operations, annual requirements were derived for a 12-24 month and 24-36 month steer summed for annual production. The rangeland herd was derived based on studies of herd structure conducted by Peeler and Ormore (1997). Tables 2.6.4.1 and 2.6.4.2 provide nutrient requirements, intake, milk yield, and meat sales for each province and production system.

2.6.5 Average Annual Fodder/Forage/Feed Values at the Province Level (yield, crude protein, net energy, TDN) - NUTBAL

The ASM input requires that forage resources be characterized in terms of average annual yield (kg/ha), crude protein content (%), and net energy concentration (mcal/kg) by province (Table 2.6.5.1). Forage/fodder resources were categorized as maize stover, Napiergrass, native forage, purchased fodder, and concentrate feed for smallholder dairy. To account for beef production in the ASM system, a rangeland component had to be added to the matrix. Yield values were derived from area-weighted estimates based on yields of crops generated from the EPIC model and forage yields from the PHYGROW model using the household surveys of the representative farms conducted for each production zone adjusted to the provinces selected for analysis in Kenya (Figure 2.6.5-1). Forage crude protein values were derived from published data provided by KARI and ILRI animal scientists. Forage net energy of maintenance (NEm) values were derived from reported total digestible nutrients (TDN) values of each forage resource and confirmed by the same KARI and ILRI scientists. Forage intake by animal class and expected milk yield were generated from these diet-quality values and weather data using the NUTBAL PRO nutritional balance analyzer.

2.6.6 Computation of Land Area Required to Provide Forage for Dairy Populations

Although hectorage for major land uses and associated crops is available in secondary data by district and through USGS land cover data in ACT, ASM requires estimates of land area for forage/fodder crops as well. These data were not available and required a derivation of land area supporting a specific animal demand. The technique relies on a reasonable estimate of animal populations by breedtype and production system. After establishing an area-weighted average forage yield, diet composition of each component, and

Table 2.6.4.1 Annual animal nutrient intake and milk production profile for a cow-unit in the four major milk production systems characterizing smallholder dairying in Kenya.

Province	Zebu Cattle Grazing Native/Roadside/ Plantation Forage	Dairy x Zebu Cattle Grazing Native/Roadside/ Plantation Forage	Dairy Breed Cattle Grazing in Semi-Zero Grazing	Dairy breed Cattle With Zero-Grazing
Central				
Intake (kg)	4955	8516	8957	9067
CP (kg)	462	605	639	647
NEm (mcal)	5307	8966	10701	11135
Milk Prod (kg)	735	1394	1941	2891
Meat (kg)	140	140	137	142
Coast				
Intake (kg)	3959	6870	7512	7672
CP (kg)	401	526	572	583
NEm (mcal)	4480	7572	9250	9670
Milk Prod (kg)	552	1394	1941	2891
Meat (kg)	265	140	137	142
Eastern				
Intake (kg)	4497	7256	7746	7869
CP (kg)	427	533	569	578
NEm (mcal)	4952	7944	9565	9970
Milk Prod (kg)	735	1394	1941	2891
Meat (kg)	140	140	137	142
North-Eastern				
Intake (kg)	4307	N/A	N/A	N/A
CP (kg)	402	N/A	N/A	N/A
NEm (mcal)	4528	N/A	N/A	N/A
Milk Prod (kg)	404	N/A	N/A	N/A
Meat (kg)	34	N/A	N/A	N/A
Nyanza				
Intake (kg)	4955	7256	7746	7869
CP (kg)	462	533	569	578
NEm (mcal)	5307	7944	9565	9970
Milk Prod (kg)	735	1394	1941	2891
Meat (kg)	140	140	137	142
Rift Valley				
Intake (kg)	4955	8516	8957	9067
CP (kg)	462	605	639	647
NEm (mcal)	5307	8966	10701	11135
Milk Prod (kg)	735	1394	1941	2891
Meat (kg)	140	140	137	142
Western				
Intake (kg)	4955	8516	8957	9067
CP (kg)	462	605	639	647
NEm (mcal)	5307	8966	10701	11135
Milk Prod (kg)	735	1394	1941	2891
Meat (kg)	140	140	137	142

Table 2.6.4.2 Inputs of annual requirements for intake, crude protein, net energy of maintenance, milk production and meat production for the rangeland cow-calf production systems and steer fattening operations in Kenya for the ASM model.

Province	Zebu x Dairy Extensive Steer Fattening	Dairy Intensive Steer Fattening	Rangeland Zebu Cow/calf
Central			
Intake (kg)	6,647	6,597	N/A
CP (kg)	411	409	N/A
NEm (mcal)	5,745	6,772	N/A
Milk Prod (kg)	0	0	N/A
Meat (kg)	300	350	N/A
Coast			
Intake (kg)	6,647	6,597	4,307
CP (kg)	411	409	402
NEm (mcal)	5,745	6,772	4,528
Milk Prod (kg)	0	0	404
Meat (kg)	300	350	34
Eastern			
Intake (kg)	6,647	6,597	4,307
CP (kg)	411	409	402
NEm (mcal)	5,745	6,772	4,528
Milk Prod (kg)	0	0	404
Meat (kg)	300	350	34
North-Eastern			
Intake (kg)	N/A	N/A	4,307
CP (kg)	N/A	N/A	402
NEm (mcal)	N/A	N/A	4,528
Milk Prod (kg)	N/A	N/A	404
Meat (kg)	N/A	N/A	34
Nyanza			
Intake (kg)	6,647	6,597	4,307
CP (kg)	411	409	402
NEm (mcal)	5,745	6,772	4,528
Milk Prod (kg)	0	0	404
Meat (kg)	300	350	34
Rift Valley			
Intake (kg)	6,647	6,597	4,307
CP (kg)	411	409	402
NEm (mcal)	5,745	6,772	4,528
Milk Prod (kg)	0	0	404
Meat (kg)	300	350	34
Western			
Intake (kg)	6,647	6,597	N/A
CP (kg)	411	409	N/A
NEm (mcal)	5,745	6,772	N/A
Milk Prod (kg)	0	0	N/A
Meat (kg)	300	350	N/A

Table 2.6.5.1 Average annual fodder/forage/feed values adjusted by province in Kenya for Agricultural Sector Model input. Values reflect a combination of model runs (Napiergrass), literature values and expert opinion.

Province	Maize Stover	Napiergrass	Native Forage	Purchased Fodder	Concentrate Feed	Rangeland Forage
Central						
Yield (kg/ha)	12,000	12391	6,000	7000	na	na
Crude Protein %	5.0	8.0	14.5	7.0	16.0	na
NEm (Mcal/kg)	1.14	1.24	1.25	1.20	1.75	na
Coast						
Yield (kg/ha)	10,000	20316	3500	5,000	na	3,000
Crude Protein %	5.0	8.0	8.0	7.0	16.0	8.0
NEm (Mcal/kg)	1.14	1.24	1.25	1.20	1.75	1.22
Eastern						
Yield (kg/ha)	12,000	15785	3500	6,000	na	3,400
Crude Protein %	5.0	8.0	8.5	7.0	16.0	8.0
NEm (Mcal/kg)	1.14	1.24	1.23	1.20	1.75	1.22
North-Eastern						
Yield (kg/ha)	0	0	3,500	0	na	1,300
Crude Protein %	5.0	8.0	8.0	7.0	16.0	8.0
NEm (Mcal/kg)	1.14	1.24	1.22	1.20	1.75	1.22
Nyanza						
Yield (kg/ha)	12,000	14752	4,500	6,000	na	3,500
Crude Protein %	5.0	8.0	8.0	7.0	16.0	8.0
NEm (Mcal/kg)	1.14	1.24	1.22	1.20	1.75	1.22
Rift Valley						
Yield (kg/ha)	12,000	13630	5,000	6,000	na	4,000
Crude Protein %	5.0	8.0	9.0	7.0	16.0	8.0
NEm (Mcal/kg)	1.14	1.24	1.26	1.20	1.75	1.26
Western						
Yield (kg/ha)	12,000	14004	5,000	7,000	na	na
Crude Protein %	5.0	8.0	14.5	7.0	16.0	na
NEm (Mcal/kg)	1.14	1.24	1.25	1.20	1.75	na

harvest efficiency (% of annual forage production or crop residues actually consumed by the animal population), the amount of land area required to support the level of forage/fodder demand of that population within a defined administrative district or province is computed. The method is essentially a "demand side" computation of land area needed to support a given population of animals. A simple spreadsheet program called LAND DEMAND was created to help compute the supporting land area for the herds by provincial level identified for the agricultural sector analysis.

2.7 Development and use of the Kenya Agricultural Sector Model

After all necessary inputs for the Agricultural Sector Model had been gathered or computed, the ASM model was run to estimate economic impacts on society derived from the evolution of smallholder dairy technology. Kenya's production value of dairy products in 1995 was about 253.75 million Kenya shillings (Ksh), or about 8.48% of total agricultural product value. Cereals accounted for 10.73% of total agricultural product value while permanent crops such as tea and coffee accounted about 54.50%. As previously stated, dairy technology improvements had already been introduced in Kenya, including cross-breeding of native Zebu cattle with European breeds; introduction of European dairy breeds; introduction of improved forages; animal health and disease controls; intensive dairy management and feeding systems including mineral and nutrient supplementation; and more efficient and effective marketing strategies for milk.

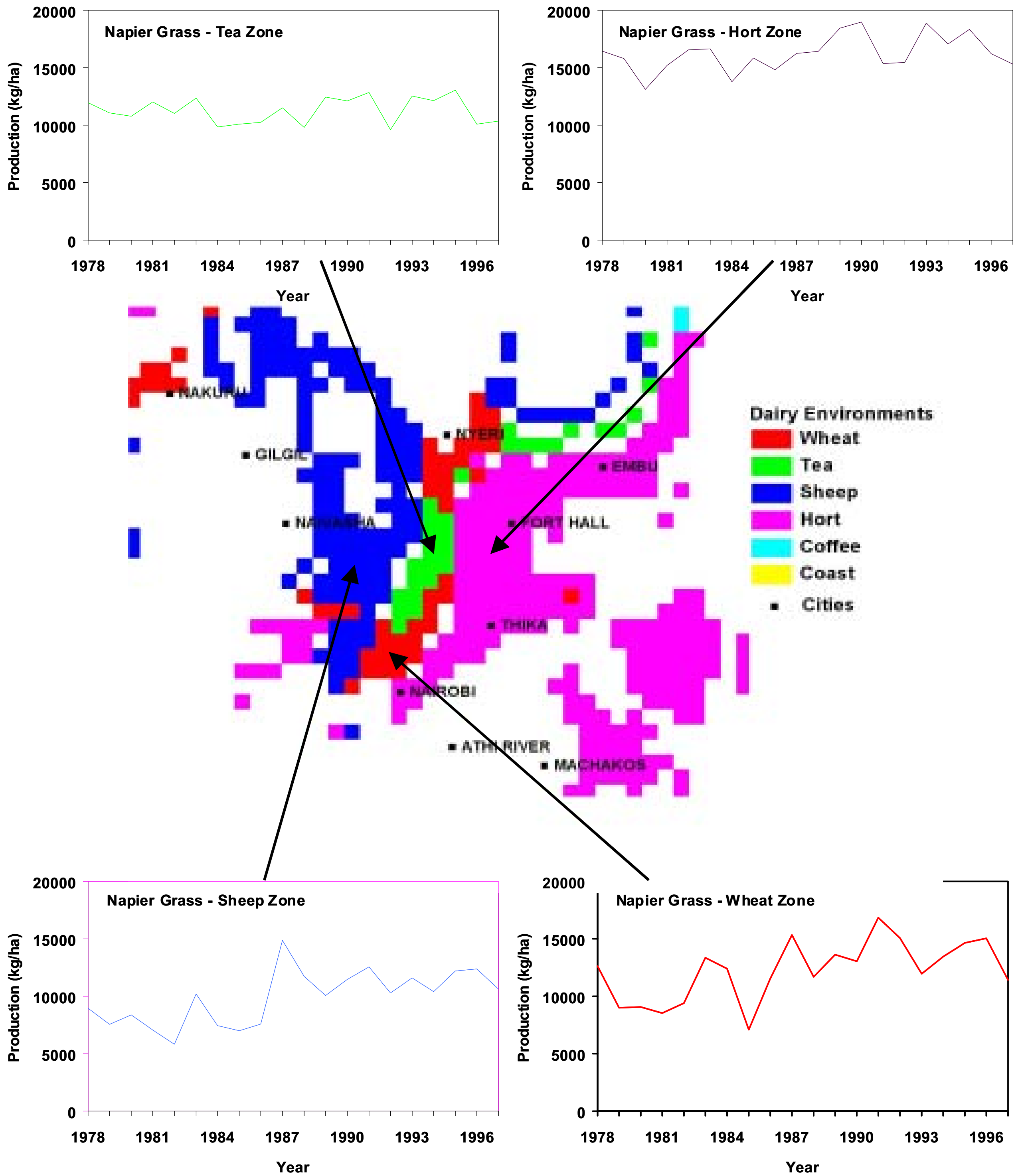


Figure 2.6.5-1. Biophysical models (PHYGROW, EPIC) were used to simulate forage and crop yields within small holder dairy in Kenya. Resulting yields are then used to develop spatially synchronized yield probabilities needed for economic risk analyses in FLIPSIM and ASM. In this example, yearly production of Napier grass is shown for several small holder dairy environments.

This analysis compared intensive dairy production systems with a scenario requiring all milk production to come from the traditional, zebu-cattle based technology. A comparison of current adoption of the intensive systems with traditional technology provides an estimate of past impacts of the technology development and transfer. A comparison of current adoption with estimates of future full adoption for the intensive systems provides an estimate of future impacts from the technologies.

2.7.1 Review of ASM literature

Various versions of the Agricultural Sector Model (ASM) have been used to investigate the economic impacts of technological change, trade policy, commodity programs, environmental policy, and global warming in the context of the U.S. agricultural sector (Baumes, Burton and Martin; Hamilton, McCarl, and Adams; Adams, Hamilton, and McCarl; Chang, McCarl, Mjelde and Richardson; Chang, Eddleman, and McCarl; Adams, Bryant, McCarl, Legler, and O'Brien). ASM has been set up as price-endogenous mathematical programs following the market equilibrium and optimization concept developed by Samuelson and Takayama and Judge, as reviewed by McCarl and Spreen and Norton and Schiefer. Such models simulate competitive equilibrium solutions under a set of demand and supply conditions in agricultural commodity and input markets.

2.7.2 Characteristics of the Kenya ASM

In ASM, the market is assumed competitive and equilibrium price and quantity are determined by the intersection of supply and demand for each commodity. Many consumers and producers are assumed to be in the competitive market. Consumers maximize their utility subject to budget constraints. Similarly, producers maximize their profit given production technology and prices; therefore, the supply function depends on prices and technology. Aggregation of each consumer demand function and each producer supply function results in market demand and supply functions. In this competitive market, social welfare is maximized when the market is in equilibrium. That is, maximum welfare will occur at the intersection of the demand and supply function. ASM includes market balance constraints and resource constraints and assumes that maximizing social welfare is the objective function. The model generates estimates of agricultural commodity prices and quantities, input use, land use and crop mixes, and consumer and producer economic surpluses.

As mentioned earlier, the Kenya ASM considers seven of the eight geographical provinces that include the Nairobi, Central, Coast, Eastern, Nyanza, Rift Valley, North Eastern, and Western regions (Figure 2.1-1). Nairobi is treated as a demand only region, and the North Eastern region is neither an agricultural production nor demand region in the Kenya ASM. The other six regions have both demand and agricultural production activities. The Kenya ASM also includes inputs on the production of 18 primary products and 9 secondary products (Table 2.7.2.1).

Crop production is defined by region, crop, and agricultural zone. Livestock production activity is by region, animal type, and agricultural zone. Major crops modeled in the Kenya ASM are maize, millet, beans, wheat, sorghum, coffee, and tea. The major livestock enterprise modeled is dairy cattle; however, beef, sheep, and hogs are also modeled. Agricultural zones depict crop growth and yield potential of land and climate resources and are designated as High, Middle, and Low zones. Labor and land are used in the crop and livestock production activities and are limited in quantity by production region.

Table 2.7.2.1 Primary and Secondary Products in the Kenya ASM

Primary Products	Secondary Products
Wheat	Coffee
Maize	Tea
Maize residue	Milk
Sorghum	Pork
Millet	Beef
Beans	Mutton/goat meat
Potatoes	Net energy maintenance
Groundnuts	Crude protein
Raw coffee	Dry matter
Raw tea	
Raw milk	
Bull calves	
Cull cows	
Heifers	
Sheep/goats	
Baconers	
Napiergrass	
Native grass	

Commodity demand in the Kenya ASM depicts three market levels: home consumption expenditures, regional markets, and international trade. Home consumption represents farmer and family self-consumption while regional markets refer to the local urban markets. International trade represents the national market which includes both exports from and imports to Kenya.

Technology improvements are evaluated by setting up different forage, animal management systems, cost of production, and associated technology adoption versions of the model to provide simulations with and without the smallholder dairy intensification technologies in Kenya agriculture. Simulation results for each technology and adoption scenario are compared to evaluate the economic impact of the technology on regional, national, and foreign consumers and producers. Current and full adoption rates for the dairy production systems are included in simulations in order to estimate past and potential economic impacts.

Current adoption rates are defined as the percentage of herds in each province using the technologies defined by the management system alternatives; the current adoption rates represent the existing mix of traditional and improved dairy production systems. Full adoption rates represent best judgements of the maximum percentages of herds using the improved dairy production systems after wide-scale introduction of the technologies. Current adoption rates for the dairy production systems were obtained from survey data from the MOA/KARI/ILRI smallholder dairy project, KARI personnel with experience in surveying technology adoption processes, and expert opinion of researchers from ILRI and KARI. We consulted with experts who had experience conducting studies of adoption profiles to estimate the full adoption rates. Experts provided information on adoption profiles for the animal breed, forage and feeding, and health components of the dairy production systems.

The technology assessment focuses on four dairy production systems (see section 2.3). The current dairy production technology has a mix of traditional though intensive production possibilities. The available data indicated that milk production primarily occurs in the Central, Coast, Eastern, Nyanza, Western, and Rift

Valley regions. The Central and Rift Valley regions are major milk production areas. Native grasses, Napiergrass, and maize residue are controlled in the analysis to meet the animal diet requirements in terms of dry matter (DRYM), crude protein (CP), and net energy maintenance (NEM).

2.7.3 Mathematical and Graphic Description of the Models

The ASM can be expressed by mathematical equations representing demand and supply functions for each commodity; an objective function; regional and national marketing balance constraints for each commodity; and constraints on regional land and labor resources, minimum nutrient requirements, and minimum and maximum adoption rates for each dairy production system (Appendix A).

Results of the ASM models can also be represented graphically Figure 2.7.3-1 shows supply and demand curves and illustrates the potential impact of technology adoption. Assume there exists aggregated demand and supply curves for a commodity in Kenya, as D_{Kenya} and S_{Kenya} in Figure 2.7.3-1. Also assume there is export of the commodity from Kenya to the rest of world (ROW). The exess supply curve ES_{Kenya} is calculated from the aggregated supply curve minus the aggregated demand curve. With an improved technology that is implemented into the production system, assume the aggregated supply curve shifts from S_{Kenya} to $S'_{Kenya.}$ The domestic production and export quantity increase while the domestic price decreases when the improved technology is adopted.

Consumers' surplus, producers' surplus, and foreign surplus also are changed due to adoption of the technology. Domestic consumers' surplus will increase as shown by the area of A while the change in producers' surplus will be the area of (E+D-B-A) when the improved technology is adopted. The producers' gain or loss depends on the sign of (E+D-B-A). Foreign surplus also changes as the area of (G-F). The Kenya ASM estimates these changes in consumers surplus, producers surplus, and foreign surplus from shifts in the milk supply resulting from the adoption of smallholder dairy technologies.

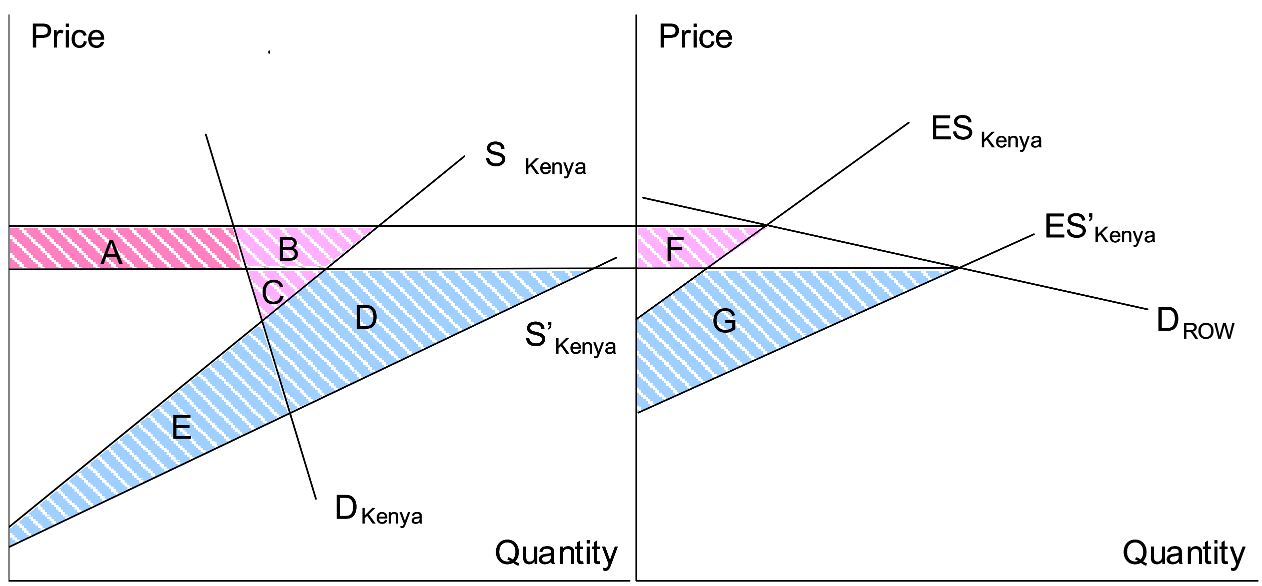


Figure 2.7.3-1. Welfare changes under alternative production technology in an open market.

2.7.3.1 Base Model Output Compared with Observed Production (Verification) for Multiple Commodities, Including Milk and Meat

To verify the output of the ASM, the outputs such as market prices, total production, exports, and imports for the current dairy production in Kenya were compared to observed baseline data. The Base Model, designated by the baseline data reflecting the current economy, is defined as improved dairy technology under current adoption rates. The outputs from the Kenya ASM solution are close to the observed data (Table 2.7.3.1.1). For example, ASM showed the raw milk price and production quantity to be 15.35 Ksh/kg and 3.72 million tons under current dairy production technology. The observed 1995 data showed the values to be close: 15.00 Ksh/kg and 3.5 million tons. Prices and production quantities for most other commodities are generally within 5% to 10% of observed values, indicating that the base Kenya ASM solution corresponds relatively close to observed agricultural production and consumption.

On the demand side, the Kenya ASM output includes home consumption, regional demand, and export quantities, as shown in Table 2.7.3.1.2. A high percentage of maize, beans, groundnuts, potatoes, and milk production is used for home consumption. Maize, tea, and coffee are the major export commodities while wheat is the major product imported into Kenya as shown in Tables 2.7.3.1.1 and 2.7.3.1.2.

In the Kenya ASM solutions, all regions except Nairobi and Coast are major producers of maize, while the Central, Eastern, and Rift Valley regions produce wheat under each of the technology scenarios, as shown in Table 2.7.3.1.3. The millet and beans production areas are in the Eastern, Nyanza, Rift Valley, and Western regions. Raw milk is produced in the Central, Coast, Eastern, Nyanza, Rift Valley and Western regions. Table 2.7.3.1.3 shows that the Rift Valley region is the major crop and milk production area.

2.7.4 Evaluating the Past and Potential Economic Impact of Alternative Dairy Production Systems

The first step in the ASM analysis compared results from the Improved Dairy Technology under current adoption to the results from the Traditional Dairy scenarios. The Improved Dairy scenario allows all the current dairy production technologies to enter the ASM solution. The current adoption rates for systems 2, 3 and 4 as shown in Table 2.7.4.1 limit the mix of these technologies in the simulation. The Traditional Dairy scenario allows only the Zebu cattle dairy production technology to be used to meet current demand. The results of this comparison showed the past impact of technology adoption.

In the second step, the Improved Dairy Technology under current adoption was compared to the Improved Dairy Technology under full adoption rates. Price, production, input use, and welfare components were compared in the following economic impact assessments. This comparison showed the potential impact of expanded technology adoption. Estimates of current and future adoption rates were made using a panel of national research and extension experts.

Table 2.7.3.1.1 Comparison of Kenya ASM Base Model Solution with Observed 1995 Data

Unit: Ksh/kg and ton

Item by Commodity	Base Model Solution	Observed Data	Base: Observed
Price (Ksh/kg)			
Wheat	15.52	15.00	1.03
Maize	8.99	8.84	1.02
Sorghum	6.69	9.00	0.74
Millet	21.45	20.00	1.07
Beans	15.64	15.00	1.04
Coffee	129.87	159.66	0.81
Tea	66.22	67.86	0.98
Raw milk	15.37	15.00	1.02
Production (ton)			
Wheat	63096	135000	0.48
Maize	2461878	2369700	1.04
Sorghum	77398	75600	1.02
Millet	54980	69700	0.79
Beans	250557	250000	1.00
Coffee	86289	95400	0.90
Tea	314575	244530	1.29
Raw milk	3729172	3500000	1.06
Export (ton)			
Maize	232552	221478	1.05
Coffee	85860	95400	0.90
Tea	314575	262146	1.20
Milk	36364	37329	0.97
Import (ton)			
Wheat	314400	314400	1.00
Milk	36365	36000	1.01

Table 2.7.3.1.2 Prices, Production, Uses, and Trade for Major Products under Alternative Dairy Cattle Technology Scenarios in the Kenya ASM

Unit: Ksh/kg, ton, %

Commodity by Region	Improved Dairy Current Adoption	Traditional Dairy		Improved Dairy Full Adoption	
		Change	Percentage	Change	Percentage
	(Value)	(Value)	(%)	(Value)	(%)
Price (Ksh/kg)					
Wheat	15.52	0.34	2.17	0.34	2.17
Maize	8.99	-0.03	-0.29	-0.09	-1.06
Sorghum	6.69	0.05	0.80	0.00	0.00
Millet	21.45	-0.07	-0.33	-0.02	-0.11
Beans	15.64	0.01	0.07	-0.04	-0.24
Coffee	129.87	-2.45	-1.89	-3.27	-2.52
Tea	66.22	0.00	0.00	0.00	0.00
Raw milk	15.37	0.94	6.13	-0.31	-2.03
Production (ton)					
Wheat	63096	-5011	-7.94	-5402	-8.56
Maize	2461878	2446	0.10	3005	0.12
Sorghum	77398	-105	-0.14	0	0
Millet	54980	0	0	0	0
Beans	250557	0	0	-69	-0.03
Coffee	86289	958	1.11	1917	2.22
Tea	314575	0	0	0	0
Raw milk	3729172	-1811071	-48.56	12964	0.35
Home Consumption (ton)					
Maize	1048331	0	0	0	0
Potatoes	156600	0	0	0	0
Groundnuts	2692	0	0	0	0
Millet	13533	0	0	0	0
Beans	141134	0	0	0	0
Milk	2168514	0	0	0	0
Regional-Demand (ton)					
Wheat	377496	-5011	-1.33	-5402	-1.43
Maize	1180995	2446	0.21	3005	0.25
Potatoes	107991	0	0	0	0
Groundnuts	5123	0	0	0	0
Sorghum	77398	-105	-0.14	0	0
Millet	41446	0	0	0	0
Beans	109422	0	0	-69	-0.06
Milk	1206302	-58568	-4.86	11732	0.97
Export (ton)					
Maize	232552	0	0	0	0
Coffee	85860	954	1.11	0	0
Tea	314575	0	0	0	0
Milk	36364	0	0	0	0
Import (ton)					
Wheat	314400	0	0	0	0
Milk	36365	1580409	4346	0	0

(Note): The percentage change is defined as the Traditional Dairy or the Improved Dairy Full Adoption minus Improved Dairy Current Adoption scenario divided by Improved Dairy Current Adoption scenario times 100.

Table 2.7.3.1.3 Regional Production for Major Commodities in the Kenya ASM Scenarios

Unit: ton

Commodity by Region	Improved Dairy Current Adoption	Traditional Dairy		Improved Dairy Full Adoption	
		Change	Percentage	Change	Percentage
	(Value)	(Value)	(%)	(Value)	(%)
Wheat					
Central	2354	-54	-2.32	-46	-1.94
Eastern	7020	-1066	-15.19	315	4.49
Rift Valley	53721	-3890	-7.24	-5671	-10.56
Maize					
Central	148254	-3445	-2.32	-2886	-1.95
Eastern	128175	0	0	0	0
Nyanza	508011	45330	8.92	-17198	-3.39
Rift Valley	1043231	4123	0.40	4123	0.40
Western	585139	-43562	-7.44	98032	11.63
Millet					
Eastern	8224	-1246	-15.16	368	4.48
Nyanza	40637	1669	4.11	188	0.46
Rift Valley	1522	-465	-30.61	-503	-33.08
Western	4597	43	0.94	-53	-1.17
Bean					
Eastern	7581	2504	33.03	-741	-9.77
Nyanza	35031	4222	12.05	-1754	-5.01
Rift Valley	94658	2386	2.52	2662	2.81
Western	104046	-9112	-8.76	8963	8.62
Milk					
Central	976886	-500217	-51.21	-185426	-18.98
Coast	138623	-79877	-57.62	458804	230.97
Eastern	473036	-12340	-2.61	0	0
Nyanza	284091	-260278	-91.62	274177	96.51
Rift Valley	1705167	-956275	-56.08	-534591	-31.35
Western	151367	-2083	-1.38	0	0

Table 2.7.4.1 The Definition of Dairy Cattle Technology and Adoption Rates for the Animal Breed/Feed/Management System Alternatives

Scenarios	Allowed Dairy Production Technology	Allowed Sources for Feed
Improved Dairy Current Adoption	Zebu-cattle, (1) Cross breed cattle, (2) Dairy breed cattle with semi zero-grazing, (3) Dairy breed cattle with zero-grazing. (4)	Napier grass Maize residue Native grass
Traditional Dairy	Zebu-cattle (1)	Maize residue Native grass
Improved Dairy Full Adoption	Zebu-cattle, (1) Cross breed cattle, (2) Dairy breed cattle with semi zero-grazing, (3) Dairy breed cattle with zero-grazing. (4)	Napier grass Maize residue Native grass

Cattle Breed/ Feeding System* / Province	Current Adoption (%) **				Full Adoption (%) **			
	1	2	3	4	1	2	3	4
Central	5	5	20	70	0	0	20	80
Coast	75	10	10	5	60	15	15	10
Eastern	50	10	20	20	30	15	25	30
Nyanza	75	10	10	5	40	15	20	25
Rift Valley	50	5	15	30	30	10	25	35
Western	80	10	5	5	40	25	10	25

* The proportion of dairy breed/feeding system (1) representing the traditional zebu breed of cattle with grazing of native grass and feeding of maize residues is allowed to enter the ASM algorithm at 100% with the numbers for the dairy technology systems 2, 3, and 4 constrained to zero percentages for each region under the Traditional Dairy scenario.

** Defined as the percent of total animals in dairy herds using the technologies defined by the animal breed/feed/management system alternatives. Full adoption represents the maximum percentage of total animals in dairy herds that would use animal breed/feed/management systems 2, 3 and 4.

2.7.4.1 Results of the ASM: Price and Production

Results of the ASM showed that Improved Dairy Technology has had a positive effect on the Kenyan economy and social welfare. Further positive impacts are possible under a full adoption scenario, although the bulk of the benefits has already been achieved given current demand. As population increases, demand will be created. Future improvement in dairy production will most likely go to meet the growing demand. The following are estimates from ASM output.

Traditional vs. Current

If current demands had to be met with Traditional Dairy technology rather than Improved Dairy technology under current adoption rates, the raw milk price would be 16.31 Ksh/kg, which is 0.94 Ksh/kg higher, or

6.1% higher, as shown in Table 2.7.4.1.1. The quantity of raw milk produced would be down by 1.81 million tons, or 48.5%. Regional demand for milk in the urban areas of Kenya would drop by some 58 thousand tons and the deficit supply for milk would have to be met with increased imports, totaling some 1.58 million tons with an import price of 18 Ksh/kg (Tables 2.7.3.1.2 and 2.7.4.1.1). The burden of the price increase for raw milk would fall primarily on home consumption by farmers and their families. Home consumption expenditures would increase some 2.2 billion Ksh annually (Table 2.7.4.1.2). Price, production, and regional demand for other commodities would be little affected, as shown in Table 2.7.4.1.3. The major change in commodity production and price would be a 7.9% decrease in wheat production with a corresponding 2.17% price increase.

Table 2.7.4.1.1 Milk Price, Production, Import and Export under 18 Ksh Import Milk Price in the Kenya ASM

					Unit: Ksh/kg, ton, million Ksh
Scenario	**Price**	**Production**	**Import**	**Export**	**Welfare**
With 18 Ksh/kg import price					
Improved Dairy Current Adoption	15.37	3729172	36365	36365	201967
Traditional Dairy	16.31	1918101	1616774	36365	199083
Improved Dairy Full Adoption	15.05	3742136	36365	36365	202672

Regional milk production would decrease if the Traditional Dairy technology was currently in use to produce all milk, as shown in Table 2.7.3.1.3. Milk production would be down substantially in the Central, Coast, Nyanza, and Rift Valley regions, with much less reduction in the Eastern and Western regions. For example, the quantity of milk produced in the Central and Rift Valley regions was 0.97 million and 1.70 million tons, respectively, under the Improved Dairy current adoption scenario. These quantities would decrease by 0.50 million and 0.95 million tons, respectively, if only the Traditional Dairy technology was available to produce milk. Regional shifts in wheat, maize, millet, and bean production also would be expected. The Rift Valley and Nyanza Regions would experience increases in maize and bean production while the Western Region would have decreases in production of these two crops. Much smaller changes in wheat and millet production would occur (Table 2.7.3.1.3). Thus, one result of the development and adoption of the Improved Dairy technologies has been to foster these changes in land use and crop production, allowing the expansion of maize production in the Nyanza and Rift Valley regions with a corresponding reduction of maize production in the Central and Western regions.

The Improved Dairy current adoption scenario resulted in an estimated 285 thousand fewer number of cows required to produce the raw milk to satisfy total demand compared to the Traditional Dairy scenario. However, the regional distribution of cow numbers had been substantially changed (Tables 2.7.4.1.5 and 2.7.4.1.6). For example, dairy cows numbers in the Central and Rift Valley regions total some 408,323 head and 1,124,878 head, respectively, under the Improved Dairy current adoption scenario. Under the Traditional Dairy scenario, the Central Region would to increase cow numbers to 682,663 head, nearly 67% more cows to produce sufficient milk to meet current demand (Table 2.7.4.1.6). The Rift Valley Region would have a total of 1,072,526 dairy cows, a 4% decrease in cow numbers. The Eastern and Western regions would experience increases in cow numbers by 95.2% and 30.0%, respectively, while the Coast and Nyanza regions would reduce cow numbers by 31.5% and 88.2%, respectively.

Current Adoption vs. Full Adoption

If full adoption conditions existed, given the current 1995 demands for the commodities, raw milk production would be increased an additional 12.9 thousand tons and the price of raw milk would be reduced 0.31 Ksh/kg, or about 2.0% (Table 2.7.4.1.3). Wheat production would be decreased by an additional 5.4 thousand tons with a corresponding increase in price of 0.34 Ksh/kg. Regional consumers in the urban areas would increase their consumption of the additional amounts of milk. These results indicate that the major portion of the benefits from the Improved Dairy technologies already has been received with the current adoption rates and current (1995) demand conditions. The full adoption of Improved Dairy technologies would be expected to contribute most to meeting future growth in demand for milk as population and per capita income growth occurs in Kenya.

Under full adoption conditions for the Improved Dairy technologies with current demand, the total production of raw milk would be increased by an additional 12.9 thousand tons. However, substantial changes in regional production of milk would occur. The Central and Rift Valley regions would reduce raw milk production by some 185.4 and 534.6 thousand tons, respectively. A corresponding increase in milk production of 458.8 and 274.2 thousand tons in the Coast and Nyanza regions, respectively, would occur. Again, this signifies the importance of growth in demand through population and per capita income increases to absorb increased milk supplies. This factor needs to be considered as programs to foster full adoption of the Improved Dairy technologies are pursued.

Under the Improved Dairy full adoption scenario, total cow numbers would be expected to decrease in the Central (24.4%), Eastern (17.3%), Rift Valley (41%), and Western (37.8%) regions, while increasing substantially in the Coast (243.2%) and Nyanza (25.3%) regions (Tables 2.7.4.1.6 and 2.7.4.1.7). A growing demand for milk through population and per capita income growth is necessary for regional stability in cow numbers and milk production to occur.

2.7.4.2 Changes in Labor and Crop Land Inputs

Traditional vs. Current

Labor and crop land usage listed in Table 2.7.4.1.2 shows that the changes in labor and crop land use varies among regions and between the dairy technology scenarios. Both labor and crop land use would be lower under the Traditional Dairy scenario as compared with the Improved Dairy current adoption scenario. About 30.2 million fewer mandays, or 5.3% less labor, would be required to produce the dairy, other livestock, and crop enterprises if current demands for milk had to be met with Traditional Dairy technologies. This decreased labor requirement would be primarily in the Coast, Nyanza, and Rift Valley regions, which would need an estimated 27.0%, 8.9% and 8.8% less labor on farms, respectively. The Central and Eastern Regions would increase labor use by 4.8% and 1.3%, respectively.

Total crop land use for Kenya would be decreased by some 1024 thousand hectares, or 8.2% with the scenario. The Eastern and Rift Valley Region would experience a 573 and 465 thousand hectare decrease in crop land use. The Central Region would also reduce crop land use under the Traditional Dairy scenario, while the Western Region would experience an increase in crop land use.

Table 2.7.4.1.2 Regional Land and Labor Usage, Producers and Consumer's Surplus, and Home-Consumption Expenditure in the Kenya ASM

Unit: 1000 man-day, 1000 hectare, million Ksh

Item by Region	Improved Dairy Current Adoption	Traditional Dairy		Improved Dairy Full Adoption	
		Change	Percentage	Change	Percentage
	(Value)	(Value)	(%)	(Value)	(%)
Labor (1000 md)					
Central	82775	3991	4.82	-5734	-6.93
Coast	15155	-4106	-27.09	25138	165.87
Eastern	71000	930	1.31	0	0
Nyanza	132770	-11775	-8.87	5462	4.11
Rift Valley	200718	-17753	-8.84	-27417	-13.66
Western	67062	-1538	-2.29	1570	2.34
Total	569480	-30243	-5.31	-980	-0.17
Crop land (1000 ha)					
Central	746.49	-17.35	-2.32	-14.53	-1.95
Coast	796.00	0	0	132.71	16.67
Eastern	3769.87	-573.59	-15.22	169.67	4.50
Nyanza	1252.01	0	0	0	0
Rift Valley	2527.33	-465.27	-18.41	-539.40	-21.34
Western	3354.81	31.67	0.94	-39.47	-1.18
Total	12446.51	-1024.58	-8.23	-291.03	-2.33
Producers' Surplus (mil Ksh)					
Central	602	-21	-3.44	-115	-19.07
Coast	14	-17	-117.53	127	900.00
Eastern	112	15	13.02	4	3.97
Nyanza	4068	-25	-0.62	1	0.02
Rift Valley	1664	-420	-25.22	-524	-31.50
Western	301	-32	-10.64	0	0
Total	6761	-500	-7.39	-507	-7.49
Home-Consumption Expenditure (mil Ksh)					
Central	-10907	-700	6.42	-12	0.11
Coast	-2012	-93	4.64	25	-1.24
Eastern	-6362	-300	4.72	4	-0.06
Nyanza	-4597	-208	4.52	82	-1.79
Rift Valley	-28029	-866	3.09	535	-1.91
Western	-2561	-77	3.00	9	-0.34
Total	-54471	-2244	4.12	642	-1.18
Consumers' Surplus (mil Ksh)					
Nairobi	45239	-231	-0.51	-44	-0.10
Central	18778	-194	-1.03	6	0.03
Coast	6995	-23	-0.33	28	0.40
Eastern	19380	37	0.19	32	0.16
Nyanza	14252	39	0.28	104	0.73
Rift Valley	47965	-132	-0.23	37	0.08
Western	7807	47	0.60	16	0.21
Total	160416	-458	-0.29	179	0.11

Table 2.7.4.1.3 Prices, Production, Uses, and Trade for Major Products under Alternative Dairy Cattle Technology Scenarios in the Kenya ASM

Unit: Ksh/kg, ton, %

Item by Commodity	Improved Dairy Current Adoption	Traditional Dairy		Improved Dairy Full Adoption	
		Change	Percentage	Change	Percentage
	(Value)	(Value)	(%)	(Value)	(%)
Price (Ksh/kg)					
Wheat	15.52	0.34	2.17	0.34	2.17
Maize	8.99	-0.03	-0.29	-0.09	-1.06
Sorghum	6.69	0.05	0.80	0.00	0.00
Millet	21.45	-0.07	-0.33	-0.02	-0.11
Beans	15.64	0.01	0.07	-0.04	-0.24
Coffee	129.87	-2.45	-1.89	-3.27	-2.52
Tea	66.22	0.00	0.00	0.00	0.00
Raw milk	15.37	0.94	6.13	-0.31	-2.03
Production (ton)					
Wheat	63096	-5011	-7.94	-5402	-8.56
Maize	2461878	2446	0.10	3005	0.12
Sorghum	77398	-105	-0.14	0	0
Millet	54980	0	0	0	0
Beans	250557	0	0	-69	-0.03
Coffee	86289	958	1.11	1917	2.22
Tea	314575	0	0	0	0
Raw milk	3729172	-1811071	-48.56	12964	0.35
Home Consumption (ton)					
Maize	1048331	0	0	0	0
Potatoes	156600	0	0	0	0
Groundnuts	2692	0	0	0	0
Millet	13533	0	0	0	0
Beans	141134	0	0	0	0
Milk	2168514	0	0	0	0
Regional-Demand (ton)					
Wheat	377496	-5011	-1.33	-5402	-1.43
Maize	1180995	2446	0.21	3005	0.25
Potatoes	107991	0	0	0	0
Groundnuts	5123	0	0	0	0
Sorghum	77398	-105	-0.14	0	0
Millet	41446	0	0	0	0
Beans	109422	0	0	-69	-0.06
Milk	1206302	-58568	-4.86	11732	0.97
Export (ton)					
Maize	232552	0	0	0	0
Coffee	85860	954	1.11	0	0
Tea	314575	0	0	0	0
Milk	36364	0	0	0	0
Import (ton)					
Wheat	314400	0	0	0	0
Milk	36365	1580409	4346	0	0

(Note) The percentage change is defined as the Traditional Dairy or the Improved Dairy Full Adoption minus Improved Dairy Current Adoption scenario divided by Improved Dairy Current Adoption scenario times 100.

Table 2.7.4.1.5 Raw Milk Production Quantity, Number of Dairy Cattle and Percentage by Region under Improved Dairy Current Adoption Scenario in the Kenya ASM

Unit: 1000 kg, cow, %

Improved Dairy Current Adoption Scenario	Zebu-cattle (Feed 1)	Cross Breed Cattle (Feed 2)	Dairy Breed with Semi Zero-Grazing (Feed 3)	Dairy Breed with Zero-Grazing (Feed 4)
Production (1000kg)				
Central	41255	27037	150585	785008
Coast	64397	21644	30137	22444
Eastern	117994	44757	124640	185644
Nyanza	152147	38475	53572	39896
Rift Valley	392723	74483	311133	926826
Western	91851	21775	15160	22580
Number of Cows (head)				
Central	20416	20416	81664	285826
Coast	122580	16344	16344	8172
Eastern	168985	33797	67594	67594
Nyanza	217898	29053	29053	14526
Rift Valley	562439	56243	168731	337463
Western	131544	16443	8221	8221
Percentage of Distribution of Herd by Region (%)				
Central	5	5	20	70
Coast	75	10	10	5
Eastern	50	10	20	20
Nyanza	75	10	10	5
Rift Valley	50	5	15	30
Western	80	10	5	5

Table 2.7.4.1.6 Raw Milk Production Quantity, Number of Dairy Cattle, and Percentage by Region under Traditional Dairy Scenario in the Kenya ASM

Unit: 1000 kg, cow, %

Traditional Dairy Scenario	Zebu-Cattle (Feed 1)	Cross Breed Cattle (Feed 2)	Dairy Breed With Semi Zero-Grazing (Feed 3)	Dairy Breed With Zero-Grazing (Feed 4)
Production (1000 kg)				
Central	476669			
Coast	58745			
Eastern	460696	Not Allowed	Not Allowed	Not Allowed
Nyanza	23813			
Rift Valley	748891			
Western	149284			
Number of Cows (head)				
Central	682663			
Coast	111822			
Eastern	659787	Not Allowed	Not Allowed	Not Allowed
Nyanza	34104			
Rift Valley	1072526			
Western	213797			
Percentage of Distribution of Herd by Region (%)				
Central	100.00			
Coast	100.00			
Eastern	100.00	Not Allowed	Not Allowed	Not Allowed
Nyanza	100.00			
Rift Valley	100.00			
Western	100.00			

Table 2.7.4.1.7 Raw Milk Production Quantity, Number of Dairy Cattle, and Percentage by Region under Improved Dairy Full Adoption Scenario in the Kenya ASM

Unit: 1000 kg, cow, %

Improved Dairy Full Adoption Scenario	Zebu-Cattle (Feed 1)	Cross Breed Cattle (Feed 2)	Dairy Breed With Semi Zero-Grazing (Feed 3)	Dairy Breed With Zero-Grazing (Feed 4)
Production (1000kg)				
Central			113752	677707
Coast	176806	111423	155145	154053
Eastern	58527	55501	128800	230207
Nyanza	101688	72323	134270	249985
Rift Valley	138994	87872	305881	637828
Western	28538	33829	18841	70157
Number of Cows (head)				
Central			61689	246757
Coast	336550	84137	84137	56091
Eastern	83820	41910	69850	83820
Nyanza	145633	54612	72816	91021
Rift Valley	199060	66353	165883	232237
Western	40871	25544	10217	25544
Percentage of Distribution of Herd by Region (%)				
Central	0	0	20	80
Coast	60	15	15	10
Eastern	30	15	25	30
Nyanza	40	15	20	25
Rift Valley	30	10	25	35
Western	40	25	10	25

Current Adoption vs. Full Adoption

Full adoption conditions for the Improved Dairy technologies would reduce both labor and crop land usage from the current adoption scenario. Labor use would decline by 5.7 million mandays in the Central Region and 27.4 million mandays in the Rift Valley Region. However, the labor use in the Coast production region would increase by 25.1 million mandays. Nationally, the net reduction would only be 980 thousand mandays, or 0.2%. Crop land use would increase in the Coast (132 thousand hectares) and Eastern Region (169 thousand hectares) but decline by some 539 thousand hectares in the Rift Valley Region. Nationally, total cropland use would be decreased by 291 thousand hectares, or about 2.3%.

2.7.4.3 Welfare Effects

The regional economic benefits to producers and consumers from the dairy technology scenarios are displayed in Table 2.7.4.1.2. The national welfare components for the traditional, current adoption, and full adoption scenarios are presented in Table 2.7.4.3.1. Producers' surplus is the return to land, labor, management and risk for all farmers and their families. Home consumption expenditure is the value of food produced and consumed on farms by rural people. Consumers' surplus is the economic benefit accruing to consumers in urban areas. Foreign surplus refers to the trade surplus in Kenya. Farmers and their families benefit from both increases in returns to land, labor, management and risk resources and reductions in home consumption expenditures. Total social welfare is the summation of consumers' surplus, foreign surplus, producers' surplus, and home consumption expenditure.

Traditional vs. Current

Producers' surplus would be 0.5 billion Ksh, or 7.4%, less annually if Kenya were dependent on the Traditional Dairy technologies (Table 2.7.4.1.2). The increase in price for the commodities would not offset the reduction in quantities produced, resulting in a slight decrease in total returns to farmer and family labor and land. Producers in most regions would experience a decrease in returns to these resources; however, producers in the Eastern Region would have 15 million Ksh more income annually. Home consumption expenditures would be higher in each region under the Traditional Dairy technologies. For Kenya as a whole, these expenditures would be an additional 2.24 billion Ksh or 4.1%, annually. When the change in producer surplus and home consumption expenditures are combined, a measure of the net economic benefits to farmers and their families from the Improved Dairy Technology is obtained. The Improved Dairy technologies under current adoption conditions resulted in 2.74 billion Ksh annual net gain to producers and their families. The net gains varied among regions, ranging from a 108 million Ksh annually in the Western Region to a 1.28 billion Ksh annually in the Rift Valley Region.

In other words, if Kenya relied solely on Traditional Dairy technologies to meet current demands, total social welfare in Kenya would be decreased 2.883 billion Ksh, or 1.43%, annually (Table 2.7.4.3.1). Most of the reduction in social welfare would result from substantially increased imports of milk (Table 2.7.4.1.1).

Table 2.7.4.3.1 Welfare Comparison under Alternative Scenarios with 18 Ksh/kg Milk Import Price

Unit: Million Ksh, %

Welfare Measure	Improved Dairy Current Adoption	Traditional Dairy	Improved Dairy Full Adoption
Consumers' Surplus	160416	159959 (-0.29)	160596 (0.11)
Foreign Surplus	89260	89578 (0.36)	89651 (0.44)
Producers' Surplus	6761	6262 (-7.39)	6255 (-7.49)
Home Consumption Expenditure	-54471	-56716 (4.12)	-53829 (-1.18)
Total Social Welfare	201967	199083 (-1.43)	202672 (0.35)

Notes: Consumers's surplus is the Kenya domestic consumers' surplus.
Foreign surplus is the trade surplus including import and export in Kenya.
Producers' surplus is the Kenya domestic producer's surplus.
Home consumption expenditure is the Kenya farmers and family home consumption expenditure.
Total social welfare is the summation of consumers' surplus, foreign surplus, producers' surplus, and home consumption expenditure.
The parentheses represent the percentage change between scenarios and Improved Dairy Current Adoption scenario.

Regional consumers in urban areas experienced economic welfare gains from the current adoption of Improved Dairy technologies compared to the Traditional Dairy technologies, amounting to 458 million Ksh annually. The gains were primarily to consumers in the Nairobi, Central, Rift Valley and Coast regions. Consumers in the Eastern, Nyanza, and Western regions experienced economic welfare losses ranging from 37 million in the Eastern Region to 47 million Ksh annually in the Western Region.

The gains to consumers from the Improved Dairy technologies not only came from increased supplies of milk and a lower price, but also from changes in the production quantities and prices of other commodities. Wheat and mutton/goat meat contributed to the gain in consumers' surplus. Maize and beef were commodities exhibiting losses in consumers' surplus as the Improved Dairy technologies were adopted (Table 2.7.4.3.2). Gains to farm families through reduced home consumption expenditures from the Improved Dairy technologies came primarily from milk.

Table 2.7.4.3.2 Consumers' Surplus and Home Consumption Expenditure by Products in the Kenya ASM

Unit: mil Ksh

Welfare Measure	Improved Dairy Current Adoption	Traditional Dairy		Improved Dairy Full Adoption	
	(Value)	Change (Value)	Percentage (%)	Change (Value)	Percentage (%)
Consumers' Surplus					
Wheat	12426	-127	-1.02	-127	-1.02
Maize	42857	26	0.06	56	0.13
Potatoes	2337	1	0.04	2	0.07
Groundnuts	87	0	0	0	0
Sorghum	1931	-4	-0.22	0	0
Millet	2219	0	0	1	0.03
Beans	14442	1	0.02	-4	-0.03
Milk	51792	-1225	-2.36	332	0.64
Pork	1231	0	0	0	0
Beef	28272	983	3.47	-65	-0.22
Mutton/goat meat	2819	-113	-4.03	-15	-0.54
Home Consumption Expenditure					
Maize	-9720	41	-0.42	83	-0.85
Potatoes	-1096	1	-0.11	2	-0.21
Groundnuts	-4	0	0	0	0
Millet	-301	0	0	0	0
Beans	-2356	1	-0.06	-6	0.25
Milk	-40994	-2288	5.58	563	-1.37

Current Adoption vs. Full Adoption

Full adoption of the Improved Dairy technologies would result in a net economic gain to producers and their families in Kenya. Producers' surplus would decrease 507 million Ksh annually but home consumption expenditures would decrease 642 million Ksh annually, or 1.18% annually, resulting in a net annual economic gain of 136 million Ksh. Producers and their families in the Coast Region would experience an annual 152 million Ksh increase in their economic welfare (Table 2.7.4.1.2).

With full adoption of the Improved Dairy technologies, consumers nationally would be expected to experience economic welfare gains totaling 179 million Ksh, or 0.11%, annually (Table 2.7.4.1.2). Consumers in the Nyanza Region and most other regions except Nairobi would be the principal beneficiaries.

The net trade balance for Kenya was decreased 318 million Ksh through the current adoption of the Improved Dairy technologies (Table 2.7.4.3.1), but it would be increased 391 million Ksh, or 0.44%, annually with full adoption.

With the adoption of the Improved Dairy technologies, total social welfare increased an additional 705 million Ksh annually. These results indicate that the Improved Dairy technologies have substantially benefitted producers and their families through expanded supplies and lower prices for milk and other commodities and through reduced milk imports. The results also indicate that when the Improved Dairy technologies are fully adopted, consumers' and national economic welfare would be further increased, but farmers and their families would realize only modest gains in their economic benefits. Reductions in the returns to land and labor resources would be nearly equal additional savings in home consumption expenditures for rural people.

2.7.4.4 Economic Impacts of Alternative Dairy Production Systems Under Future Demand Growth Conditions (2015)

The final step in the economic analysis was estimating the impact of the improved dairy systems under the project future demands for the year 2015. The Improved Dairy Current Adoption base model solution is compared with the simulation reflecting full adoption of existing dairy production technologies under projected 2015 demand conditions. Population projections to year 2015 in urban and rural areas within each province of Kenya were used to project food demands by commodity. Projected food demands for farmer and family home consumption and domestic regional consumers in towns and cities by province were based on current per capita consumption rates for each commodity by province and place of residence, i.e. rural or urban.

Price and Yield Changes

Table 2.7.4.4.1 provides the results from modeling full adoption of existing dairy improvement technologies under 2015 demand projections. The table shows the yield increases for all commodities necessary to meet year 2015 demand near 1995 price levels. Wheat and millet prices increase 17.6% and 19.0%, respectively. All other commodity prices are within 1.0% to 6.0% of base 1995 price levels. Raw milk price decreases 0.9 Ksh/kg, or 5.86%. Corresponding increases in production quantities of 438.7 and 40.5 thousand tons, or about 695.0% for wheat and 74.0% for millet, respectively, would be required to meet projected demand levels. Milk production would increase 1.41 million tons, or some 117.0% to meet future demands by regional consumers in towns and cities and home consumption by farmers and their families.

Home consumption for cereal grains, potatoes, and groundnuts would almost double. Milk consumption by farmers and their families would increase 113.0%. Domestic regional consumption would more than double for wheat, maize, potatoes, and groundnuts, and increase 68.0% and 85.0%, respectively, for sorghum and millet. The quantity of milk consumed by regional domestic consumers would increase 117.0%. Yield increases to meet projected 2015 demands at near 1995 price levels would need to average about 0.3% to 0.5% per year for maize, potatoes, sorghum, and raw milk. Yields for beans and raw coffee would need to increase about 0.9% annually, while beef and millet yields would need to grow at a 2.5% annual rate. Groundnut yields would need to increase near 4.5% per year, while wheat yield would require an annual growth rate of 6.25% to meet 2015 projected demands at near 1995 price levels. These price and quantity changes include the effects of both trended productivity growth in all commodities and the effects of full adoption of the Improved Dairy technology.

Table 2.7.4.4.1 Prices, Production, Uses, and Trade for Major Products and Comparison Between Current and Full Adoption of Improved Dairy Production Technologies Under 2015 Demand and Yield Increase

Unit: Ksh/kg, ton, %

Item by Commodity	Improved Dairy Current Adoption	Improved Dairy Full Adoption	
	(Value)	Change Value	Percentage (%)
Price (Ksh/kg)			
Wheat	15.52	2.73	17.59
Maize	8.99	0.09	1.10
Sorghum	6.69	0.08	1.20
Millet	21.45	4.07	18.98
Beans	15.64	0.08	0.51
Coffee	129.87	6.17	4.75
Tea	66.22	0.41	0.62
Raw milk	15.37	-0.90	-5.86
Production (ton)			
Wheat	63096	438700	695.29
Maize	2461878	2844340	115.54
Sorghum	77398	66058	85.35
Millet	54980	40493	73.65
Beans	250557	233061	93.02
Coffee	86289	-3835	-4.44
Tea	314575	0	0
Raw milk	3729172	4255884	114.12
Home Consumption (ton)			
Maize	1048331	1295652	123.59
Potatoes	156600	171903	109.77
Groundnuts	2692	2546	94.56
Millet	13533	12347	91.23
Beans	141134	133833	94.83
Milk	2168514	2440528	112.54
Regional-Demand (ton)			
Wheat	377496	438700	116.21
Maize	1180995	1544258	130.76
Potatoes	107991	114494	106.02
Groundnuts	5123	5766	112.74
Sorghum	77398	66058	85.35
Millet	41446	28146	67.91
Beans	109422	99228	90.68
Milk	1206302	1410951	116.96
Export (ton)			
Maize	232552	4430	1.90
Coffee	85860	-3816	-4.44
Tea	314575	0	0
Milk	36364	0	0
Import (ton)			
Wheat	314400	0	0
Milk	36365	0	0

(Note) The percentage change is defined as the Improved Dairy Full Adoption minus Improved Dairy Current Adoption scenario divided by Improved Dairy Current Adoption scenario times 100.

Welfare Effects

Changes in national welfare components for the demand growth for all commodities and for the full adoption for the Improved Dairy Technology scenario are shown in Table 2.7.4.4.2. Also provided in the table are the separate welfare effects from the full adoption of the dairy technology. The portion attributable to dairy technologies alone we obtained by running the ASM under two scenarios. The first scenario used 2015 demands with current adoption of Improved Dairy technologies and trended productivity increases in all other commodities. The second scenario used 2015 demands with full adoption of Improved Dairy technologies and trended productivity in all other commodities.

When the dairy technology improvements are fully adopted under demand growth rates associated only with rising population for the next 15 years, as contrasted to current adoption rates and year 2015 demand levels, both regional consumers and farm families benefit. Regional consumers in towns and cities nationally gain 585 million Ksh (0.24%) annually, while home consumption expenditure by farmers and their families is reduced 4.61 billion Ksh (8.46%) annually. Producers return to land and labor are reduced 944 million Ksh each year. The decrease in home consumption expenditure for food substantially outweighs the decrease in producers return to land and labor. Foreign surplus increases only slightly, up 158 million Ksh annually, or about 0.2%. Total social welfare in Kenya is increased 4.21 billion Ksh (2.08%) annually from the full adoption of the dairy technologies under the demand growth scenario. These results indicate that under future demand growth conditions, domestic consumers in towns and cities and farm families as consumers will likely benefit most from the smallholder dairy technology adoption relative to rural producers' return to resources as the new technologies are adopted and the available domestic milk supply increased.

2.8 Economic Impact of Smallholder Dairy Technologies at the Farm (Household) Level

The agricultural sector model (ASM) provides a description of expected impact on production, trade, and economic welfare at regional, national, and global scales for a technological change in agriculture. It also provides information on changes in resource allocations, prices, and quantities consumed. The ASM approach does not, however, examine impacts of technological innovation at the farm level. By incorporating equilibrium price and quantity changes from the ASM solutions into a farm-level economic model such as Farm Level Income and Policy Simulation (FLIPSIM), an assessment of the impacts of a technological innovation at the farm level may be achieved.

2.8.1 Brief Description of FLIPSIM Model

Representative farms were used to evaluate the farm-level economic impacts of adopting the smallholder dairy technologies in Kenya. The farm-level analysis considered both deterministic and stochastic conditions with regard to commodity prices and yields for representative farms. In both types of analyses, the FLIPSIM model was used to simulate the impact on individual farms of adopting the smallholder dairy technologies. The stochastic simulations describe the risk to a producer associated with adoption of a technology through use of yield and price variations over time and generation of probabilistic projections of future outcomes. Figure 2.8.1-1 describes the general steps in performing the analysis.

Base macro-economic and technology conditions for representative farms in each dairy production zone were established through a joint effort between U.S. researchers and research/extension personnel in Kenya. Results from the ASM baseline analysis were examined by the East Africa personnel and modified

Table 2.7.4.4.2 Welfare Comparison between Current and Full Adoption Scenarios Under 2015 Demand and Yield Increase and 18 Ksh/kg Milk Import Price

Unit: Million Ksh, %

Welfare Measure	Improved Dairy Current Adoption (Value)	Improved Dairy Full Adoption (Change in Value)
Consumers' Surplus		
all commodities	160416	181541
		(113.17)
dairy technology only		385
		(0.24)
Foreign Surplus		
all commodities	89260	274
		(0.31)
dairy technology only		158
		(0.17)
Producers' Surplus		
all commodities	6761	11794
		(174.43)
dairy technology only		-944
		(-13.96)
Home Consumption Expenditure		
all commodities	-54471	-58296
		(107.02)
dairy technology only		4607
		(8.46)
Total Social Welfare		
all commodities	201967	135312
		(67.00)
dairy technology only		4206
		(2.08)

(Note) Consumers's surplus is the Kenya domestic consumers' surplus.
Foreign surplus is the trade surplus including import and export in Kenya.
Producers' surplus is the Kenya domestic producer's surplus.
Home consumption expenditure is the Kenya farmer and family home consumption expenditure.
Total social welfare is the summation of consumers' surplus, foreign surplus, producers' surplus, and home consumption expenditure.
The numbers in parentheses represent the percentage change between full adoption and Improved Dairy Current Adoption scenario.

to represent alternative technology scenarios for the representative farms. On-farm data collection was conducted by a Kenya Agricultural Research Institute (KARI) livestock specialist working on secondment to ILRI (Kaitho; Staal).

Results from the ASM were used to determine changes in equilibrium commodity prices under the different dairy technology scenarios. These national crop and livestock price forecasts were used as a reference base for estimating representative farm-level commodity prices. Prices from the ASM results were modified by randomly selected error terms, calculated as percentage deviations from observed historical mean prices, and used as initial prices for all years in the FLIPSIM stochastic runs. Certain macro-economic variables included in FLIPSIM, such as the inflation rate, were held constant in the farm-level analysis.

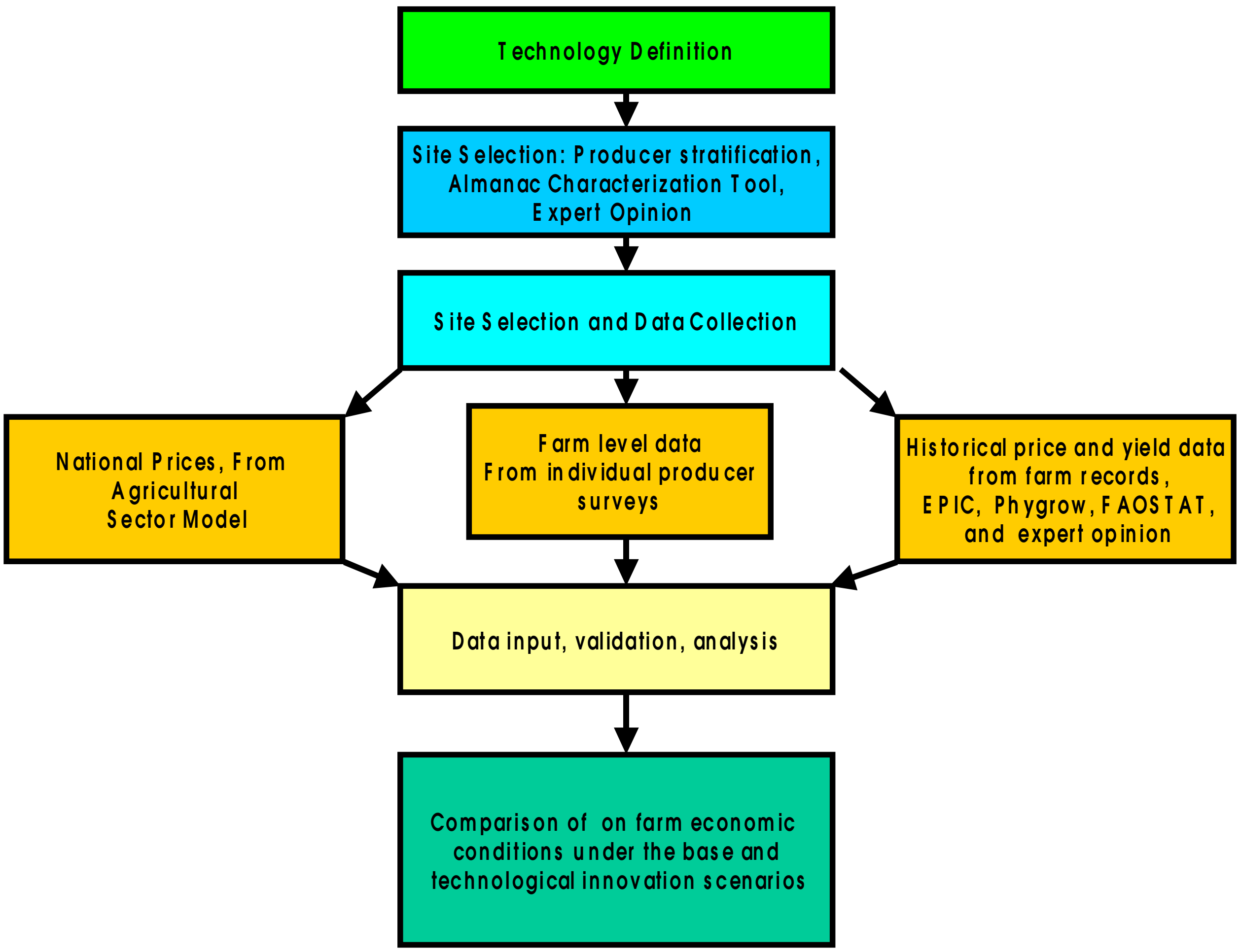


Figure 2.8.1-1. Farm level economic analysis methodology.

2.8.2. Representative Farms for Impact Assessment at Household Level

Table 2.8.2.1 provides a profile of seven representative farms in Kenya. Each representative farm is associated with a particular dairy zone dominated by a commodity (e.g , coffee, tea, horticultural crops, sheep, wheat) or a location (e.g, peri-urban, coast). Land cropped by each farm ranges from 0.149 hectares for the peri-urban farm to 1.68 hectares for the coastal zone representative farm. Productivity constraints vary among zones. The coastal zone faces high cattle disease pressures and low soil fertility, whereas the sheep and wheat zones face low forage production due to cold temperatures. Grass land available to producers varies from 0 hectares in the peri-urban zone with high population density and the coastal zone to communal grazing with undetermined available hectares. Most representative farms had 1.2 or more hectares of grass land. Producers also had access to an organized milk collection system and dairy processing facilities in most of the country's seven dairy zones.

Table 2.8.2.1 Kenya Representative Farms Profile Under Current Conditions

	Dairy Zone						
Variable	**Coffee**	**Hort**	**Tea**	**Peri_urban**	**Sheep**	**Wheat**	**Coast**
Latitude	-0.7773	-0.5606	-0.9868	-1.1782	-0.7149	-0.3086	-4.2717
Longitude	37.0610	37.2708	36.7316	36.8915	36.8587	35.7402	39.5814
District	**Muranga**	**Kirinyaga**	**Kiambu**	**Nairobi**	**Muranga**	**Nakuru**	**Kwale**
Cropland (ha)	1.214	1.335	1.255	0.149	1.639	1.214	1.680
Grass Land* (ha)	1.38	1.38	1.48	0	1.27	Communal	0
Napier (ha)	0.10	0.03	0.1	0	0.35	0	0
Cattle Type Current Technology	Friesian	Friesian	Friesian	Friesian	Friesian	Friesian	Friesian
Current Mean Milk Yields (kg/cow)	1222	1206.25	1531.25	1625	1025	1185	1000
Number of Dairy Cows	1	1	1	2	2	3	1
Cattle Type Old Technology	Zebu	Zebu	Zebu	Zebu	Zebu	Zebu	Zebu
Traditional Milk Yields (kg/cow)	643	635	806	855	529	623	526

*Estimated based on current population of humans and animals, and farm numbers (source Angerer)

Historic crop yields were sought by interviewing producers on the representative farms. Most producers were unable to provide a 10-year history of yields. In instances where historical yields were incomplete for a farm, the EPIC crop model was used to generate yield estimates. These estimated yields from the bio-physical model were adjusted to represent the farms' yields. The ratio of simulated yield to historic yield for years that historical yield data existed for a farm was calculated and used to estimate historic yields for the missing years.

Forage yields were estimated with the PHYGROW forage simulation model. Available nutrients for animal consumption were then calculated from these estimated yields. Surveys of land use conducted in the 1970's in Kenya were used to estimate the amount of grazing land available for cattle on communal lands and the resulting hectares allocated to each representative farm. Yields estimated from the PHYGROW model applied to the estimated land area provided an estimate of forage yield variation for the representative farms. These yield variations were used in the FLIPSIM analysis to estimate the farm-level impacts of the dairy technologies. Producers were assumed to sell surplus forage, or conversely, to purchase forage if yields did not meet feed requirements of animals on the farm. For each representative farm surveyed, producers that did not produce Napiergrass on their farm but had Napiergrass in their dairy rations were assumed to purchase Napiergrass for their cows.

2.8.3 Results from the Deterministic Analysis

The deterministic analysis used mean yields and prices in the simulations. Results from adopting the dairy technologies on each representative farm in the seven dairy zones are summarized in Table 2.8.3.1. Net present value (NPV) increased for the horticulture, peri-urban, and coastal farms. NPV is defined as the present value of net cash farm income plus changes in real net worth over the 10-year planning horizon. The horticultural farm experienced a 27.0% increase in net present value, whereas the growth in NPV was only 4.9% for the peri-urban farm and 2.5% for the coastal farm. The NPV became less negative for the coffee farm (by 28.2%) and the wheat farm (by 2.9%). However, an actual decline in NPV resulted for the tea (-4.1%) and sheep (-1.0%) farms.

Table 2.8.3.1 Kenya Representative Farms Deterministic Mean Net Present Values, Total Cash Receipts, Total Cash Costs, Net Cash Farm Income, and Real Net Worth Under the Base (old) and Current Small Holder Dairy Technology in 1,000's Kenya Shillings.

Dairy Zone	Net Present Value		Total Cash Receipts		Total Cash Costs		Net Cash Farm Income		Real Net Worth	
	Old	Current	Old	Current	Old	Current	Old	Current	Old	Current
Tea	1420.0	1220.0	90.0	100.0	30	50	60	50	1570	1460
(% change)		(-14.08)		(11.11)		(66.67)		(-16.7)		(-7.01)
Coffee	-390	-280	40	50	50	50	-10	0.00	-70	-10
(% change)		(28.21)		(25.00)		(0.0)		(100)		(85.71)
Hort.	850.0	1080.0	40	60	10	20	30	40	1010	1013
(% change)		(27.06)		(50.00)		(100.0)		(33.33)		(0.29)
Peri - Urban	1230.0	1290.0	30	80	10	50	20	30	1500	1530
(% change)		(4.88)		(166.67)		(400.00)		(50.00)		(2.00)
Sheep	970.0	960.0	160	160	40	40	120	120	2720	2720
(% change)		(-1.03)		(0.00)		(0.00)		(0.00)		(0.00)
Wheat	-340.0	-330.0	60	70	60	70	0.00	0.00	3600.0	3400.0
(% change)		(2.94)		(16.67)		(16.67)		(0.0)		(-5.56)
Coast	5270.0	5400.0	560	580	60	70	500	510	3900.0	3960.0
(% change)		(2.47)		(3.57)		(16.67)		(2.00)		(1.54)

Total cash receipts increased for all representative farms except the sheep farm that maintained annual cash receipts of 160 thousand Ksh. The peri-urban and horticulture farms exhibited the largest relative growth in total cash receipts, 167% and 50%, respectively. However, total cash costs increased for all representative farms except the coffee and sheep farms. Resulting net cash farm income remained constant for the sheep and wheat farms; grew by 10 thousand Ksh annually for the coffee, horticulture, peri-urban and coast farms; and declined by 10 thousand Ksh annually for the tea farm. The horticulture, peri-urban, and coast farms experienced a positive change in real net worth (RNW) from adoption of the dairy technologies. Only the coffee farm continued to exhibit a negative RNW, but even this farm had a positive change (85.7%) in its RNW. The tea and wheat farms experienced RNW declines of 7.0% and 5.5%, respectively, after adoption of the dairy technologies. The horticulture, peri-urban, and coast farms had a slight growth in RNW whereas the sheep farm experienced no change in RNW. Figures 2.8.3-1. to 2.8.3-10 present these results graphically.

2.8.4. Results from the Stochastic Analysis

The stochastic analysis used probability distributions for commodity yields and prices in the simulations. The average net present value (NPV) under current adoption of improved technology declined on three repre-

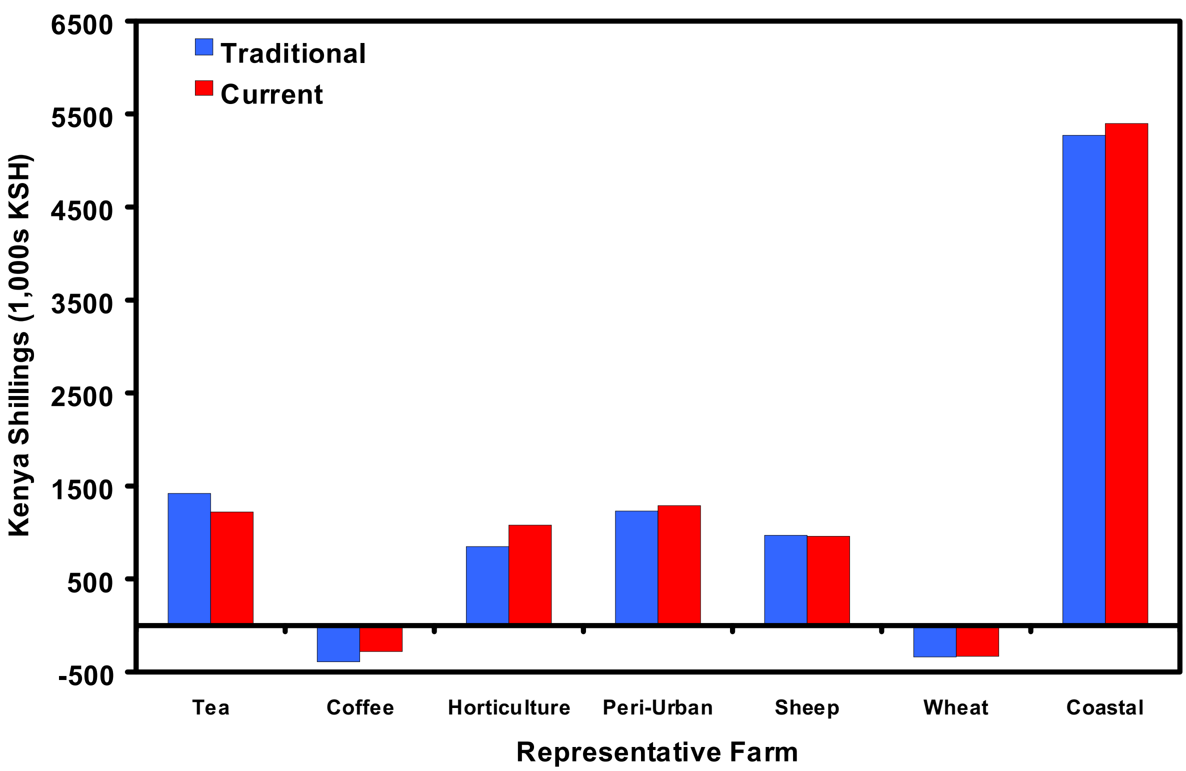


Figure 2.8.3-1. Net present value (NPV) for Kenyan representative farmers under the traditional (zebu cattle/native forage) and the current technology, deterministic scenarios.

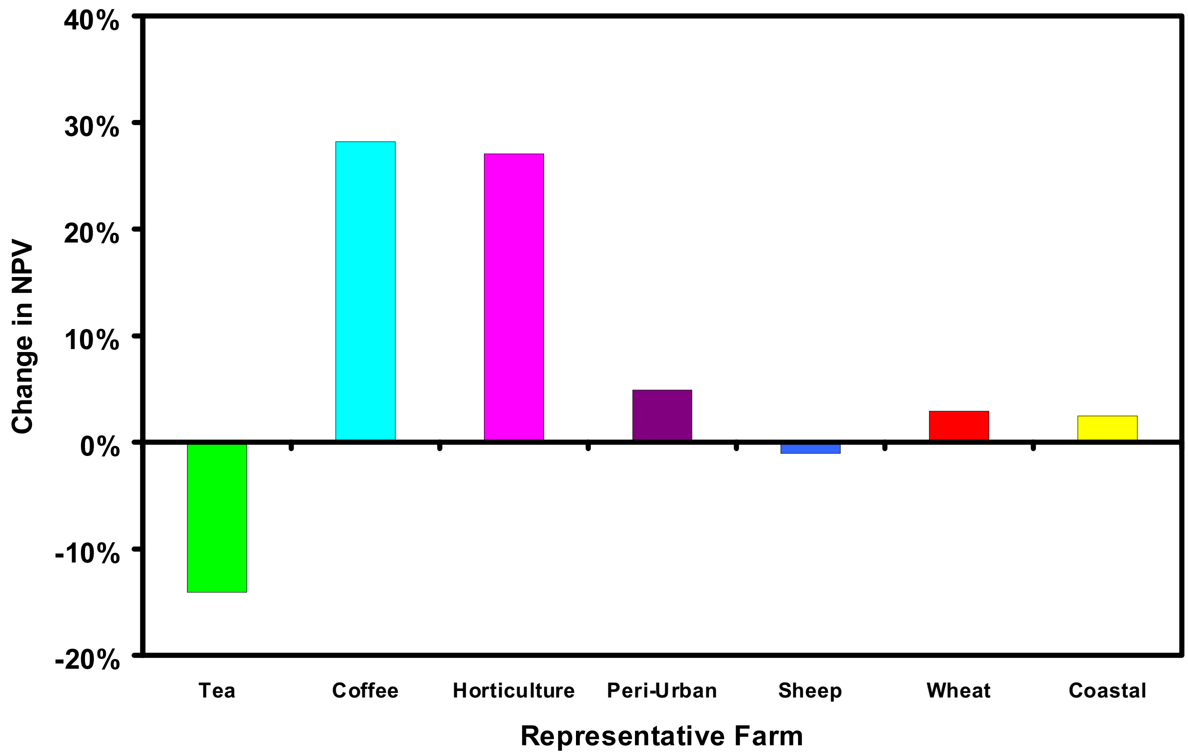


Figure 2.8.3-2. Percent change in net present value (NPV) for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the deterministic scenario.

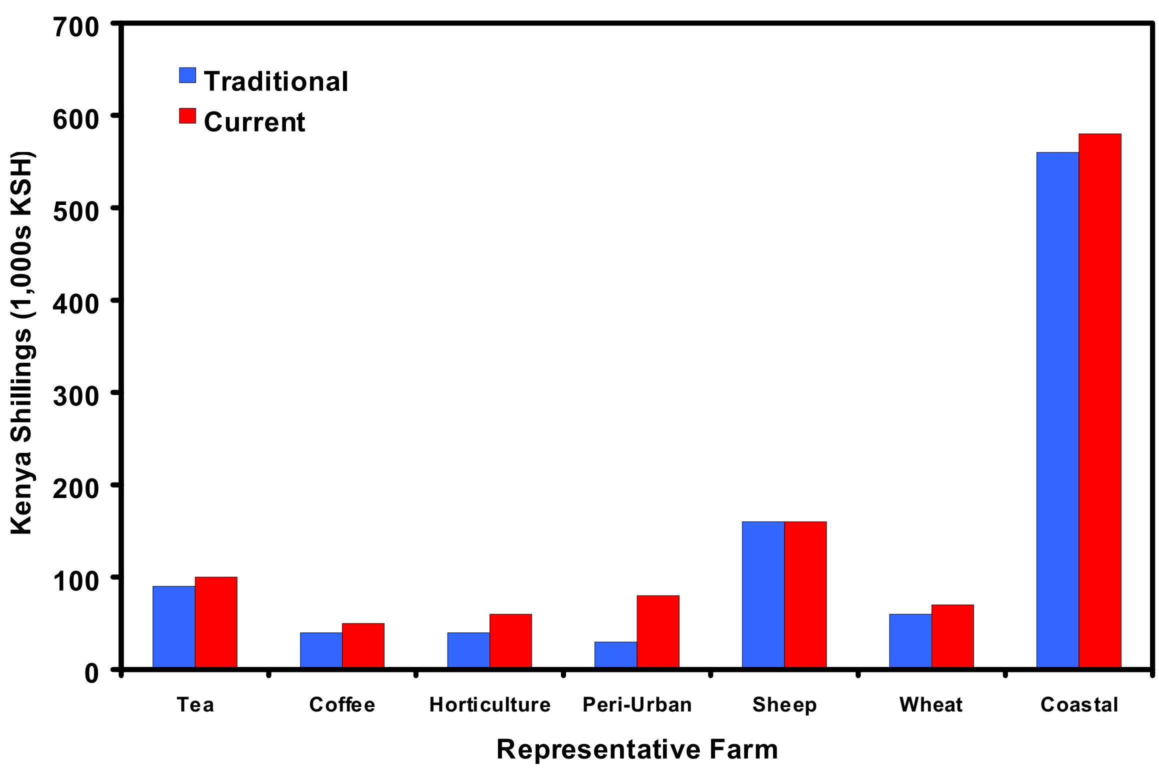


Figure 2.8.3-3. Total cash receipts for Kenyan representative farmers under the traditional (zebu cattle/native forage) technology and the current technology, deterministic scenarios.

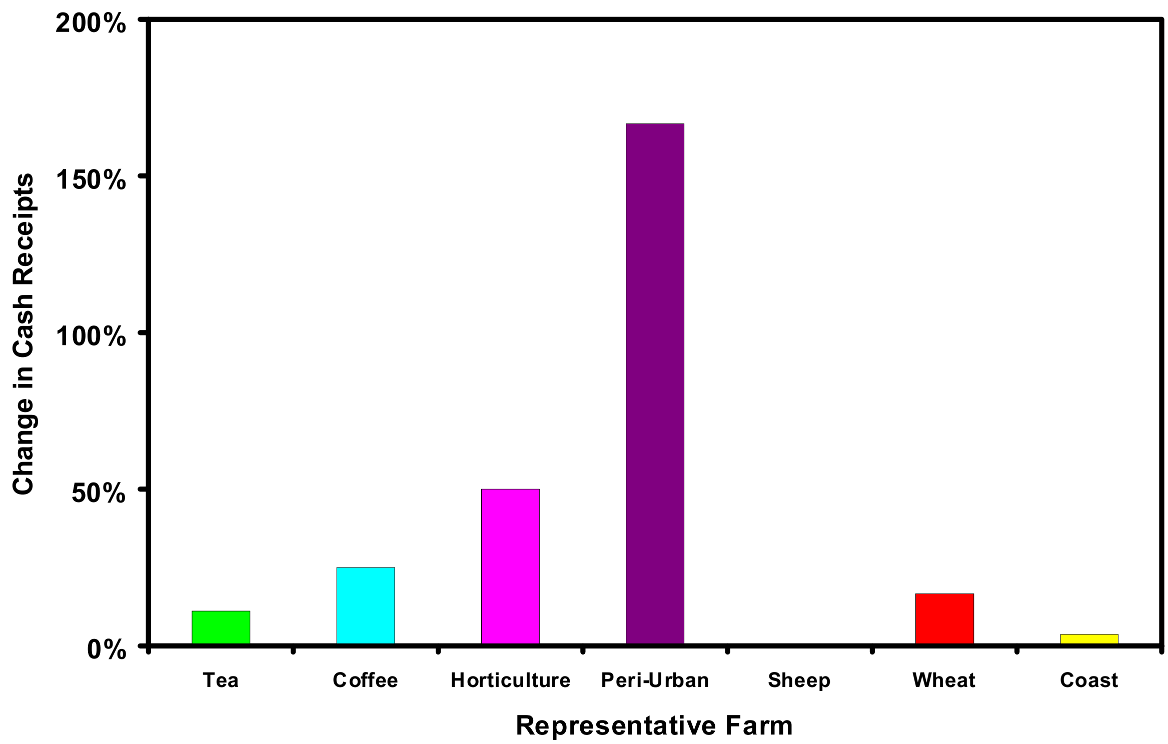


Figure 2.8.3-4. Percentage change in cash receipts for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the deterministic scenario.

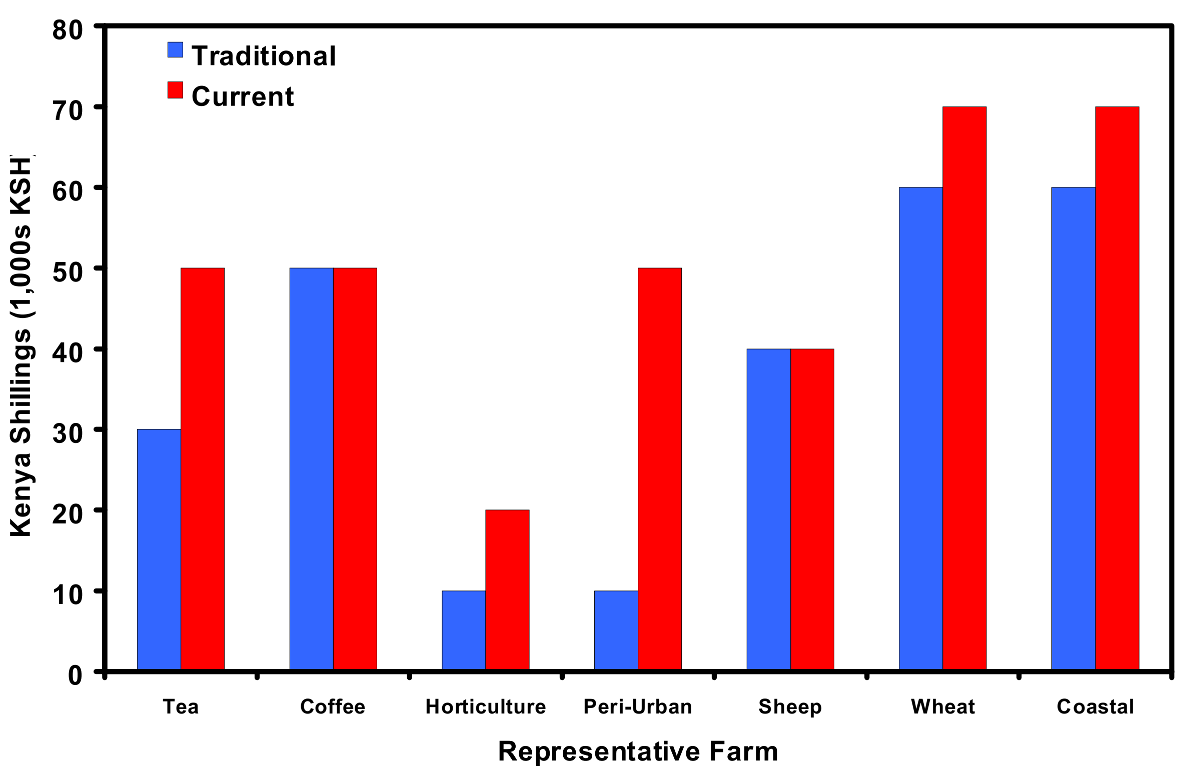


Figure 2.8.3-5. Total cash costs for Kenyan representative farmers under the traditional (zebu cattle/native forage) technology and the current technology, deterministic scenarios.

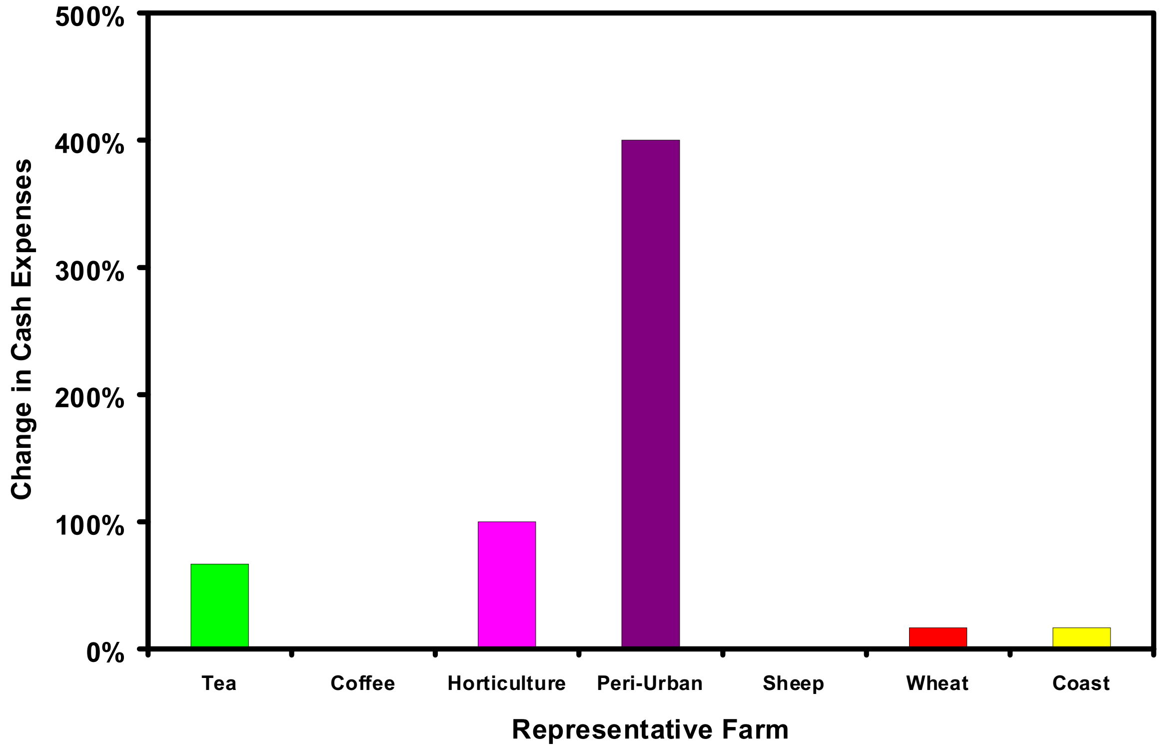


Figure 2.8.3-6. Percent change in cash expenses for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the deterministic scenario.

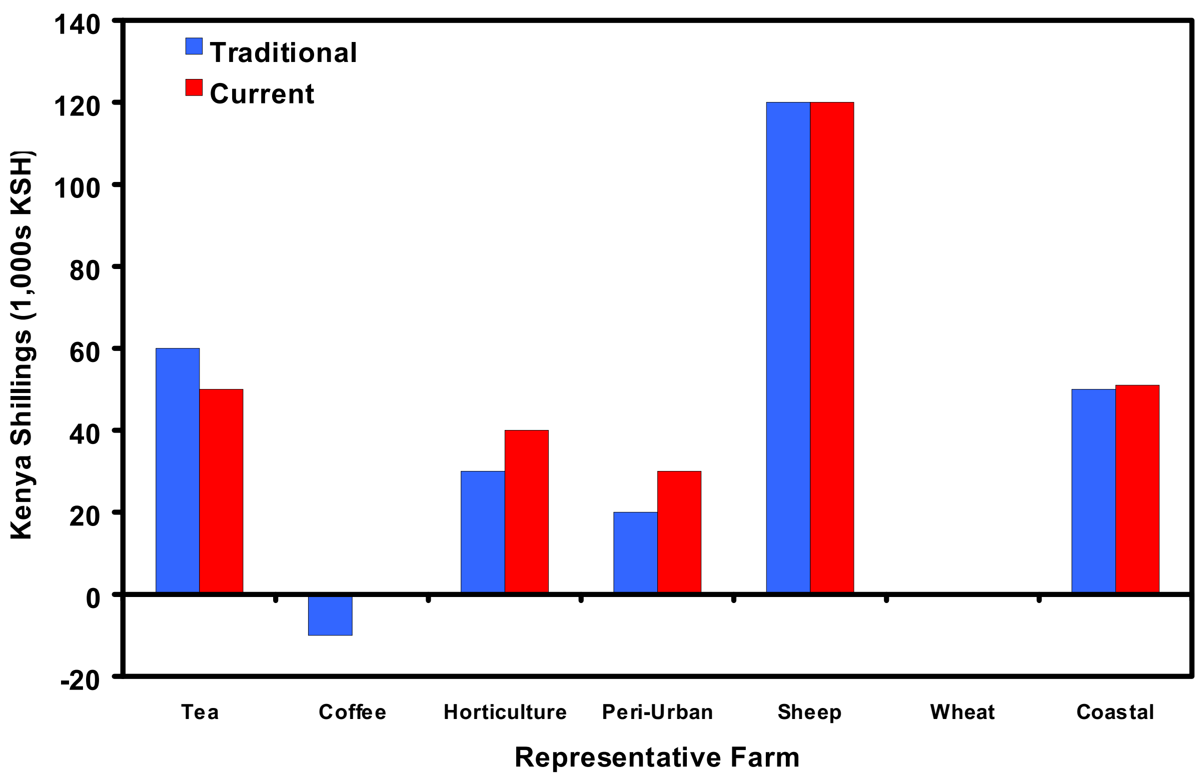


Figure 2.8.3-7. Net cash farm income for Kenyan representative farmers under the traditional (zebu cattle/native forage) technology and the current technology, deterministic scenarios.

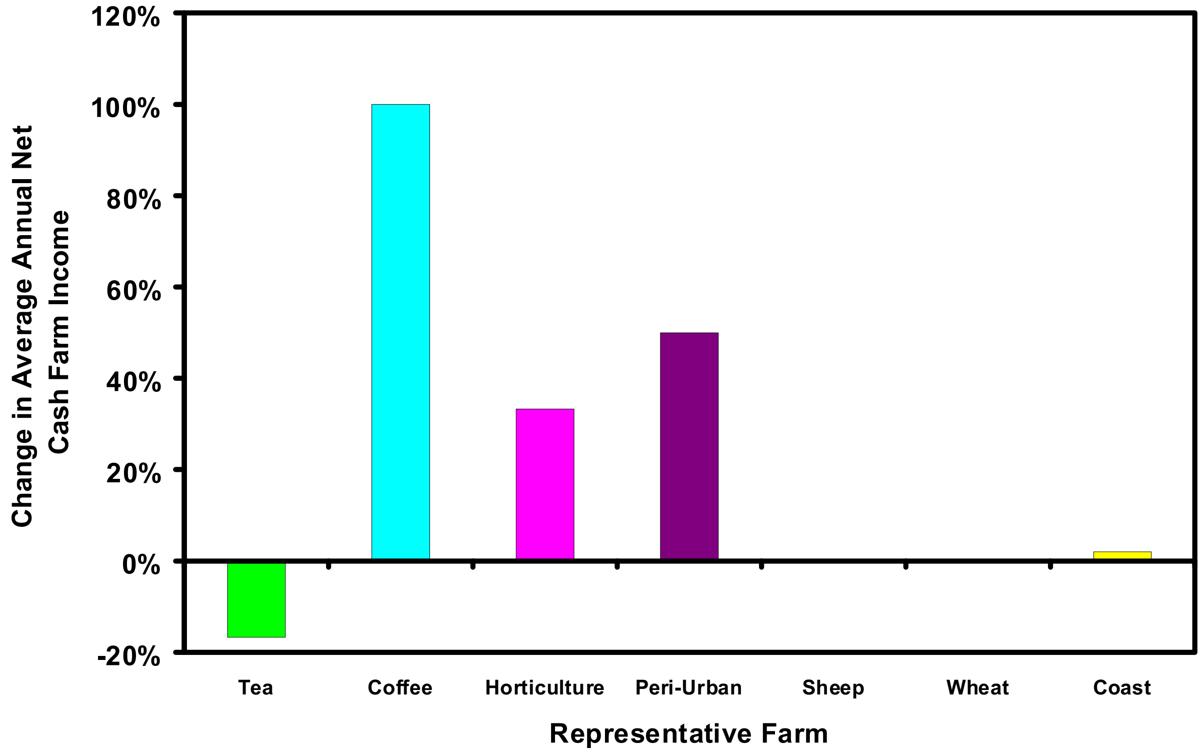


Figure 2.8.3-8. Percentage change in average annual net cash farm income for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the deterministic scenario.

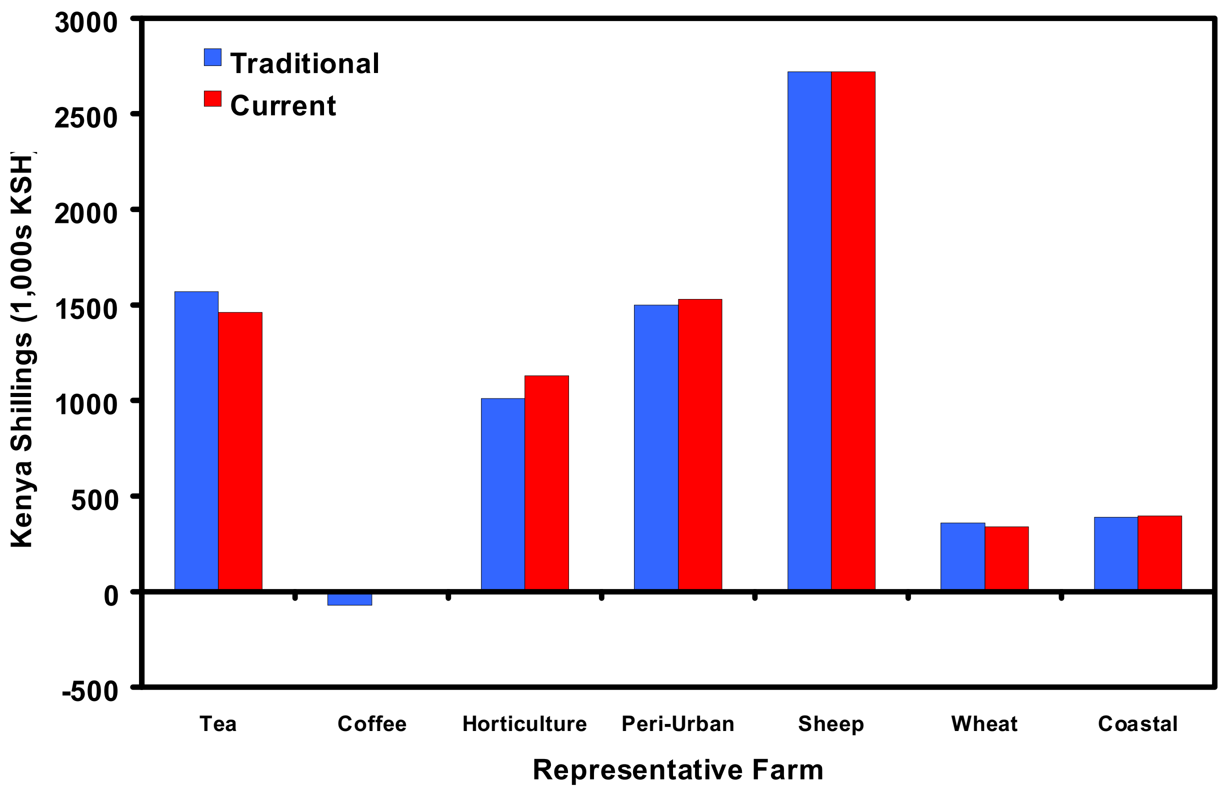


Figure 2.8.3-9. Real net worth (RNW) for Kenyan representative farmers under the traditional (zebu cattle/native forage) technology and the current technology, deterministic scenarios.

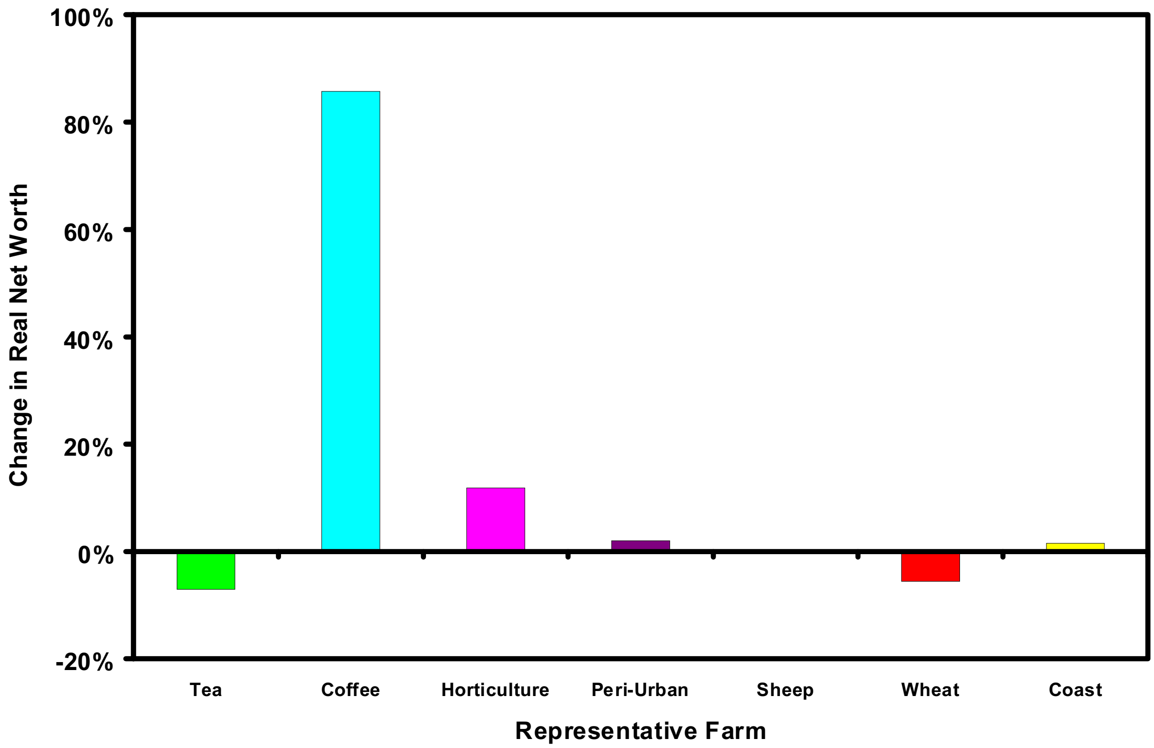


Figure 2.8.3-10. Percentage change in real net worth for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the deterministic scenario.

sentative farms (tea, peri-urban, wheat) after adoption of the new technology (Table 2.8.4.1). The wheat farm was most impacted, experiencing a 61.3% reduction in NPV. Net present value either became less negative (coffee) or increased on the remaining farms. Net present value increased 42% for the coffee farm did not become positive. NPV remained unchanged for the horticulture farm, and it increased by 2.4% for the coast and about 5% for the sheep farms. Differences in mean values for the deterministic and stochastic NPVs indicate a skewed distribution for the variable over the 10-year period. In general, mean values for total cash receipts were higher in the stochastic analysis than the deterministic analysis, and total cash costs remained relatively unchanged. Consequently, mean values of net cash farm income were slightly higher in the stochastic analysis than in the deterministic analysis.

Real net worth declined for the three farms that experienced decreases in NPV (wheat, peri-urban, tea). The wheat farm experienced a 37% reduction in RNW, whereas the peri-urban and tea farms had RNW declines of about 3%. The coffee farm had the greatest relative gain in RNW (300%) with a mean value increase of 60 thousand Ksh under the improved dairy technology relative to the base technology. Figures 2.8.4-1 to 2.8.4-10 exhibit the expected mean values of the economic variables for the base scenario and improved technology scenario and percentage changes. Figures 2.8.4-11 to 2.8.4-15 provide graphic examples of the distribution of the NPV, total cash receipts, total cash costs, net cash farm income, and RNW for the representative farm in the tea zone for the two scenarios.

Table 2.8.4.1: Kenya Representative Farms Mean and Standard Deviations (STD) of Net Present Values, Total Cash Receipts, Total Cash Costs, Net Cash Farm Income, and Real Net Worth Under the Base (old) and Current Small Holder Dairy Technology in 1,000's Kenya Shillings Under Stochastic Conditions

Dairy Zone	Net Present Value		Total Cash Receipts		Total Cash Costs		Net Cash Farm Income		Real Net Worth	
	Old	Current	Old	Current	Old	Current	Old	Current	Old	Current
Tea	1680.00	1600.00	120.00	140.0	30.00	50.00	90.00	90.0	1670.00	1610.00
(% Change)		(-4.76)		(16.67)		(66.67)		(0.00)		(-3.59)
STD	220**	240.00	17.13	18.14	0.00	0.00	15.78	19.32	481.00	457.00
Coffee	-310.00	-180.00	40.00	50.00	50.00	50.00	-10.00	0.00	-20.00	40.00
(% change)		(41.94)		(25.00)		(0.00)		(100.0)		(300.0)
STD	36.10	36.10	3.16	3.16	0.00	0.00	22.73	21.21	295.75	254.89
Horticulture	291.68	291.83	50.00	60.00	10.00	20.00	40.00	40.00	232.97	233.05
(% change)		(0.05)		(40.00)		(100.0)		(0.0)		(0.03)
STD	36.20	36.20	5.14	5.14	0.00	0.00	5.66	5.66	122.38	122.42
Peri - Urban	1290.00	1160.0	40.00	90.00	10.00	70.00	30.00	20.00	1670.00	1620.0
(% change)		(-10.1)		(125)		(600.0)		(-33.33)		(-2.99)
STD			8.43	4.22	3.16	3.16	4.22	6.75	147.66	108.55
Sheep	810.00	850.00	160.00	160.00	40.00	40.00	120.00	120.00	2640.00	2660.00
(% change)		(4.94)		(0.00)		(0.00)		(0.00)		(0.76)
STD			4.22	8.43	3.16	3.16	4.22	4.22	205.28	216.24
Wheat	1550.00	600.00	190.00	120.00	30.00	40.00	160.00	80.00	1480.00	930.00
(% change)		(-61.30)		(-36.8)		(33.33)		(-50.00)		(-37.16)
STD			41.91	23.12	0.00	0.00	42.70	24.15	389.40	159.55
Coast	5410.00	5540.00	580.00	600.00	60.00	70.00	520.00	530.00	3960.00	4020.00
(% change)		(2.40)		(3.44)		(16.67)		(1.92)		(1.52)
STD			22.14	24.24	5.16	9.94	24.70	24.40	1470.34	1511.70

* Mean in 1'000's of Kenya Shillings (Ksh)
**Standard deviation

Results from the FLIPSIM analysis indicated that farmers relied primarily on family labor for each representative farm. The coastal and wheat farms were exceptions which had hired labor costs of 18,000 and 24,000 Ksh per year, respectively. Introduction of zero-grazing technology and improved dairy cattle breeds increased revenues to producers but also increased costs. Consequently, net cash farm income increased only slightly (from 0 to 10 thousand Ksh annually) or decreased on farms where increased revenues did not offset increased costs given the price and yield variabilities faced by these farms. The representative farm in the dairy–wheat zone would experience the greatest absolute decline in net cash farm income (80 thousand Ksh annually).

2.8.5 Interpretation and Summary

Results from the deterministic and stochastic simulations of the representative farms indicate that the horticulture, peri-urban, and coast farms generally benefit most from the adoption of the improved dairy technologies. NPV, net cash farm income, and RNW are positive and increase as the dairy technologies are

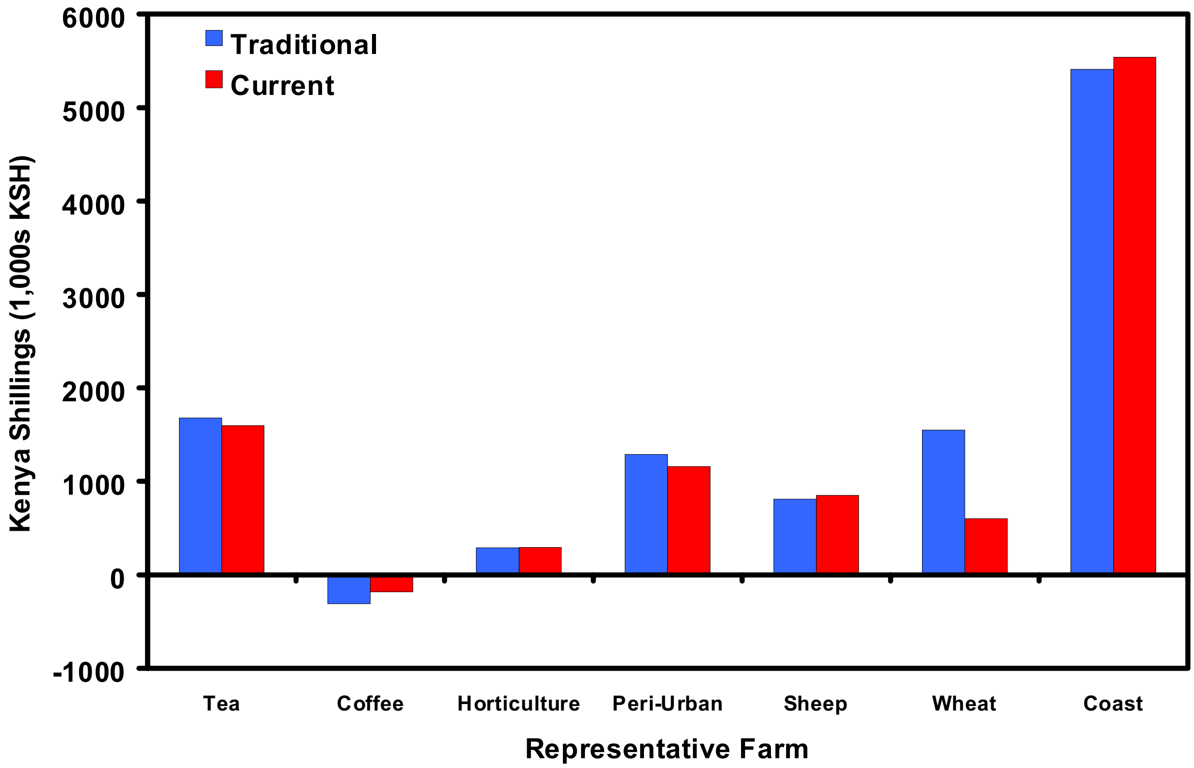


Figure 2.8.4-1. Net present value (NPV) for Kenyan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

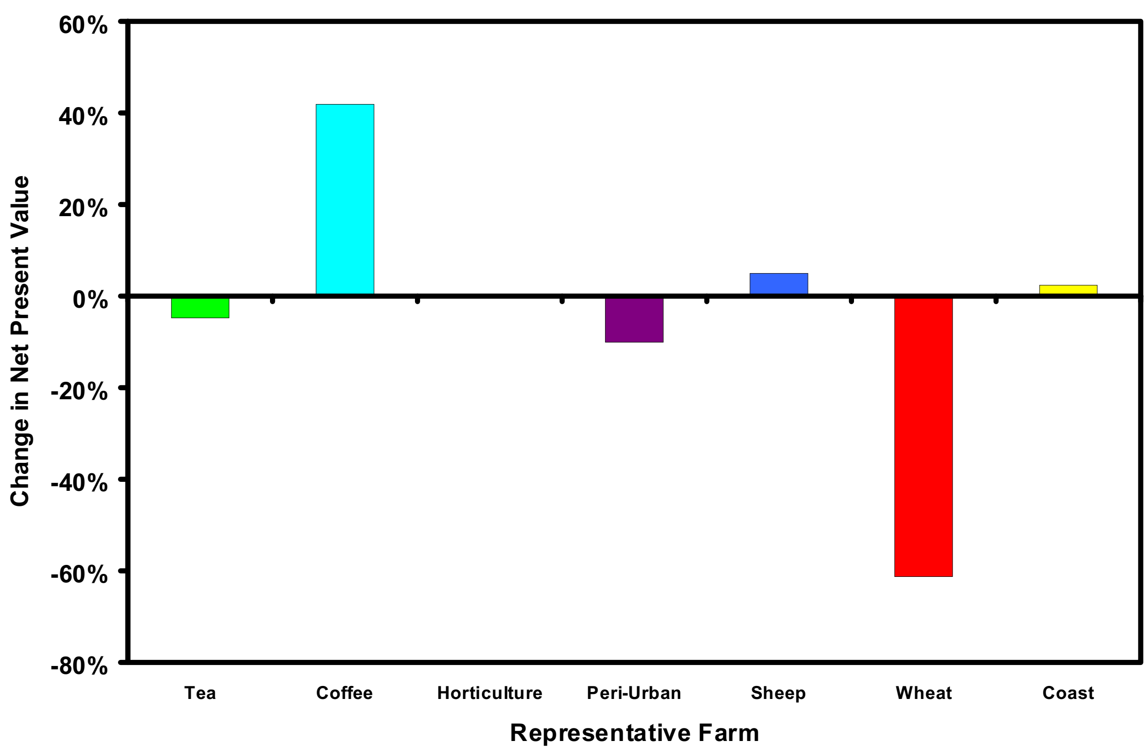


Figure 2.8.4-2. Percentage change in net present value (NPV) for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the stochastic scenario.

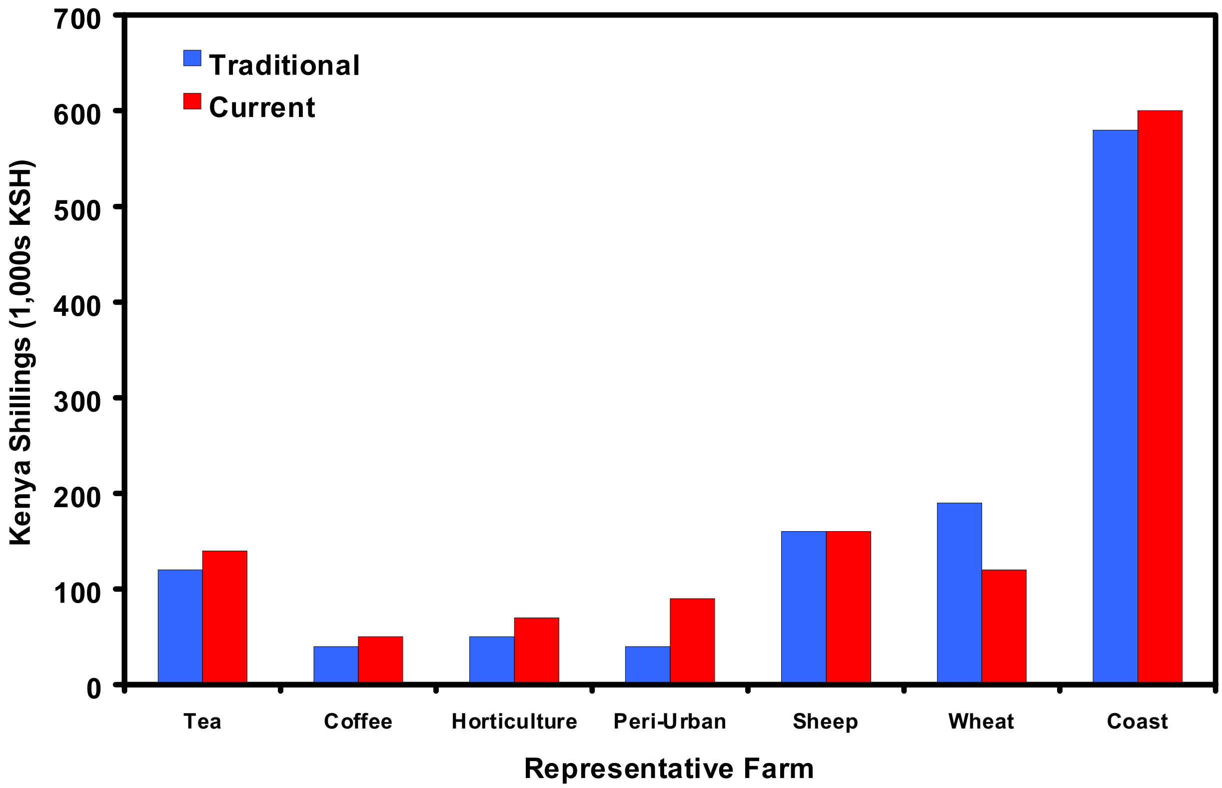


Figure 2.8.4-3. Total Cash Receipts for Kenyan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

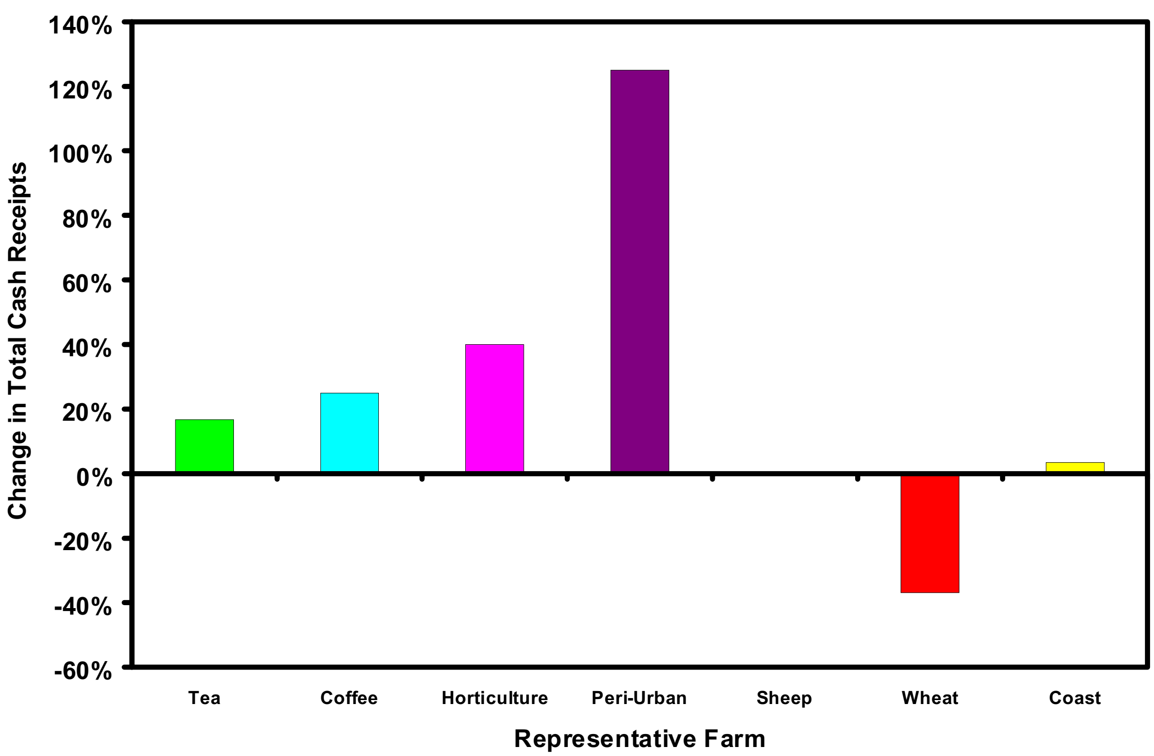


Figure 2.8.4-4. Percentage change in total cash receipts for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the stochastic scenario.

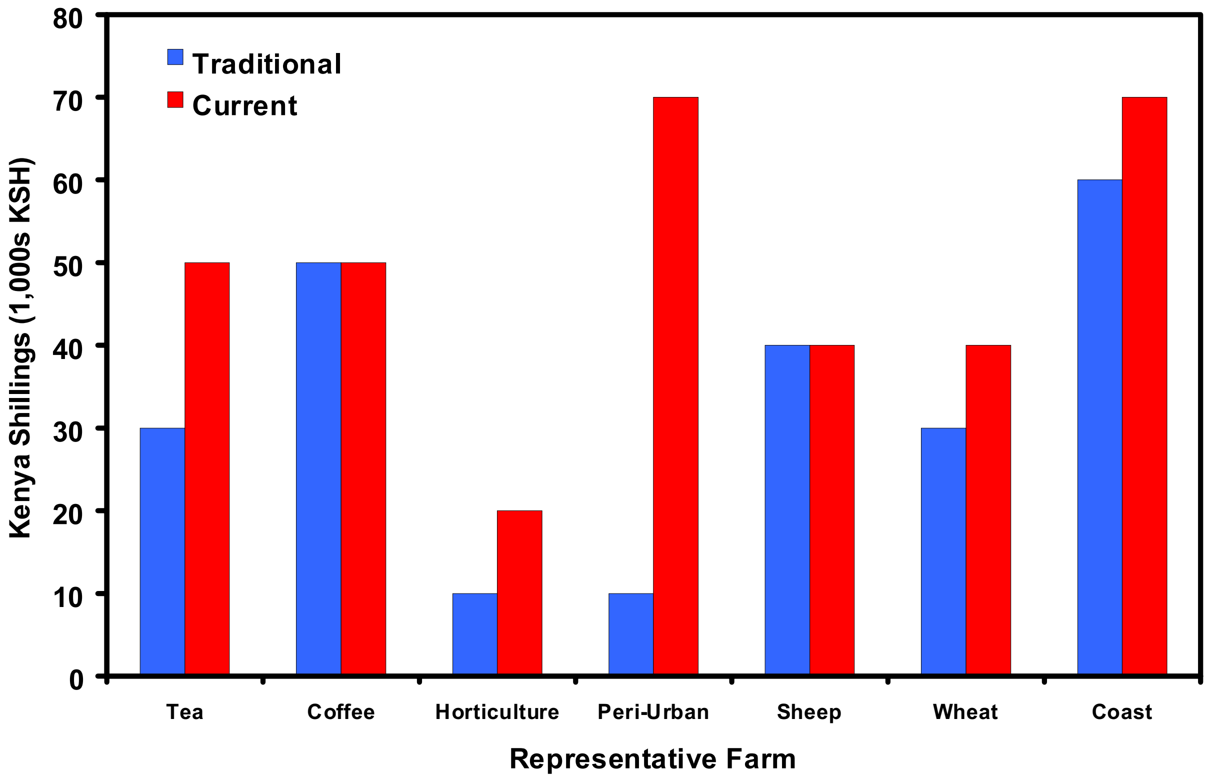


Figure 2.8.4-5. Total cash costs for Kenyan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

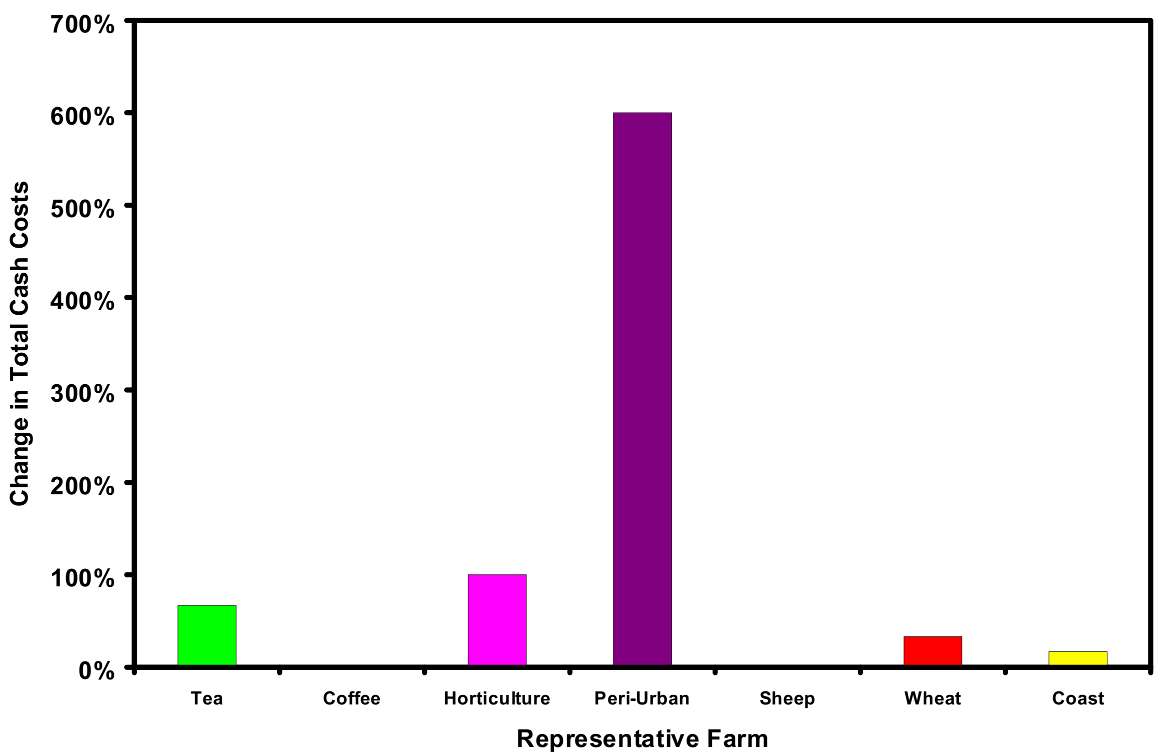


Figure 2.8.4-6. Percentage change in total cash costs for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the stochastic scenario.

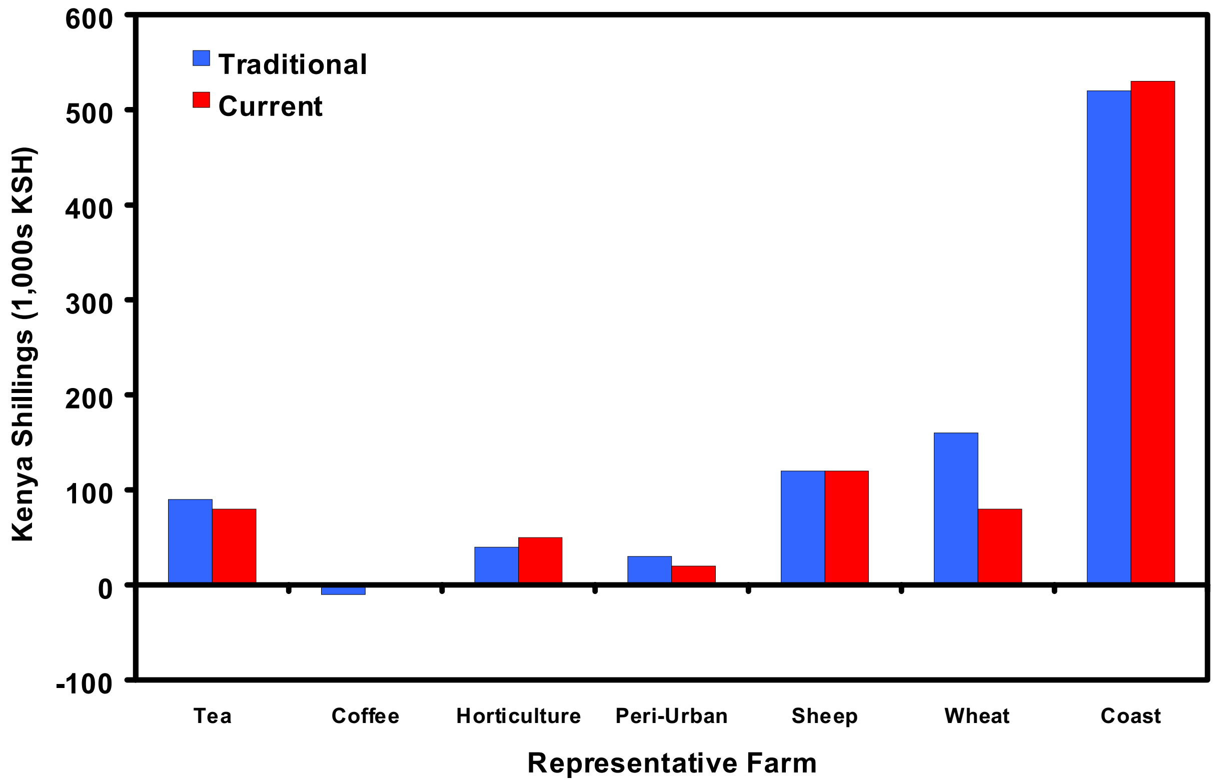


Figure 2.8.4-7. Net farm income for Kenyan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

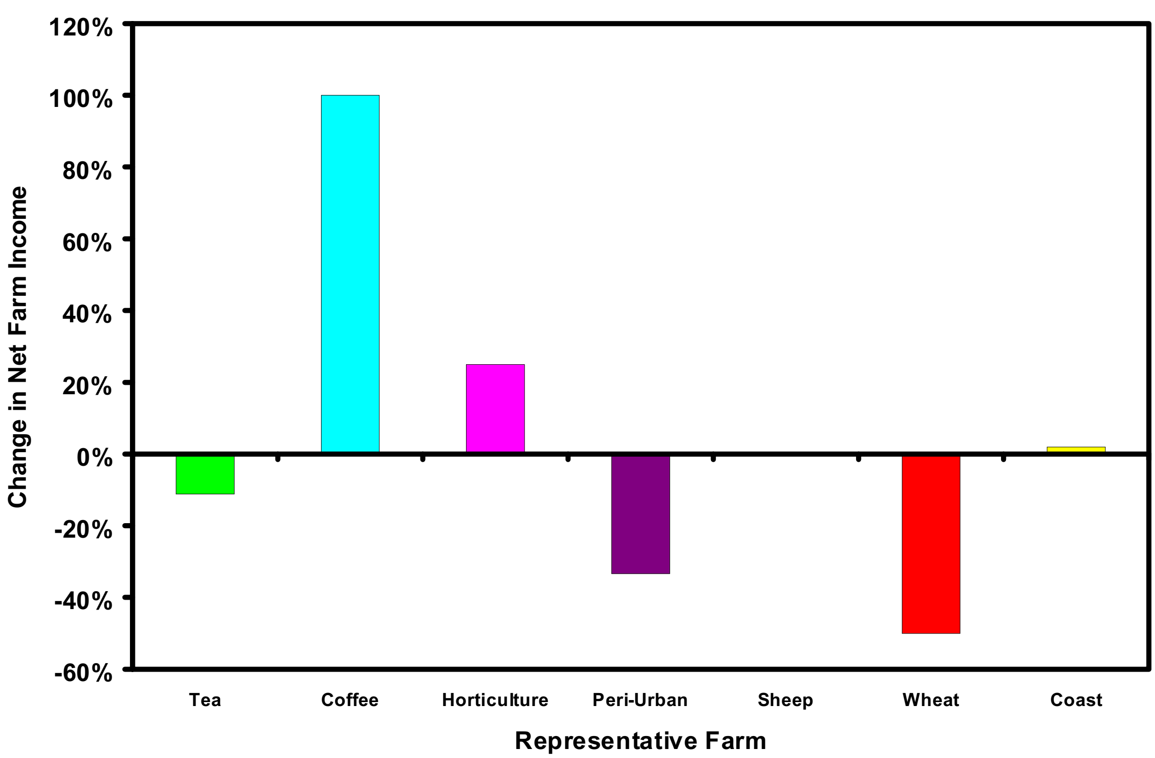


Figure 2.8.4-8. Percentage change in net farm income for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the stochastic scenario.

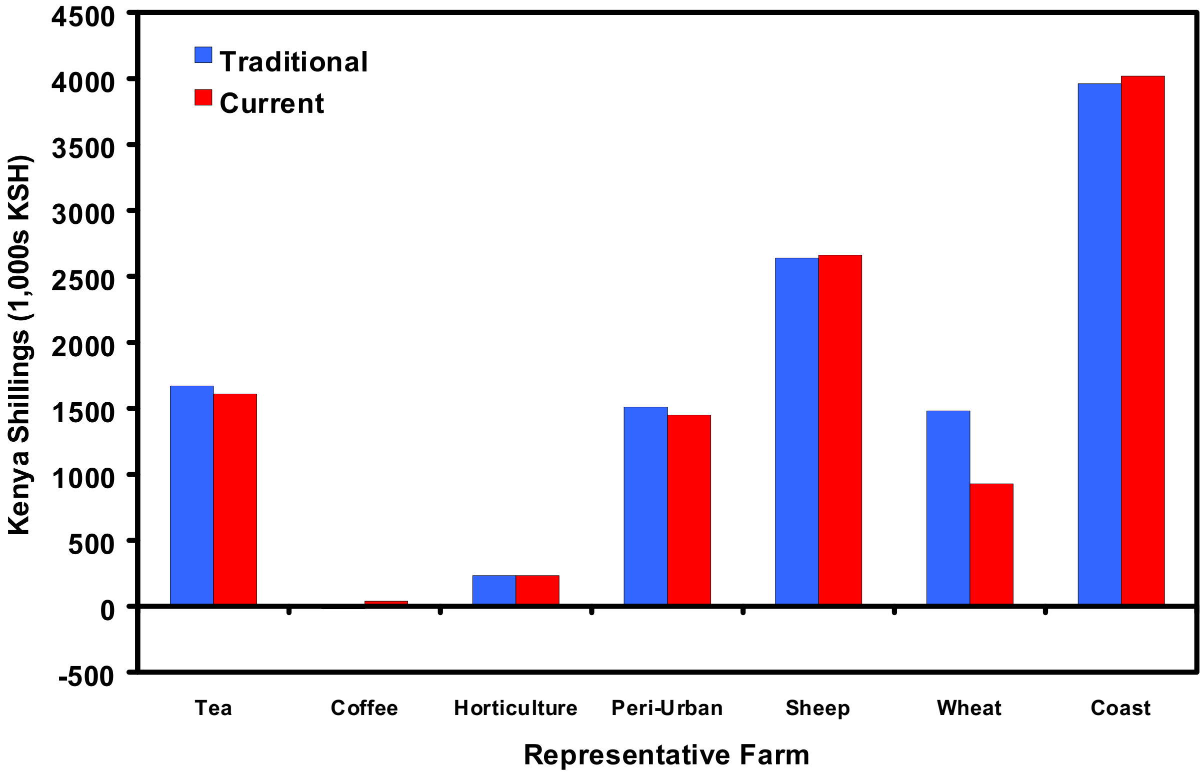


Figure 2.8.4-9. Real net worth (RNW) for Kenyan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

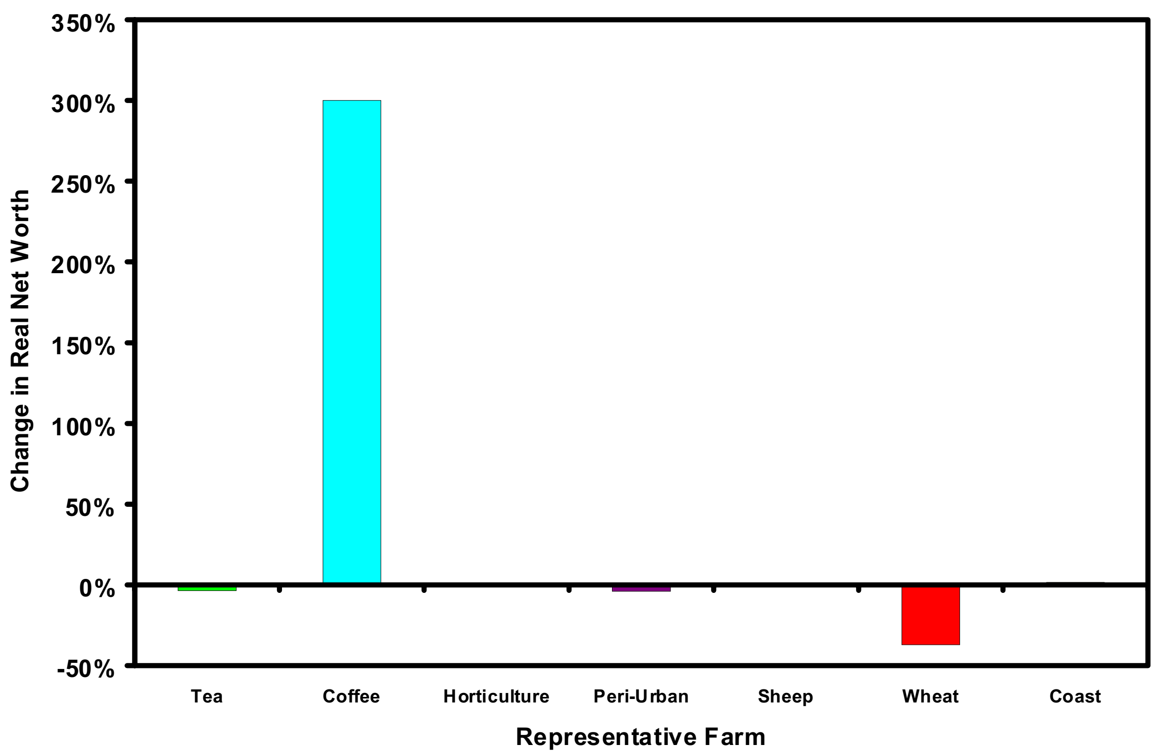


Figure 2.8.4-10. Percentage change in real net worth (RNW) for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in seven dairy environments in Kenya under the stochastic scenario.

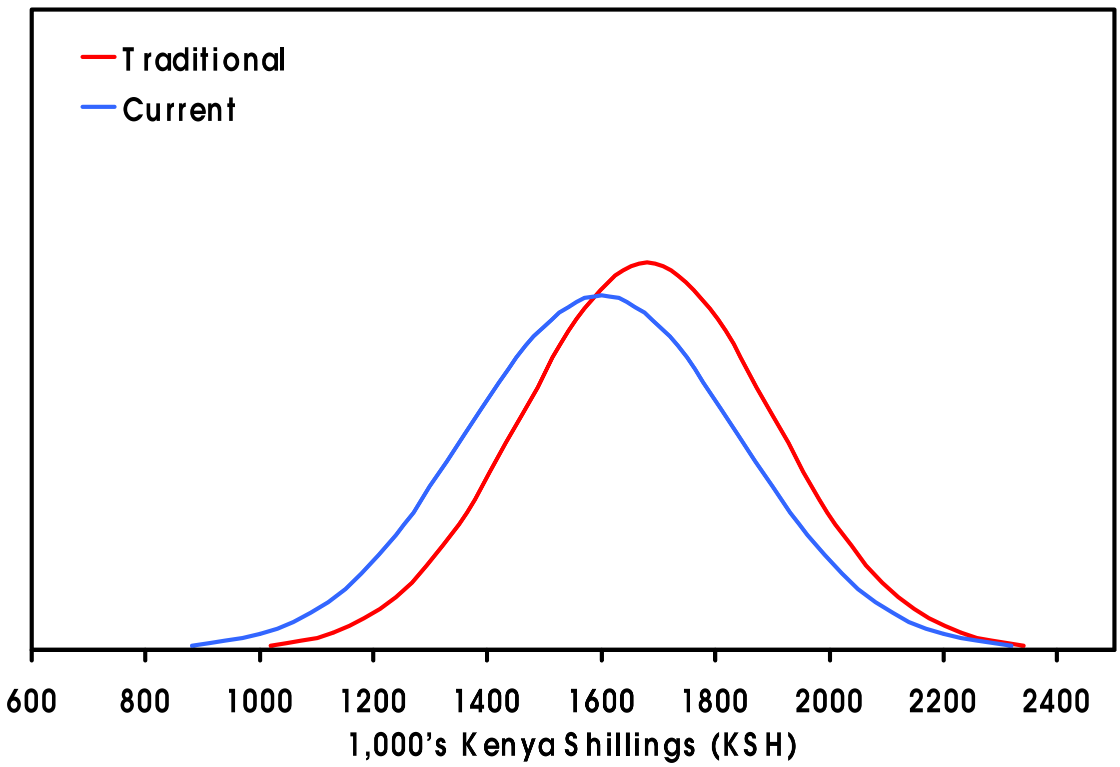


Figure 2.8.4-11. Distribution of net present value under traditional and current small holder dairy technologies on a representative tea farm in Kenya.

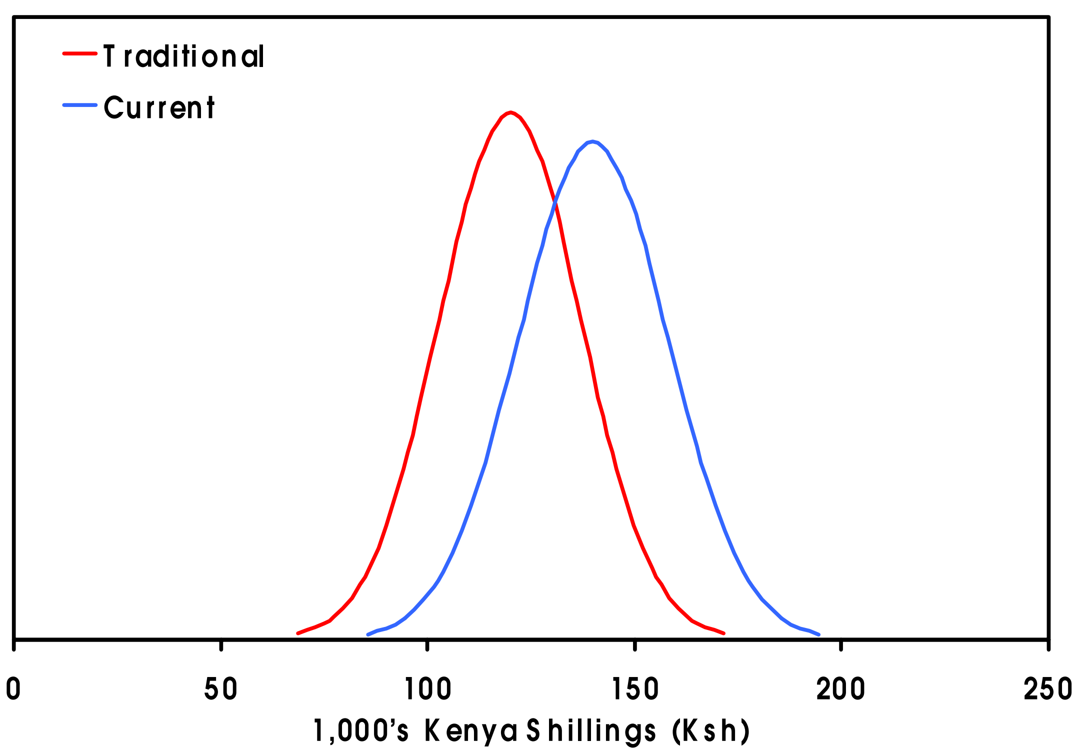


Figure 2.8.4-12: Distribution of total cash receipts under traditional and current small holder dairy technologies on a representative tea farm in Kenya.

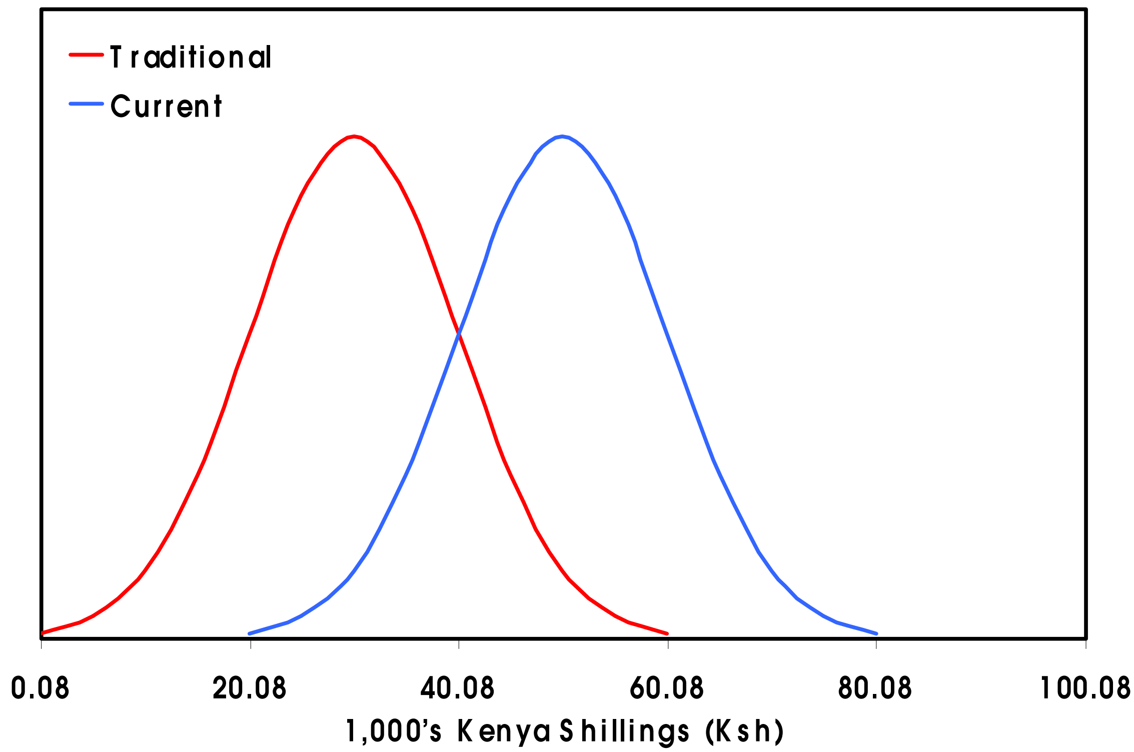


Figure 2.8.4-13. Distribution of total cash costs under traditional and current small holder dairy technologies on a representative tea farm in Kenya.

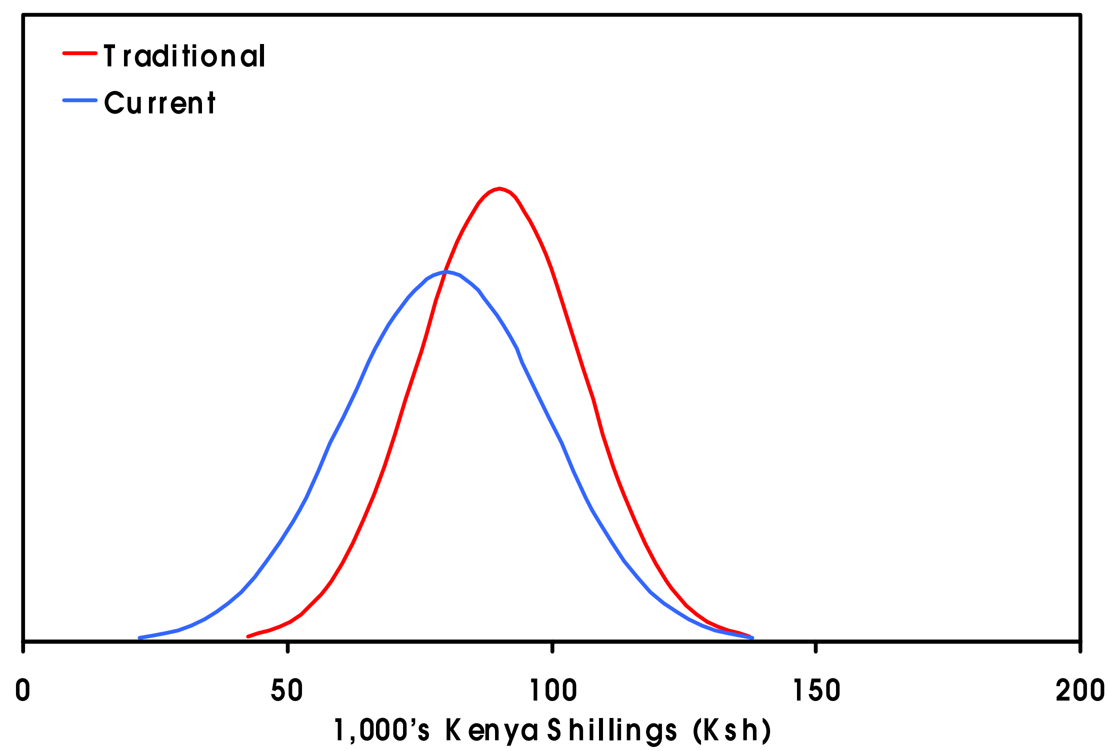


Figure 2.8.4-14. Distribution of net cash farm income under traditional and current small holder dairy technologies on a representative tea farm in Kenya.

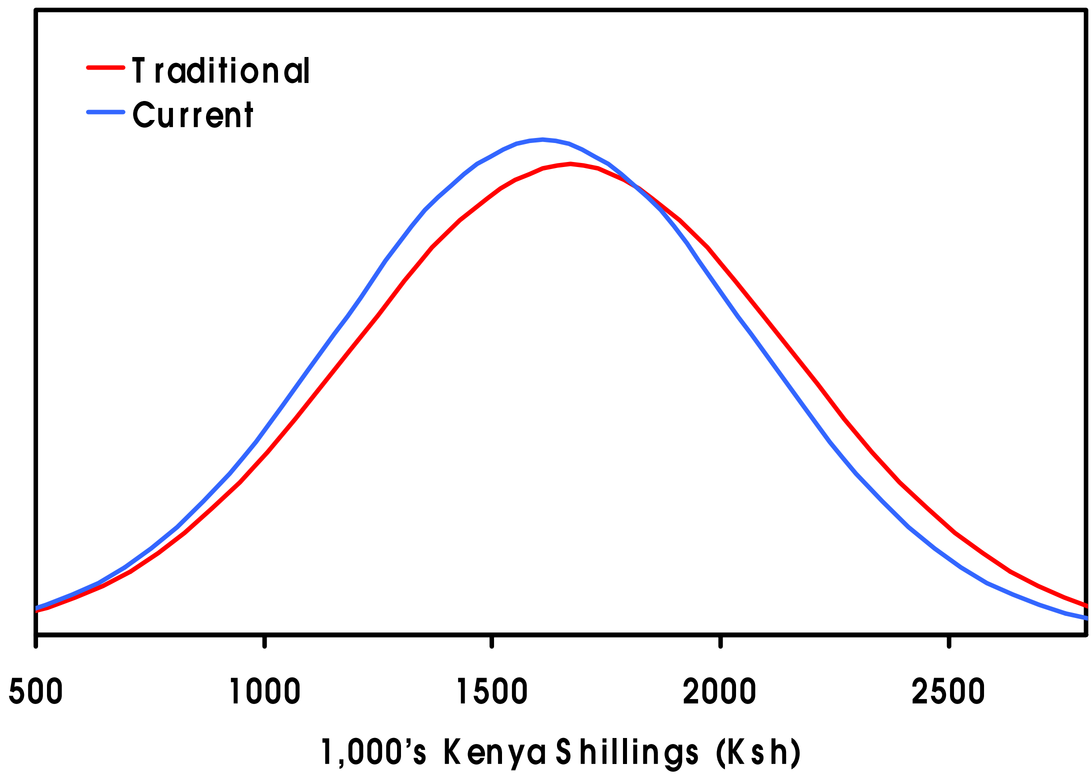


Figure 2.8.4-15. Distribution of real net worth under traditional and current small holder dairy technologies on a representative tea farm in Kenya.

adopted on these farms under deterministic conditions. When price and yield variabilities are taken into account, only the coast farm and the horticulture farm experienced slight increases in NPV, net cash farm income, and RNW from adoption of the improved dairy technologies. Other farms exhibit a mixed pattern of income and net worth mean values as a result of the dairy technologies. For example, the representative farm in the coffee zone consistently experienced negative NPV, net cash farm income, and RNW under both the deterministic and stochastic analyses for the base dairy technology. Under the improved dairy technology, NPV and net cash farm income mean values remained negative or zero, but the RNW under the stochastic analysis became positive. The representative farm in the sheep zone was little affected by the improved dairy technology, as the NPV, net cash farm income, and RNW mean values remained relatively unchanged under both the deterministic and stochastic analyses. The FLIPSIM analyses of the representative farms generally provided results at the household level that were consistent with the aggregative macro-level impacts as revealed by the ASM results for Kenya. These analyses are based on assumptions of current demand (population).

2.9 Environmental Impact of Smallholder Dairy Technology Options in Kenya

An analysis of the environmental impact of smallholder dairy technology followed the economic analysis. Environmental impacts were assessed at regional and watershed levels. Several environmental indicators were monitored and reported as part of the simulation process. Two of the important ones were water runoff and erosion.

In the simulations for Kenya, these indicators were extracted for each of the simulations conducted on the selected representative farms. The area-weighted mean water runoff and soil erosion loss for each province delineated for agricultural sector analysis was computed.

2.9.1 Methodology

The Erosion Productivity Impact Calculator (EPIC) was used to assess the runoff and soil erosion impacts. Simulation were set up for representative households that reflected crop rotations and practices for each of the ecological zones. For these environmental impact calculations, results from the same simulations were used in all districts when a zone crossed more than one political district. In retrospect, a more refined approach should conduct simulations for each zone/district combination.

EPIC is a hydrologically based model capable of growing multiple crops in rotation as impacted by soil moisture, fertility, management practice, and crop production coefficients. The model output shows crop yields, biomass production, hay, and environmental responses such as runoff, nutrient loss and carbon and pesticide loading.

In this study, erosion and runoff were targeted since limited fertilizer and pesticides were used on these farms.

The runoff and erosions simulations were extracted from each of the 20-year simulations by crop rotation and ecological zone. To expand these representative household simulations to the Kenya political units (province), each ecological zone was assigned a weight (fraction) for each of the six provinces. If a crop was not reported in an ecological zone, a zero was assigned to the weight for that zone. For example, coffee was not reported in the wheat zone of the Rift Valley province so a zero value was reported for the weighted value of coffee. After these assignments were made, the zone area-weighted yields for each crop were recalculated for each district. The number of hectares for each crop in each political district was obtained from the equilibrium values from ASM model. No attempt was made in this analysis to reallocate weighted yields used for each ecological zone within a political district among scenarios. Only the total change in area used by each crop rotation for each scenario among political districts was considered.

A land use category of idle land was added to make district totals of cropland equal in all scenarios. Since no simulations were made to estimate erosion on unused (idle) cropland, the erosion and runoff rates from native grass were used as proxies for these coefficients.

2.9.2 Results

This environmental impact analysis indicates that impacts due to the land allocations between districts among the scenario are environmentally neutral for runoff and erosion. Many simplifying assumptions were made in this analysis. One should note that technologies can be used to impact the environment. For example, this analysis assumed fixed distribution of crop rotations across soils and slope. With the increases in areas of native grasses, opportunities exist for development of policies to encourage the planting of the grasses on the highly erosive soil types and the lands with steep slopes. This would definitely reduce erosion. Individual simulations indicated erosion reductions of up to 40% when moving from crops like maize to native grasses on the same fields. For example, in the coffee zone, the erosion estimate for maize was 11.6 vs. 6.3 mt/ha for native grasses. With further sub-divisions of the land base, these differences in land allocation and resulting environmental implications could be quantified.

Although there were wide variations in the simulated values of the respective land uses (e.g. annual erosion rates from 20.1mt/ha in maize in the wheat zone vs. 2.6 mt/ha for native grass in the coastal zone), there was no significant environmental impact across any of the political districts for the four technology scenarios considered. The changes in land uses associated with the technology packages were environmentally neutral in Kenya at the household level. Table 2.9.2.1 shows the relative weights assigned to each of the zones by the six political districts. These values are the fraction of total zonal land area falling in each province. These weights were adjusted in the individual crop calculations as described above. Table 2.9.2.2 provides the average runoff by zone and district weighted by the respective crop rotation areas. Table 2.9.2.3 gives the erosion rates using the same procedure. Both the runoff and erosion tables report the values for the "Improved Dairy Current Adoption" scenario. Values for the Traditional Dairy and the Improved Dairy Full Adoption Scenarios are not reported here because they show only very minor changes from the Current Adoption scenario. Only one of the cell values in either table varies more than 3% from the Current Adoption values. The only exception was reported in the horticultural zone of the Western Province where erosion dropped from 8.6 mt/ha with the current adoption of existing technology to 5.5 mt/ha for both the traditional and full adoption technology scenarios (not shown in the tables). This is traceable to the changes in crop areas dedicated to groundnuts and sorghum in the Current Adoption scenario coming from and returning to the idle land category in the Traditional and full adoption technology scenarios respectively. However, this environmental zone only accounts for 6% of the Western District's total area.

2.10 River Basin Level Environmental Impacts-The Sondu River

2.10.1 Selection of Watershed

The final analysis in the Kenyan case study was to assess the environmental impact smallholder dairies were having on the Sondu River watershed. To assess changes at a watershed scale, we linked the projected land

Table 2.9.2.1 Weights used in Runoff and Erosion Calculation by Ecological Zones and Kenya Districts

District	Wheat	Tea	Sheep	Horticulture	Coffee	Coast	Total
Central	0.13	0.10	0.45	0.32			1.00
Coast				0.07		0.93	1.00
Eastern	0.04	0.02	0.03	0.91			1.00
Nyanza		0.23		0.32	0.45		1.00
Rift Valley	0.15	0.18	0.16	0.37	0.14		1.00
Western		0.24	0.10	0.06	0.60		1.00

Table 2.9.2.2 Weighted Average Runoff (mm/ha) by Ecological Zones and Kenya Districts for the Current Adoption scenario							
District	**Wheat**	**Tea**	**Sheep**	**Horticulture**	**Coffee**	**Coast**	**Total**
Central	644	164	164	228			324
Coast				228		183	186
Eastern	643	166	166	227			234
Nyanza		163		207	205		205
Rift Valley	633	170	170	223	203		267
Western		177	177	204	201		186

Table 2.9.2.3 Weighted Average Erosion Rates (M tons/ha) by Ecological Zones and Kenya Districts for the Current Adoption scenario							
District	**Wheat**	**Tea**	**Sheep**	**Horticulture**	**Coffee**	**Coast**	**Total**
Central	17	18.1	18.1	5.6			9.6
Coast				5.3		2.6	2.8
Eastern	16.8	18	18	5.7			5.8
Nyanza		18.2		8.2	8.6		8.7
Rift Valley	16.2	17.7	17.7	6.2	7.8		8.6
Western		17.6	17.6	8.6	7.8		9.3

use from the Agricultural Sector Model (section 2.7), which had been stratified by agricultural production zone, with the Soil and Water Assessment Tool (SWAT) model, thereby allowing basin-scale assessment of environmental impacts including laminar flow of runoff, soil erosion, and soil and pesticide loading.

The Sondu River basin was chosen because it had a diversity of environmental types and a high proportion of its land area possessed 4 of the 7 dairy production zones. These characteristics were identified when the watershed boundaries theme layer in ACT was overlaid with a map of the dairy production zones. Also, the Sondu River, located on the northern edge of Lake Victoria in western Kenya, is one of many watersheds that drain directly into that lake; therefore, it represents how land use change impacts waterflows and sediment flows in this important body of water.

2.10.2 Spatial Characterization Procedures for the Sondu Watershed - population growth, dairy production technology

Land use within the watershed for each of the small holder dairy technology scenarios was estimated using a combination of population data and demographic survey data. Population densities, calculated on a 2.5 minute grid scale for the years of 1960 to 1990 (NCGIA, University of California Santa Barbara; Africa Data Sampler, Population density as calculated by Diechmann), were used as the basis for determining land use at the household (farm) level and numbers of households within each grid. For the Traditional Dairy scenario, household density per grid was determined by dividing the 1980 population density within each grid by the average number of persons per household, as reported for the representative Kenya administrative units (Figure 2.1-1) in 1979 (Jaetzold and Schmidt 1983) (Table 2.6.3.1). Household density for the Current Adoption scenario was determined using the 1990 population density within each grid and dividing it by the average number of persons per household in 1979 (as above) with an assumed increase of 30 percent. This 30 percent increase in household size was based on the household survey results reported by Staal et al. (1998) for the Kiambu district in Kenya. It is assumed that the household size in the districts in the Sondu watershed increased at a similar rate. For the "Future Adoption" scenario, a 30 percent increase in population within each grid was assumed and household size remained the same as in the Current Adoption scenario.

Once the number of households per grid were determined for each of the technology scenarios, the total land area within each grid was divided by the number of households to provide the land area per household (ha). In areas of low population density, the household land area was limited to 5 ha so that crop land area would not be overestimated. Land area assigned to each household was broken down proportionally into 2 major categories: 1) Agricultural land, 2) Non Agricultural Land (representing roads, rivers, homesteads, forest reserves, and, unsuitable land) using land area proportions reported by Jaetzold and Schmidt (1983) (Table 2.6.3.1). Agricultural land was further broken down into categories of 1) pastureland, 2) cropland, and 3) other agricultural land. Pastureland and cropland for each household were further disaggregated into native grass, Napier grass, food crops, and cash crops (Table 2.8.4.1) based on the proportions of these found on the representative farms surveyed for the FLIPSIM analysis. Since land use proportions for the representative farms used in the FLIPSIM analysis represent the Current Technology scenario, these proportions were modified for the Traditional and Future Technology using the following rules:

For crops, land use proportions for each small holder dairy production environment (Figure 2.4.4-1 production enviroments) were modified using the change in land area for the technology scenarios calculated by the Agriculture Sector Model (ASM, see section 2.7). If the ASM model did not predict a change in land area for a crop, the Current Technology proportions were used.

The assumption was made that Napier grass increase from Traditional Dairy to Future Adoption would be at the expense of native grass. It was assumed for the purpose of this analysis, that the amount of Napiergrass for the Traditional Dairy Scenario was zero. For the Current Technology scenario, the land area occupied by Napier grass was based on the household adoption rate for this technology (45%, see ASM section 2.7). For example, if the household density of the grid was 100, then the number of households having Napiergrass would be 45 (based on 45% adoption rate). The proportion of pasture land area occupied by Napiergrass for the representative farms was then multiplied by the number of households to calculate total land area of Napiergrass in the grid. Napier grass land area in the Future Technology scenario was calculated the same way except the adoption rate was 60%.

It was assumed that the proportion of non-agricultural and other agricultural land use did not change when going from Traditional Dairy technology to Future Adoption.

In areas of low population density, land that was not classified as land area occupied by a household (exceed the 5 ha household size describe above) was classified as forest land for modeling purposes.

The proportions of the various land uses were then applied to each grid cell to provide a calculation of land area per grid that is occupied by the various land uses for each Smallholder Dairy technology scenario. The grid then acted as sub-basins in the SWAT model, and water, erosion, and pesticide loads were routed through the watershed based on the designated land use and area within the grid.

2.10.3 Land Use Change

In this analysis, the increase in population over time and the adoption of smallholder dairy technology influenced land use within the Sondu Watershed. The adoption of smallholder dairy technology resulted in an increase in the amount of Napiergrass at the expense of native pasture and also influenced maize production (Table 2.10.3.1; Figures 2.10.3-1 and 2.10.3-2 spatial representation of maize land area). Land area for all crops, with the exception of potatoes, increased with the movement from Traditional Dairy technology to Full Adoption. This was most likely the result of increased population pressure on the land rather than changes resulting from the adoption of smallholder dairy technology since many of the crops were not predicted to have land area changes by the ASM model (Table 2.7.4.1.2). The results of this characterization indicate that increasing population pressure most likely influences land use changes greater than the adoption of smallholder dairy technology.

2.10.4 Linking Relevant Data Using GIS Methods and Developing Inputs to the SWAT Model (elevation, soils, weather, river stream flow, land use data)

Geographic Information Systems have been playing an important role in natural resources modeling and proving to be an effective tool for non-point source pollution models. The SWAT-GIS Interface (GRASS or ArcView versions http://www.brc.tamus.edu/swatgrass/index.html) helps in integrating the spatial information on the topography, soil, land use/land cover with hydrologic modeling by preserving the spatially distributed parameters of the entire basin and homogeneous characteristics within a sub-basin. Basins can be delineated into hundreds or thousands of grid cells or sub-watersheds using this interface. The interface also helps to collect and transport the output data from SWAT model runs into a GIS system of maps, charts, and graphs to display the results. The GRASS GIS version of SWAT GIS Interface (Srinivasan and Arnold, 1994; Srinivasan et al., 1997) was used to extract the inputs needed for Sondu river basin SWAT model runs from appropriate GRASS coverages and other spatial databases.

Table 2.10.3.1 Household and Land use information for administrative districts within the Sondu Watershed (from Jaetzold and Schmidt 1983)

	Kenya Administrative District			
Land Area Information	**Nakuru**	**Kericho**	**South Nyanza**	**Kisumu**
Persons/household	4.12	5.04	6.07	4.87
Agricultural Land (%)	85	87	87	87
Pasture land (%)	60	65	65	65
Cropland (%)	25	32	32	32
Other Ag Land (%)	15	3	3	3
Non Agricultural Land	15	13	13	13
Roads, Rivers, Homesteads (%)	80	77	77	77
Forest Reserves (%)	<1	<1	<1	<1
Unsuitable (%)	<1	<1	<1	<1
Other (%)	19	22	22	22

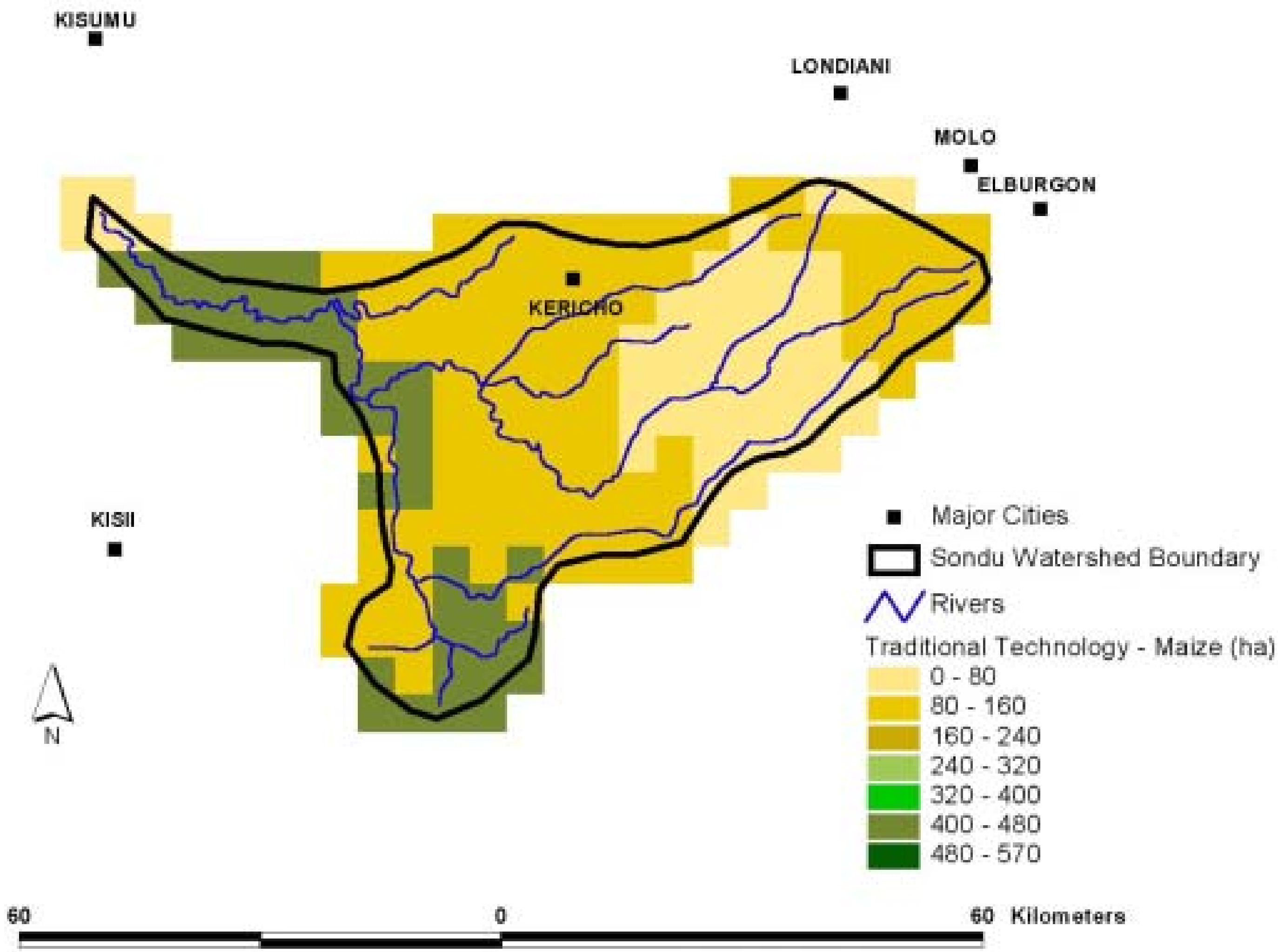


Figure 2.10.3-1. Estimated hectares of maize within the Sondu watershed under traditional small holder dairy technology.

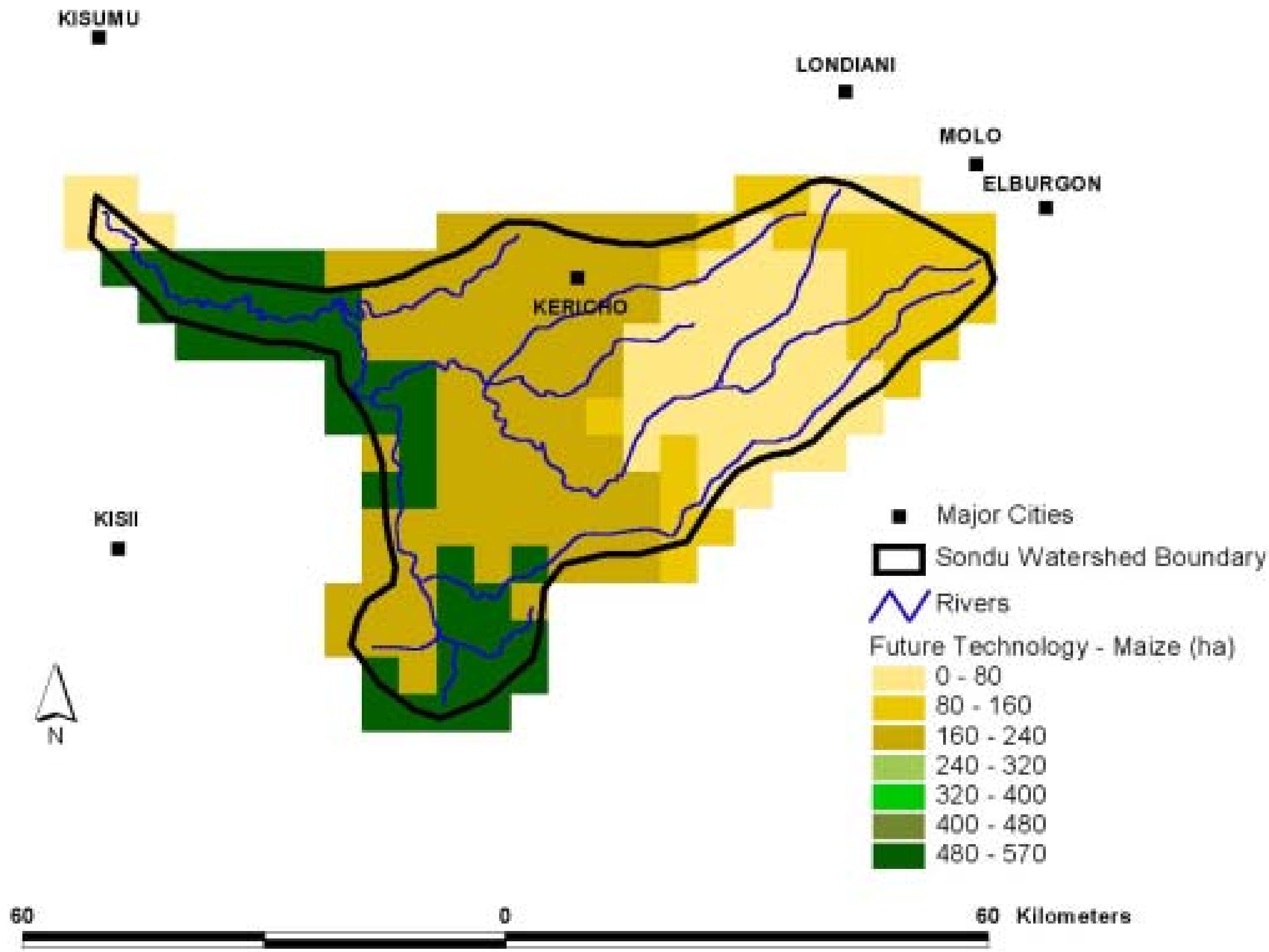


Figure 2.10.3-2. Estimated hectares of maize within the Sondu watershed under future adoption of small holder dairy technology.

The following datasets were assembled for parameterizations of the SWAT Sondu River Basin hydrology model:

1. Digital Elevation Model with 1-km resolution.

2. Only one soil information was available for the entire river basin. That soil was used for all sub-basins.

3. Three weather stations, namely Kisumu, Kericho, and Kisii, are located near Sondu river basin (Figure 2.10.4-1). Out of these three, Kericho is the influencing weather station for whole of Sondu basin. So precipitation and temperature data from Kericho weather station for the period 1978-97 were used for SWAT simulations. Daily precipitation and daily maximum/minimum air temperatures data were available. All missing precipitation and temperature data at Kericho were filled with data from Kisumu and Kisii weather stations, as they were available.

4. Observed mean daily streamflow data were available for three streamgages namely, 1JG03 (basin outlet), 1JA02, and 1JF06 (Figure 2.10.4-1). 1JG03 had observed data from 1979 to 1996, 1JA02 from 1979 to 1994, and 1JF06 from 1979 to 1991. Stream flow data were missing for several days at the three stream gauges. Drainage areas of the three stream gauges were also not available.

5. Land use data were provided for three scenarios discussed earlier: 1) current adoption, 2) full adoption, and 3) traditional technology for square grids (subbasins in SWAT), each with an area of about 2146 hectares (Figure 2.10.4-1). Land use consisted of seven crops, (banana, beans, coffee, corn, potato, tea, and tomato), native grass, Napiergrass, urban, forest, and water. Land area for each crop was derived based on proceedures described in section 2.10.3.

6. No observed sediment data was available to calibrate the models sediment output estimates.

2.10.5 Basin-Scale Data Processing and Analysis for the Sondu River

ArcView GIS and GRASS GIS were used extensively for data processing. Grid layers in a geographic projection were converted to raster coverage with 200-m resolution in GRASS using the Albers Equal Area projection, serving as the sub-basin map for the three scenarios. For grids along the river basin boundary, only the part within the river basin was considered for analysis. Percentages of each land use in each grid for the three scenarios was assembled as an ASCII file in the format required by the SWAT GIS-GRASS Interface.

A Digital Elevation Model in geographic coordinates was available as a grid in ArcView. It was exported as ASCII data and imported into GRASS as a raster layer and was resampled to 200 m resolution. Soils data were assembled as an ASCII file in the format required by SWAT-GRASS interface.

Daily precipitation and temperature data of Kericho weather station were organized as ASCII files in the format required by SWAT model. Mean monthly streamflow was calculated for each month at the three stream gauges using the daily data.

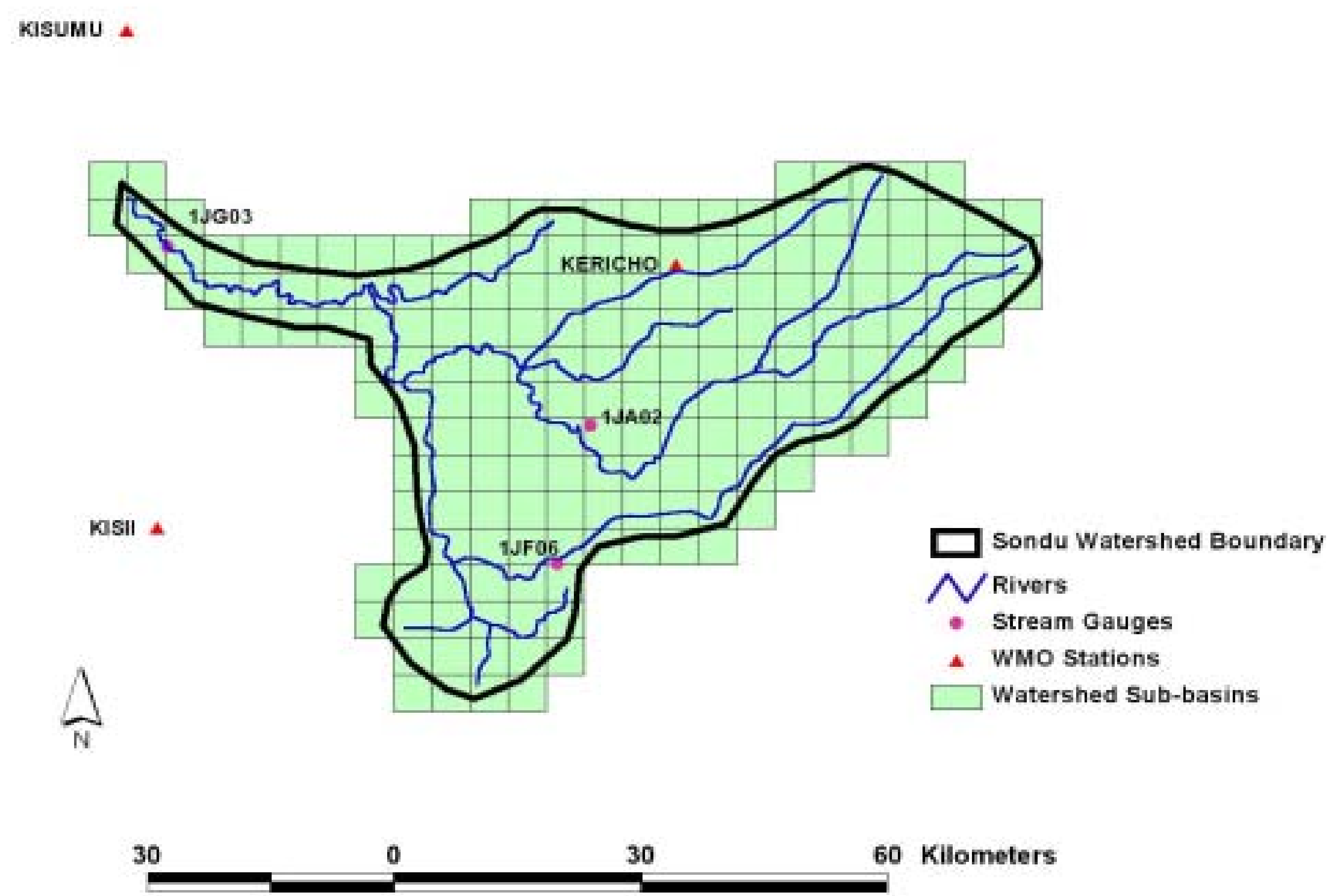


Figure 2.10.4-1. Location of stream gauges, World Meteorological Organization (WMO) weather stations, and sub-basins within the Sondu River Watershed in Kenya.

The following simulations were conducted with SWAT to evaluate the impact of the change in land use associated with introduction of smallholder dairy technologies:

1. 1978 to 1988 was considered as model calibration period and 1989-97 was the validation period.

2. 1978 was considered as model stabalization period to reduce the effects of the differential and initial conditions were eliminated from the analysis.

The SWAT model was calibrated for 1979-88 using the current land use technology. Model parameters such as curve number (abstraction coefficient), available soil water capacity, and soil evaporation compensation factor were adjusted interactively to get reasonable match between observed and simulated mean monthly stream flow at the three streamgages. Streamflow and sediment loads were simulated using the calibrated parameters for the validation period and results were compared.

The calibrated model parameters were used with full adoption and traditional land use technology so that the results can be compared and the effect of changing land use on water and sediment yield can be assessed. The same calibration and validation periods using future and old land use scenarios. Statistics were calculated for the simulations with the three scenarios and the results were compared.

2.10.6 Results

2.10.6.1 Changes in Streamflow and Sediment Loads

Mean monthly simulated streamflow and associated standard deviations at the basin output (1JG03) and one of the subbasins compared well with the observed data. However, simulated values were higher compared to observed values at the other subbasin stream gauge (1JA03). Monthly flow patterns compared reasonably well with the pattern of rainfall data used in the simulation. Variability in streamflow estimates compared to actual guage data indicated that the limited weather station coupled with minimal representation of soils in the basin and spatially variable rainfall did not capture the spatial heterogeneity of the basin. This may be due to the limited data on weather and soil. Since only one weather station was used for the entire basin, the spatial variability of rainfall was not adequately represented. Because of these differences in the monthly streamflow values, the r^2 values and Nash-Sutcliffe efficiencies were not guaged to be satisfactory. The time series analysis of streamflow for the land use change can be found in appendix.

2.10.6.2 Comparisons of Modeled and Measured Variables

At the outlet of the Sondu River basin, there was a simulated increased water flow of 23% from the traditional smallholder dairy to the current land use composition reflecting adoption patterns to date. However, given the increased use of Napiergrass and crop shifts, there is only an anticipated 2% increase when full adoption is attained.
Figure 2.10.6.2.1 presents the simulated cumulative sediment outflow from the Sondu river basin to Lake Victoria from 1979 to 1997. The sediment load is around 7 million tonnes at the end of the 20-year period for all three scenarios. Full adoption technology land use increases the sediment load by 0.93% while land use representing pre-smallholder technology was 5% less than current levels of land uses representing a

slightly less than 6% increase in sediment loading from traditional to full adoption. There are no observed sediment data to compare and validate the simulated results. Figure 2.10.6.2-1 presents the increase in sediment load to Lake Victoria over time using the current adoption, full adoption, and traditional technology

Table 2.10.6.2.1 Cumulative Sediment Load to Lake Victoria : 1979-97.

Landuse	Sediment Load (Million Tonnes)	Increase/Decrease with respect to. current landuse
Current	7.242	---
Future	7.309	+ 0.93 %
Traditional	6.904	- 4.67 %

land uses, espectively.

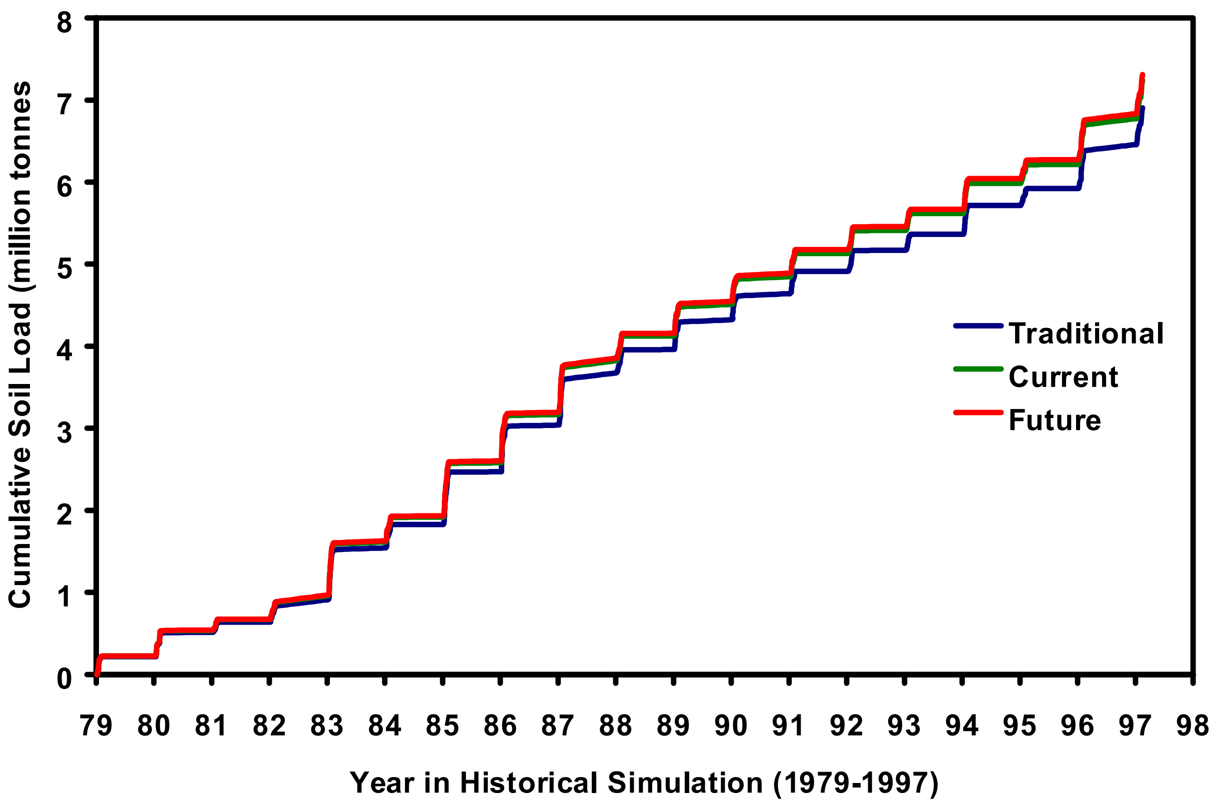


Figure 2.10.6.2-1. SWAT-derived cumulative sediment outflow (million tonnes) from the Sondu River Basin in Kenya for each of the small holder dairy technology scenarios.

2.11 Conclusions

Improved Dairy Technology has had a positive effect on the Kenyan economy and social welfare. Further positive impacts are possible under a full adoption scenario, although the bulk of the benefits have already been achieved, based on current population demand. Future improvement in dairy production will most likely go to meet the growing demand. With the adoption of the Improved Dairy technologies, total social welfare increased an additional 705 million Ksh annually. These results indicate that the Improved Dairy technologies have substantially benefited producers and their families through expanded supplies and lower prices for milk and other commodities and through reduced milk imports. The results also indicate that when the Improved Dairy technologies are fully adopted, consumers and national economic welfare would be further increased, but farmers and their families would realize only modest gains in their economic benefits. Reductions in the returns to land and labor resources would be nearly equal additional savings in home consumption expenditures for rural people.

When the dairy technology improvements are fully adopted under demand growth rates associated only with rising population for the next 15 years, as contrasted to current adoption rates and demand levels, both consumers and producers benefit. Regional consumers in towns and cities nationally gain 181.54 billion Ksh (113.2%) annually, while home consumption expenditure by farmers and their families is increased 58.3 billion Ksh (107.0%) annually. Producers return to land and labor are increased 11.8 billion Ksh each year. The increase in home consumption expenditure for food substantially outweighs the increase in producer's return to land and labor. Foreign surplus increases only slightly, up 274 million Ksh annually, or about 0.3%. Total social welfare in Kenya is increased 135.31 billion Ksh (67.0%) annually under the demand growth scenario. Increased production and consumption of milk accounts for near one-third of the increase in welfare of regional consumers in towns and cities, and about 72% of the increase in home consumption expenditures of farmers and their families. These results indicate that even under demand growth conditions, domestic consumers in towns and cities are likely to be the major beneficiaries of the smallholder dairy research and technology transfer relative to rural producers and their families that adopt the new technologies and increase the available domestic supply of milk.

Results from the deterministic and stochastic simulations of the representative farms indicate that the horticulture, peri-urban and coast farms generally benefited most from the adoption of the improved dairy technologies. NPV, net cash farm income, and RNW are positive and increase as the dairy technologies are adopted on these farms under deterministic conditions. When price and yield variabilities are taken into account, only the coast farm and the horticulture farm experienced slight increases in NPV, net cash farm income, and RNW from adoption of the improved dairy technologies. Other farms exhibit a mixed pattern of income and net worth mean values as a result of the dairy technologies.

The impact of smallholder dairy technologies has been environmentally neutral when averaged across administrative districts. However, the evolution of these technologies from traditional zebu dairying on common grazing lands to the current mix of farms and technologies has resulted in an increased streamflow of approximately 23% while sediment loading has risen by 5% using the Sondu River basin as a point of reference in the Highlands of Kenya.

Point based sampling and subsequent derivation of agro-ecological zones that represent different types of dairying environments offered a robust method to establish a spatial sampling frame for the biophysical simulations. These spatially explicit biophysical simulations allowed us to address both the issue of economic and environmental impact across administrative zones and agro-ecological zones using the same simulations. Using area-weight responses of biophysical crop/forage yield responses and animal nutritional responses provided spatially coherent average yields for the sector model. Using the representative farms, it was possible to aggregate point based simulation data across sub-basins to derive spatially explicit river basin level responses. Feedback from land use change predicted by the ASM model allowed a direct linkage to the environmental modeling work via the ACT tool and spatial sampling frame established in the beginning of the case study.

The limited availability of well distributed weather data and limited soil information presented a challenge to the effort that was overcome by application of data approximation techniques. Such tools as soil parameter estimators, land demand algorithms, weather generators and satellite weather data play a critical role in supporting the biophysical models and ultimately parameterization of the economic models.   The use of the spatial sampling frame allowed identification of areas where representative farms should be selected and determination of areas of "geographical equivalence" that comprised the agro-ecological zones established for the smallholder dairy production systems.

Careful selection of the representative farms and economic analysis of those farms generally provided results at the household level that were consistent with the aggregate macro-level impacts as revealed by the ASM results for Kenya. The suite of tools when used in the proper sequence proved to be less than perfect but robust enough to be linked in a spatially coherent manner and applied in a manner to allow systems feedback between the economic models and the environmental models and yield valued information for policy decision makers.

Section 3: Extrapolation of the Impact Assessment of Smallholder Dairy Technology in Kenya to Adjacent East African Countries

There are a number of situations in which it would be useful to be able to make at least first order approximations of the predicted economic, environmental, and societal impacts of policy or technology options in areas outside those where explicit experimental data exists. In section 2, we forecasted the utility of several levels of intensity of smallholder dairy operations at varying levels of scale from farm to national.

In this section, we describe methods that were developed and evaluated to assess the potential impact of technology or policy options from one country to another. As a specific example of the general methodology, we dealt with the extrapolation of smallholder dairy technology from Kenya, as described in section 2, to Uganda and Tanzania. Methods to perform such extrapolations will be of substantial use to multinational sponsors of research or to rapidly emerging regional organizations of developing countries that engage in joint planning, conduct, and evaluation of research.

The methods involve the use of GIS techniques to identify areas of geographic equivalence between Kenya, Uganda, and Tanzania. This is followed by identification of other spatially explicit geographic, biophysical, economic, and socio-cultural factors that affect the adoption of new technology in target countries. In the case of the smallholder dairy studies, we then described the current industry and its locations in target countries. The almanac characterization tool was used to define sampling frames from which relevant individual farms could be selected for further evaluation. An agricultural sector model was developed for Uganda and the smallholder dairy technology impact assessed using this tool at national and regional levels. The FLIPSIM model, described in section 2, was used to assess economic impact of Kenya smallholder dairy technology at the farm level in relevant areas of the two target countries.

Extrapolation of Results of Impact Assessment of Smallholder Dairy from Kenya to Uganda

Summary of Methods and Outputs	
Activity	***Purpose***
3.1 Spatial extrapolation of Kenya production systems to adjacent countries	General description of use of geographic equivalence and overview of first results
3.2.1 Spatial characterization of smallholder zones in Uganda	Describes the use of geographic equivalence method as first approximation and the subsequent addition of other relevant GIS layers to reflect areas of potential adoption
3.2.2 Description of current dairy sector in Uganda	Brief description of the industry, the consumption of milk, and potential land resources available for dairying
3.2.3 Definition of three production systems modeled	(1) old or base technology, (2) existing technology including fenced pastures with cross or purebred animals, and (3) new technology with zero grazing with purebred animals and improved forage
3.2.4 Geographic descriptions of dairy zones to define sampling frames	Location of the existing industry in relation to the production zones from the Kenya extrapolation and other relevant factors such as population, markets, roads
3.2.5 Defining yields from biophysical models	Describes the use of PHYGROW and NUTBAL models to generate the forage-livestock inputs and the use of EPIC to generate crop yields as input to ASM
3.2.6 Use of Agricultural Sector Model to estimate impact of smallholder dairy technology from Kenya in Uganda	Describes the ASM development and application to three representative production systems in Uganda by region and at the national level
3.2.6.1 Potential impact of large-scale dairy production	Assumes large-scale dairy operations are introduced as an exogenous source of milk, estimates increased efficiency of production and models the impact on smallholder dairy operations in competition
3.2.7 & 3.2.8 Estimates of economic impact of smallholder dairy technology at farm level	Six farms were surveyed in the Kampala and Highland zones. Analysis based on both average values and statistical variations over time
3.2.9 Summary and Interpretation	Interpretation of results and discussion of the utility of methods

Extrapolation of Results of Impact Assessment of Smallholder Dairy from Kenya to Tanzania

Summary of Methods and Outputs	
Activity	***Purpose***
3.3.1 Characterization of dairy industry	Brief description of the industry in Tanzania
3.3.2 Analysis relating adaptation to adoption	Shows areas of geographic equivalence for the Kenya zones and describes related variables used in the stratification such as locations of population centers and disease statistics
3.3.3 Analysis of representative farms	Selection of three representative farms with related production statistics and results of FLIPSIM analysis
3.3.4 Regional economic differences in smallholder dairy technology impact	Comparison of impacts in Kenya, Uganda, and Tanzania
3.3.5 Interpretation of methodological results for regional extrapolation	Assessment of the utility of the methods and the capacity provided for future analysis in Tanzania. Identifies need for further capacity building with users

3.1 Spatial Extrapolation of Kenya Production Systems to Adjacent Countries

The critical first step for the regionalization analysis was to use the description of the Kenya smallholder dairy environments and extrapolate those conditions over Uganda and Tanzania. This kind of evaluation of other countries would not have been possible using the traditional Jaetzold and Schmidt agro-ecological zone map as their zonation scheme was designed specifically for Kenya and was not applicable in Uganda or Tanzania. Using the description of the resulting 'types' of smallholder from the spatially defined areas in Kenya (details in Table 2.4.5), we sought similar biophysical situations throughout Uganda and Tanzania. The results of that initial extrapolation are presented in Figure3.1-1.

The climatic parameters derived for the Kenya smallholder dairy zones were extrapolated to both Uganda and Tanzania (Figure 3.1-1) using the ACT query tool. The HORT (horticultural) zone is by far the most dominant environmental zone to be projected into both Tanzania and Uganda. However, it was obvious to our local collaborators that there are areas of known major milksheds that are not included in these extrapolation maps. Based on rapid appraisal surveys of the major milksheds, we determined that the Kampala milkshed in Uganda was not identified by the geographic extrapolation of similar zones in Kenya. The northwest side of Mt. Kilimanjoro was detected in the environmental extrapolation to Tanzania. Therefore, we sampled these areas using the ACT for each country and derived a new set of environmental parameters and created two new zonal conditions. Figure 3.1-2 shows the Mt. Kilimanjaro zone for Tanzania in addition to the zones with Kenyan analogues. It is interesting that the 'type' of environment identified from conditions on the slopes of Mt. Kilimanjaro was also found over a fairly large area to the south and west of the actual Kilimanjaro milkshed as well as a zone in the southern highlands of central Tanzania. Knowledge of similar biophysical situations help researchers understand both production and disease constraints (and opportunities).

3.2 Uganda

3.2.1 Spatial Characterization of Smallholder Zones in Uganda

The criteria for spatial stratification in Kenya was applied in Uganda with the addition of the Kampala milkshed and associated environmental constraints. The various smallholder dairy ecologies stratified by disease pressure and population density are provided in Tables 3.2.1.1 to 3.2.1.6. Again, we elected to map only those disease / ecology / population groups with the largest number of people. Figure 3.2.1-1 shows the data for the 'Horticultural' ecology of Uganda, while Figure 3.2.1-2 provides a breakdown of the 'Kampala' milkshed ecology. Tables 3.2.1.3 to 3.2.1.6 provide the data describing the more minor smallholder dairy ecologies of Uganda.

The most compelling characteristic of the Kampala type milkshed ecology is the universally high population density irrespective of the combination of disease pressures. Just 10% of the area of Kampala type ecology has a population density in 1990 of less than 16 persons per square kilometer. This ecological type would seem to be a prime candidate for smallholder dairy investment as the population density would indicate a ready market for fresh milk products.

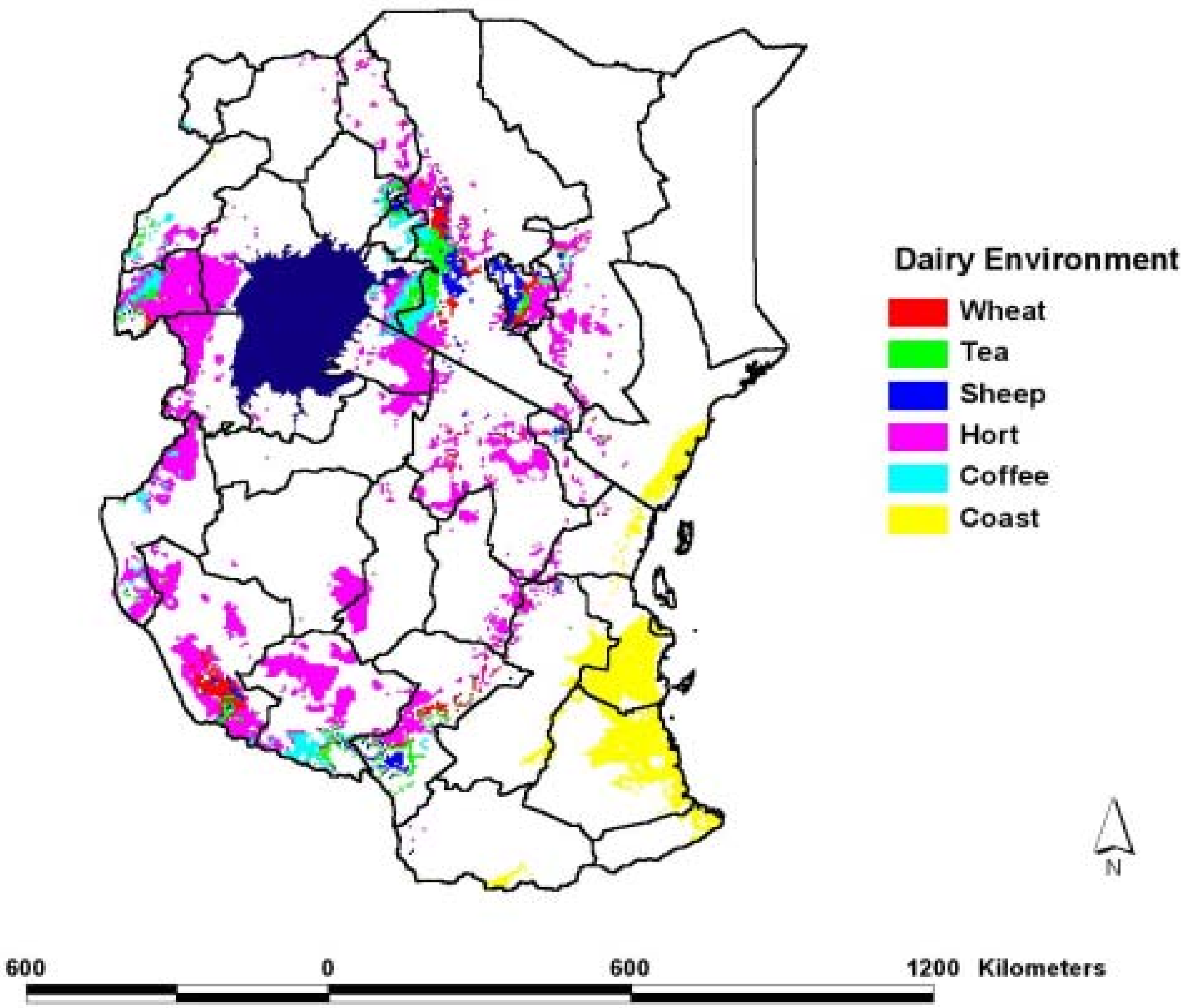


Figure 3.1-1. Extrapolation of Kenya small holder dairy environments to Uganda and Tanzania.

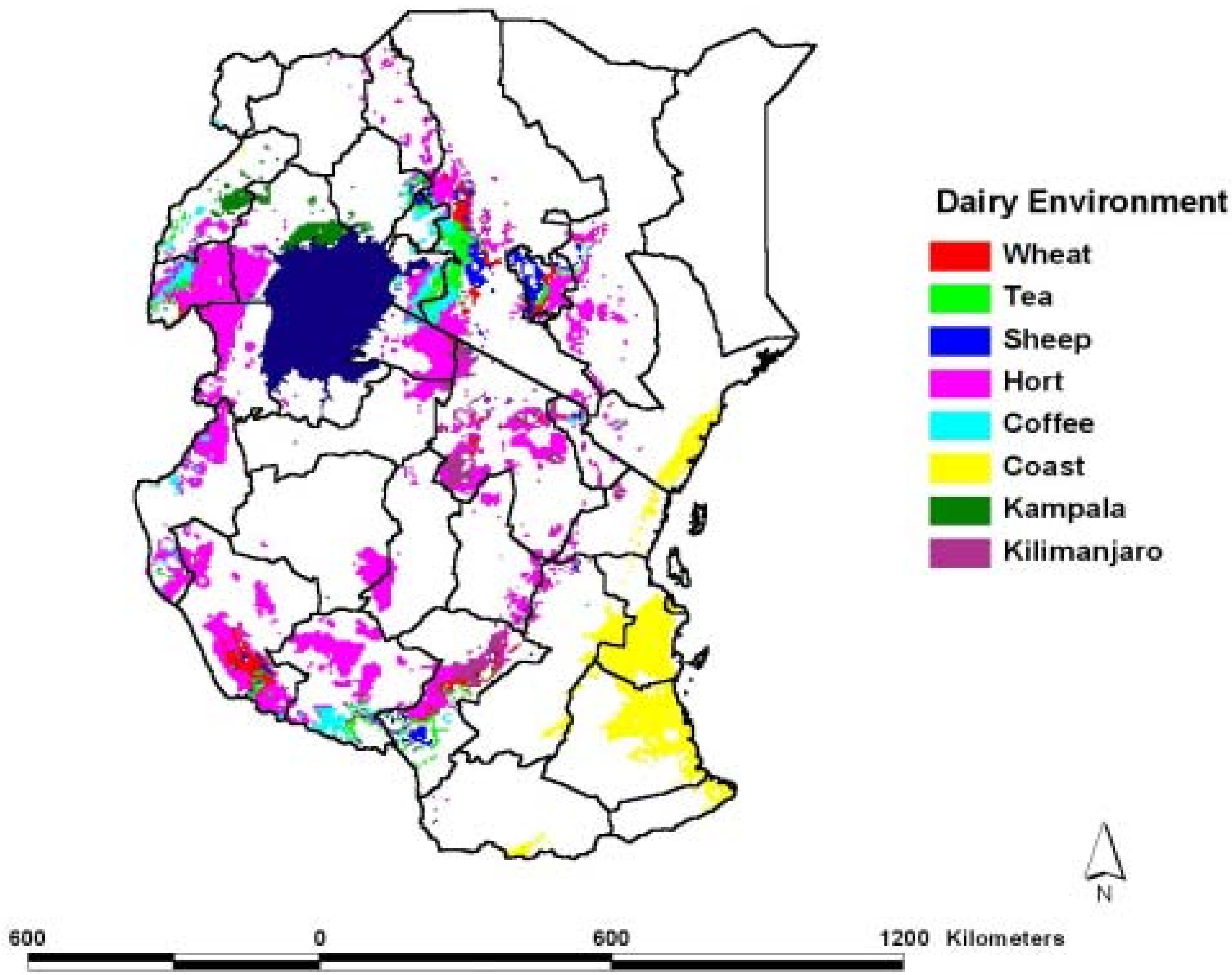


Figure 3.1-2. Characterization of missed dairy environments in Tanzania and Uganda

Table 3.2.1.1: Uganda Horticulture Zone spatial characterization

	Parva (ECF)	Tstete									
Ticks Present?	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?	Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/ (km^2)	Population Density in Areas having >16 people/ (km^2)	Total Area (km^2) with Population <16 people/ (km^2)	Population Density in Areas having <16 people/ (km^2)
Yes	**Antibodies**	**No**	**No**	**No**	**23949**	**2587931**	**20331**	**2567579**	**3618**	**20352**
Yes	**Antibodies**	**Yes**	**Yes**	**No**	**3721**	**263179**	**1814**	**248440**	**1907**	**14740**
Yes	Antibodies	Yes	No	No	376	49984	297	49536	79	448
Yes	Antibodies	No	Yes	No	316	37329	222	36695	93	634
Yes	Antibodies	Yes	Yes	Yes	482	36935	278	35908	205	1028
Yes	Antibodies	No	No	Yes	304	35836	272	35453	32	384
Yes	Antibodies	No	Yes	Yes	288	18682	132	17974	156	708
No	No	No	No	No	971	14863	165	8247	806	6617
Yes	Antibodies	Yes	No	Yes	44	7865	44	7865		
No	Antibodies	No	No	No	220	1584			220	1584
Yes	No	No	No	Yes	15	1508	4	1508	11	0
Yes	No	No	No	No	79	1417	75	1413	4	4
No	No	No	Yes	No	65	64			65	64
No	No	Yes	No	No	12	64			12	64
No	No	Yes	Yes	No	2	5			2	5

Table 3.2.1.2: Kampala Dairy environment spatial characterization

	Parva (ECF)	Tstete								
Ticks Present?	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?	Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/ (km^2)	Population Density in Areas having >16 people/ (km^2)	Total Area (km^2) with Population <16 people/ (km^2)	Population Density in Areas having <16 people/ (km^2)
Yes	Antibodies	No	No	Yes	4134	1642269	3897	1641775	237	494
Yes	Antibodies	No	No	No	1884	225723	1820	225642	63	81
Yes	Antibodies	Yes	Yes	No	1964	96324	1964	96324		
No	Antibodies	No	No	Yes	616	80200	533	80200	83	0
Yes	Antibodies	No	Yes	Yes	216	40558	157	40558	58	0
Yes	No	No	No	Yes	553	39903	149	39903	404	0
No	Antibodies	No	Yes	Yes	115	23576	111	23576	4	0
Yes	Antibodies	Yes	No	No	630	16108	584	15494	46	615
No	Antibodies	Yes	Yes	Yes	37	8977	33	8977	4	0
Yes	Antibodies	Yes	Yes	Yes	82	7147	82	7147		
No	No	No	No	Yes	185	5800	43	5800	142	0
Yes	Antibodies	No	Yes	No	147	3967	118	3938	29	29
Yes	No	No	Yes	Yes	10	2675	7	2675	3	0
Yes	No	Yes	Yes	Yes	27	716	2	716	25	0
No	No	Yes	Yes	Yes	243	1	0	1	243	0
No	No	No	No	No	19	0			19	0
Yes	No	Yes	No	Yes	16	0			16	0

Table 3.2.1.3: Uganda "Coast" type spatial characterization

	Parva (ECF)	Tstete								
Ticks Present?	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?	Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/ (km^2)	Population Density in Areas having >16 people/ (km^2)	Total Area (km^2) with Population <16 people/ (km^2)	Population Density in Areas having <16 people/ (km^2)
Yes	Antibodies	No	Yes	Yes	154	133	4.291	133	150	0

Table 3.2.1.4: Uganda Coffee Zone spatial characterization										
	Parva (ECF)	**Tstete**								
Ticks Present?	**Theileriosis Present?**	**Fusca Present?**	**Morsitans Present?**	**Palpa Present?**	**Total Area (km^2)**	**Total Population Density**	**Total Area (km2) with Population >16 people/ (km^2)**	**Population Density in Areas having >16 people/ (km^2)**	**Total Area (km^2) with Population <16 people/ (km^2)**	**Population Density in Areas having <16 people/ (km^2)**
Yes	Antibodies	No	No	No	1958	386646	1924	386505	34	141
Yes	Antibodies	No	Yes	No	601	78660	568	78548	33	112
Yes	Antibodies	Yes	Yes	Yes	410	41205	363	41004	47	201
Yes	Antibodies	No	Yes	Yes	241	34491	222	34411	18	80
Yes	Antibodies	Yes	Yes	No	336	25880	268	25419	69	462
Yes	Antibodies	No	No	Yes	159	23067	155	23067	5	0
Yes	Antibodies	Yes	No	No	102	17987	101	17977	1	10
No	Antibodies	No	No	No	16	2342	16	2342		
Yes	Antibodies	Yes	No	Yes	9	1370	9	1370		

Table 3.2.1.5: Uganda Sheep Zone spatial characterization										
	Parva (ECF)	**Tstete**								
Ticks Present?	**Theileriosis Present?**	**Fusca Present?**	**Morsitans Present?**	**Palpa Present?**	**Total Area (km^2)**	**Total Population Density**	**Total Area (km2) with Population >16 people/ (km^2)**	**Population Density in Areas having >16 people/ (km^2)**	**Total Area (km^2) with Population <16 people/ (km^2)**	**Population Density in Areas having <16 people/ (km^2)**
Yes	Antibodies	No	No	No	459	71686	385	71,105	74	582
No	Antibodies	No	No	No	67	2314	67	2,314		
No	No	No	No	No	31	398			31	398

Table 3.2.1.6: Uganda Wheat Zone spatial characterization										
	Parva (ECF)	**Tstete**								
Ticks Present?	**Theileriosis Present?**	**Fusca Present?**	**Morsitans Present?**	**Palpa Present?**	**Total Area (km^2)**	**Total Population Density**	**Total Area (km2) with Population >16 people/ (km^2)**	**Population Density in Areas having >16 people/ (km^2)**	**Total Area (km^2) with Population <16 people/ (km^2)**	**Population Density in Areas having <16 people/ (km^2)**
Yes	Antibodies	No	No	No	507	80813	470	80625	37	189
No	No	No	No	No	136	1558			136	1558
Yes	Antibodies	No	Yes	No	18	1549	6	1549	13	0
Yes	No	No	No	No	31	515	31	515		
No	No	No	Yes	No	18	36			18	36

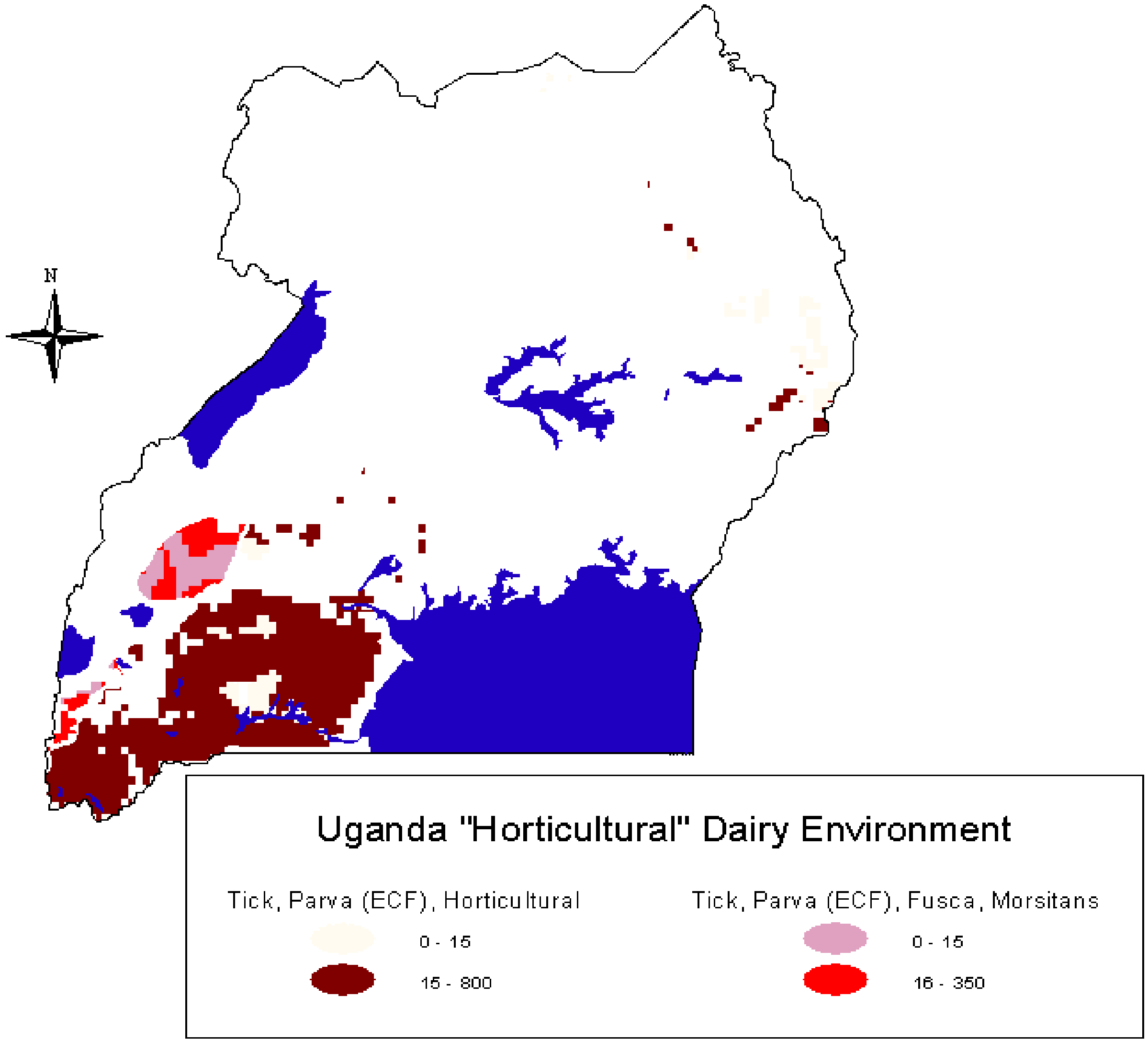


Figure 3.2.1-1. Characterization of the “Hort” dairy environment in Uganda based on disease pressure and population density.

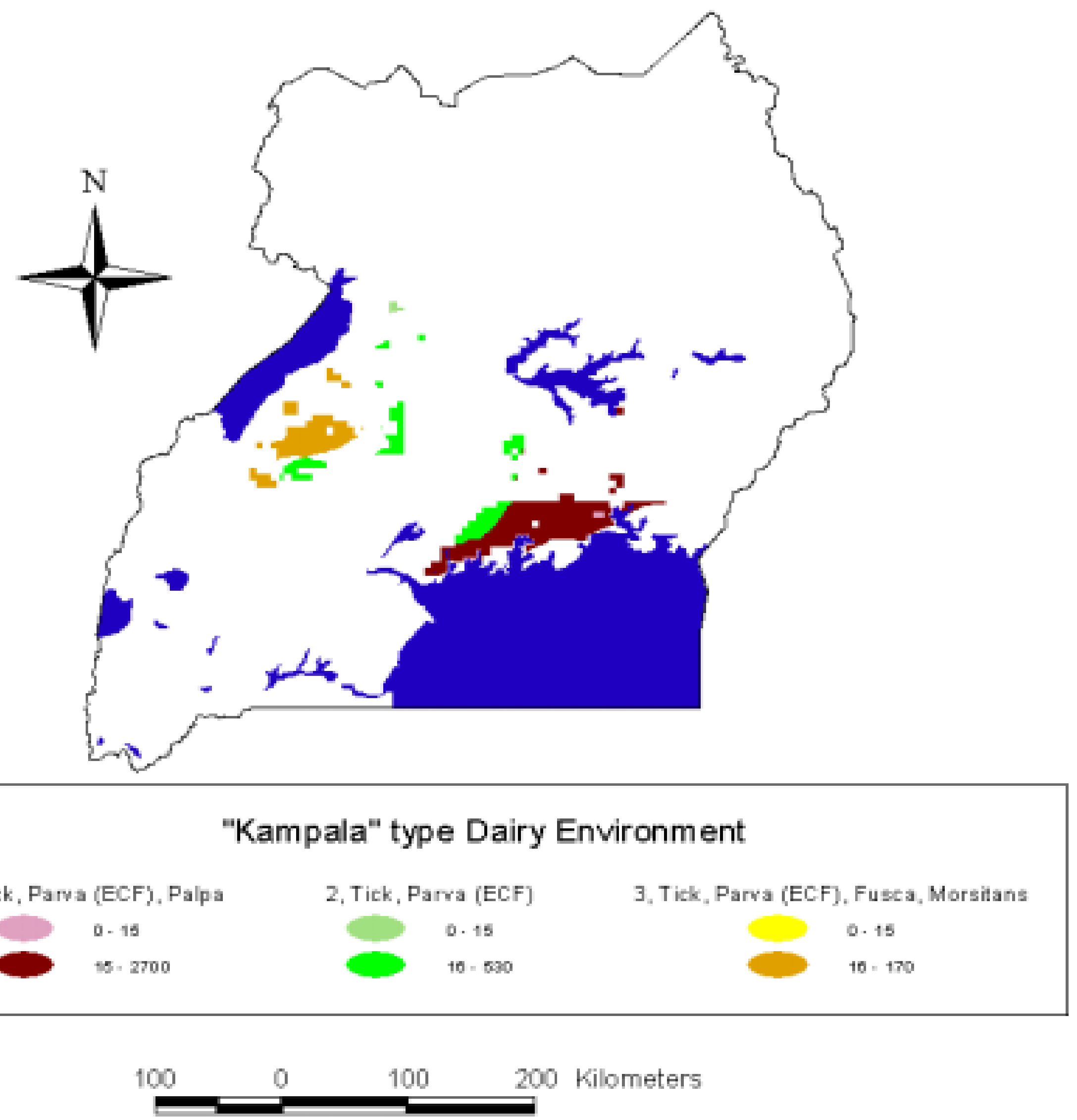


Figure 3.2.1-2. Characterization of the Kampala dairy environment in Uganda based on disease pressure and population density.

3.2.2 Description of the Current Dairy Sector in Uganda

Current annual consumption is 22 liters of milk per person which is well below the FAO recommended 200 liters annual consumption per person. The potential for expansion is high given the natural resources of Uganda. Seventy five percent of the land (18 million square kilometers) could be used for crops or grazing. Currently only 5 million hectares is used for pastures and grazing land (Ministry of Agriculture, Animal Industry, and Fisheries).

There are 5.6 million cattle in Uganda. The Ankole longhorn (Sanga) breed is the most common comprising 50 % of the population. The Small East African Zebu breed follows with 30% of the total population. The Nganda intermediate breed represents 16 % of the total population. The exotic breeds and their crosses make up only 4 % of the total population. Table 3.2.2.1 provides a description of the different breeds and their crosses.

Table 3.2.2.1 Summary of Dairy Performance of indigenous and Exotic Breeds and Their Crosses in Uganda (Ministry of Agriculture, Animal Industry, and Fisheries)

Breed	Calving Interval (days)	Milk Yield (kg.)
East African Zebu	393	618.00
Ankole/Sanga	379	1,450.00
Nganda	420	1,100.00
Jersey	379	2,100.00
Friesian	447	3,000.00
Guernsey	401	2,307.00
Friesian X Nganda	435	2,570.00
Jersey X Nganda	392	1,965.00

Source: Ministry of Agriculture, Animal Industry, and Fisheries

3.2.3 Definition of the Three Production Systems Modeled

The Ministry of Agriculture, Animal Industry, and Fisheries 1997 report on the national breeding policy described the Ugandan dairy systems in Table 3.2.3.1. Three main smallholder dairying systems were studied in the economic model: An old or base technology that includes Ankole or Zebu cattle and grazing, a fenced technology with cross bred or pure bred dairy animals, and a zero grazing technology with purebred dairy cattle and Napiergrass or Kikuyu grass (see Table 3.2.3.2). Three scenarios are considered: old, existing, and new.

Table 3.2.3.1 Description of Ugandan Dairy Systems

Characteristic	Small Farmer Dairy		Commercial Semi-Intensive		Dairy/Beef Ranch	Large Commercial	Rural Subsistence	
	Peri/Intra Urban	Rural Mixed	Peri/Intra Urban	Rural			Communal/ Agro Pastoral	Pastoral
Milking herd	1-2 cows Exotic	2-5 Local	5-10 Exotic	9-15 Exotic/Local	9-15 Exotic/Local	20-25 Exotic	1-2 milking Local	5-10 Local
Priority of Farmer	Sale of Milk	Milk/Meat production Soil Fertility Draught	Sale of Milk	Sale of Milk	Milk/meat production	Sale of Milk Sale of Breeding Stock	Subsistence Milk/meat production draught	Subsistence Milk/meat production livestock numbers
Farmer's Attitude	Cash Income	Spreading of Risk Integration	Cash Income	Cash Income	Cash Income Spreading of Risk	Cash Income	Aversion of Risk	Aversion of Risk
Feed Resources	Cultivated or Purchased Fodder, Concentrate mixtures	Enclosed grazing, improved pastures, crop residues	Enclosed grazing, improved pastures, crop residues, cultivated fodder, concentrate mixtures	Enclosed grazing, improved pastures, Milling by-products & concentrates occasionally	Enclosed grazing	Enclosed grazing, improved pastures, cultivated fodder, concentrate mixtures	Communal grazing, crop residues	Communal grazing
Land Available/animal	0-0.5 hectares	0.5-2.0 hectares	0-0.5 hectares	0.5-2.0 hectares	5.0-10.0 hectares	0.5-2.0 hectares	variable	variable
Major Inputs Used	Concentrates, Fodder, Credit, extension services training, Veterninary Curative & preventative services, hired labor, breeding (AI) services	Extension services training, Veterinary Curative & preventative services, family labor	Concentrates, Credit, extension services training, Veterinary Curative & preventative services, hired labor, breeding (AI) services	extension services, training, Veterinary Curative & preventative services, hired labor, breeding (AI) services	extension services training, Veterinary Curative & preventative services, hired labor, breeding, Credit	Concentrates, Credit, extension services training, Veterinary Curative & preventative services, hired labor, breeding (AI) services	Veterinary Services (mainly vaccinations) , family labor	Veterinary Services (mainly vaccinations), family/communal labor
Milk Surplus Liters/day	18, 10 - 20 continuous	8, 2 - 10 mainly seasonal	106, 100 plus continuous	35, 25-50 continuous	69, 50-100 continuous	208, 200 plus continuous	1, 1-5 continuous	3, 1-10 seasonal

Source: Ministry of Agriculture, Animal Industry, and Fisheries' report, Background to the National Animal Breeding Policy, 1997

Table 3.2.3.2 Dairy Production Systems

Production Characteristics	Zebu Cattle Grazing Indigenous Grass	Cross-breed Cattle Improved Pasture	Dairy Breed, Zero-grazing
Calf rearing method	**7 month suckling**	**7 month suckling**	**16 wk whole milk bucket feeding**
Forage Sources	Kikuyu grass, star grass	Kikuyu grass, star grass	Napier grass (predominantly)
Feeding System	permanent grazing	rotational grazing	
Disease Control	none	dipping	dipping+drenching
Supplementation	none	minerals - 15 kg	minerals - 25 kg; concentrates - 1000 kg
	Production/Cow Unit/Year for Sale or On-Farm Consumption		
Milk (kg)	618	2200	3000
Liveweight Meat (kg)	62	96	97
Surplus heifers	0.1	0.12	0.12
	Forage Requirements/CU/Year		
Dry Matter (kg)	3740	5200	7200
TDN (kg)	1650	2560	3500
DCP (kg)	210	301	420
Labor/CU/Year	**Labor/CU/Year**		
Milking,feeding, young stock rearing (hours)	162	132	123
Forage Production (hours)	168	238	367

3.2.4 Geographic Description of Dairy Zones to Establish Sampling Frames and Comparison to Dairy Zones in Kenya

A spatially explicit, geographic equivalence analysis was used to differentiate homogeneous agricultural climatic zones. This formed the basis for selecting the regions suitable for data gathering and farmer interviews. Uganda is modeled as four regions including: 1) the semi-arid dry North, 2) the semi-arid East, 3) the moist lake, Crescent zone near Lake Victoria (Central), and 4) the semi-arid Western province. Two dairying regions differed in terms of agro-ecological zones from those delineated in the Kenya zones; the lake crescent zone (Central region) and the Western Highlands which include the highly productive stream fed pastures in the Kabale district. Figure 3.2.4-1 provides a description of the cattle densities by region. Note the higher cattle densities in the southern and western regions where higher moisture conditions prevail.

An important part of the process of determining how well the Kenyan dairy technologies can be transferred to Ugandan was to identify which regions of Uganda had similar dairy production potential as Kenya. Figure 3.2.4-2 describes the regions that correspond to similar ecological and economic environments in Kenya.

The concept of geographic equivalence was recognized to be limited to the identification of areas in Uganda and Tanzania that have similar geographic features to those defined in Kenya. The method provides a first

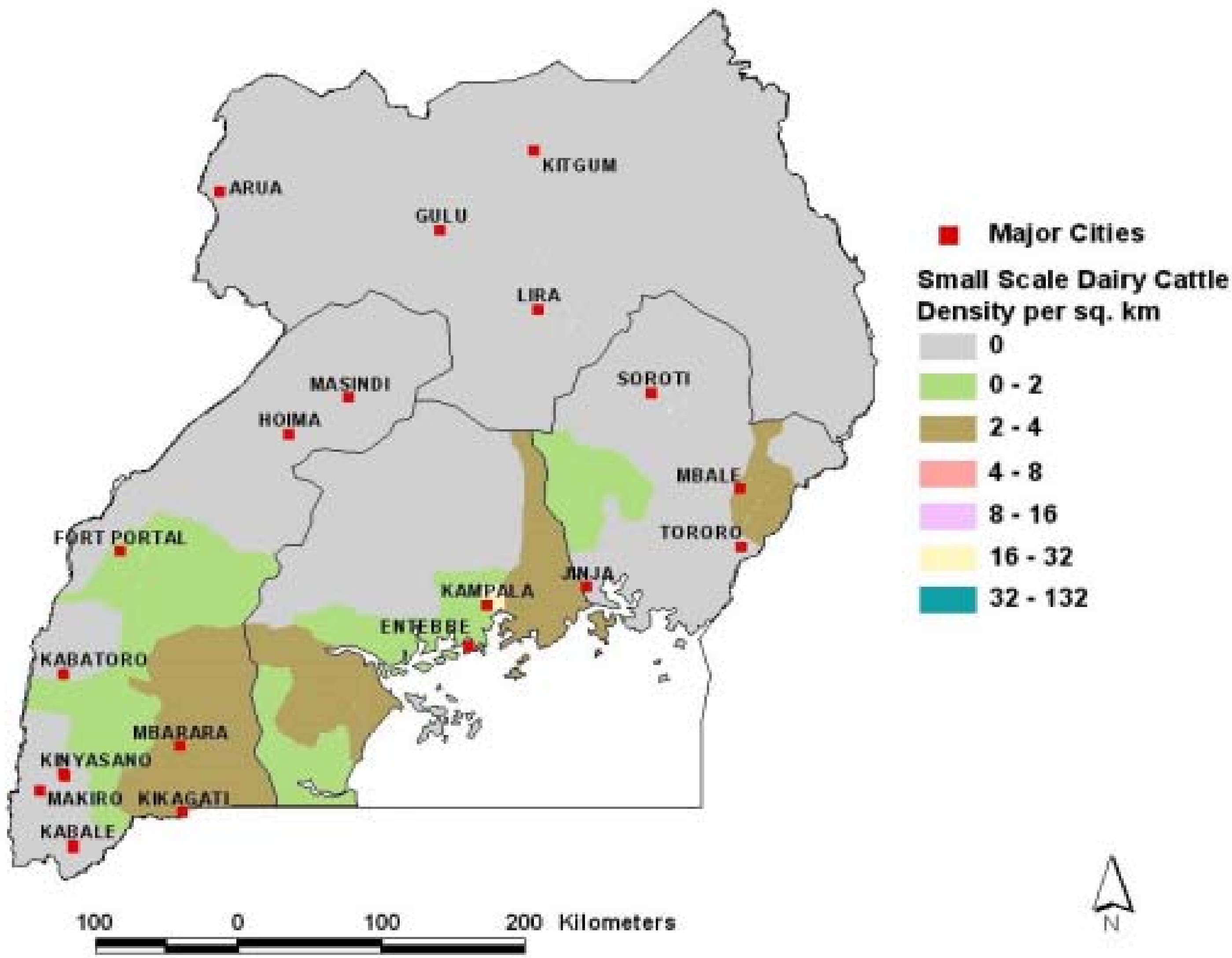


Figure 3.2.4-1. Small scale dairy cattle density (number/km^2) in Uganda.

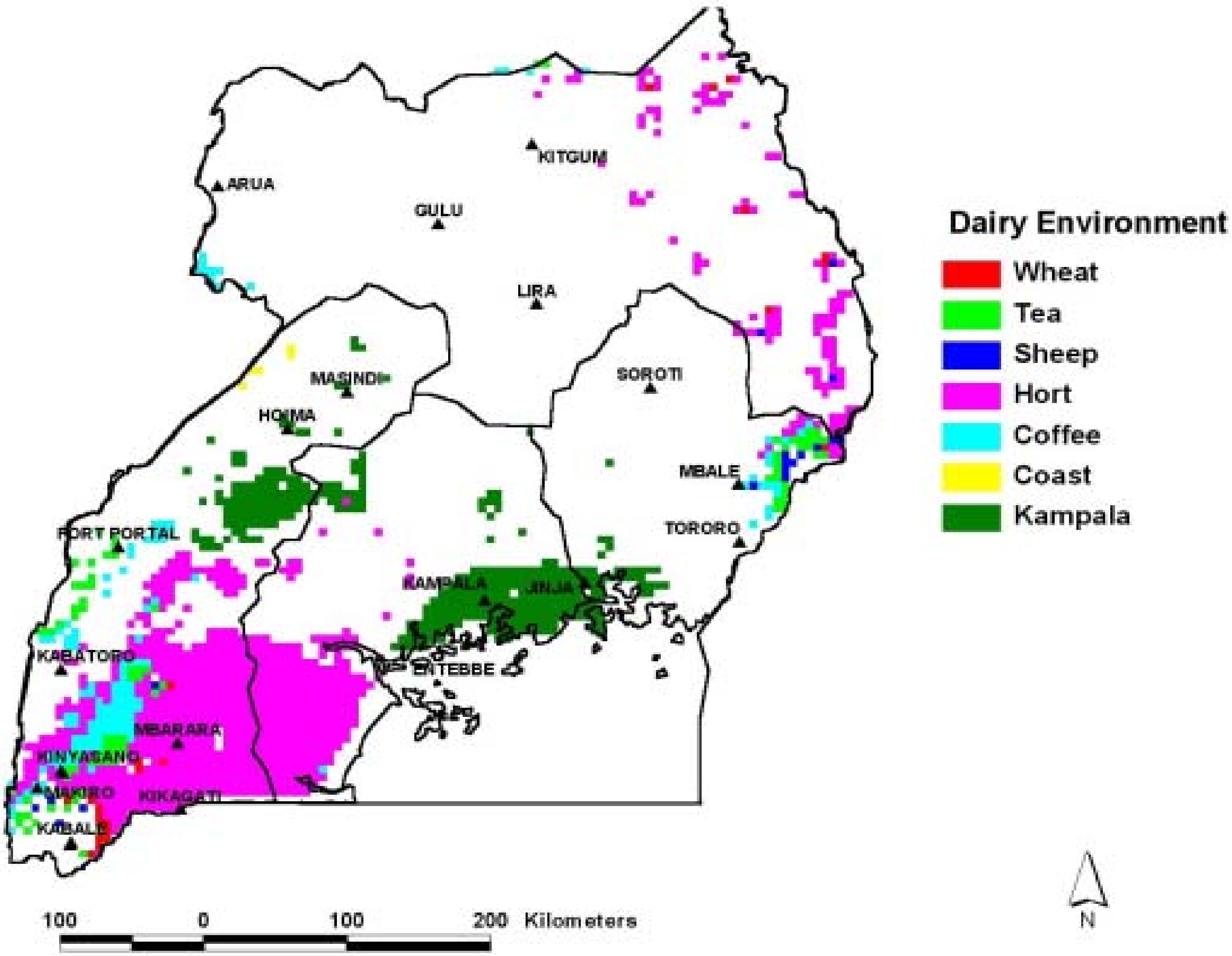


Figure 3.2.4-2. Location of small holder dairy environments in Uganda with similar ecological and economic environments to that examined in Kenya (with the exception of Kampala environment).

order approximation of areas where technology developed and demonstrated in one location might be adaptable to others. The method is not intended to necessarily be highly correlated with the location of actual dairy operations on other locations. This is because there are factors other than geographic equivalence that dictate the presence of dairy operations in places other than where the technology package was evaluated. We recognized that such non-modeled factors as disease and disease vector prevalence would limit the development of dairying in areas that are geographically similar to modeled zones in Kenya. We also recognized that there would be areas where dairying would exist in response to market pressures that overcome limitations in available natural resources. In these limited assessments, we found evidence of these several factors other than geographic equivalence to areas in Kenya that also influence the development and presence of dairying operations in Uganda and Tanzania.

The analysis shown in Figure 3.2.4-2 assisted in identifying the most relevant areas of data gathering by combining smallholder dairy farm activity with the Kenyan equivalent dairy zones. The limit to the methodology is apparent in the inability of the ACT method to identify the highly productive dairy zone in the Kabale district in southwestern district. The methodology did identify the Mbarara region (horticulture in Kenya) in southwestern Uganda as a major smallholder dairy zone under a horticulture environment. More detailed study showed that the region is comprised of pastoral and extensive dairy producers. However, the area is too dry for intensive dairy production. These exceptions verify that on-ground expertise is essential to add to other relevant variables for a more complete geographical extrapolation across regions to properly characterize production zones. The Kenya extrapolation did capture a great deal of the environmental characteristics and provided a useful tool for making an initial assessment of the appropriate target areas for stratification and selection of representative farms.

Overlaying the cattle density (Figure 3.2.4-3) with similar agriculture zones and road networks (Figure 3.2.4-4) provided a means of identifying which areas of potential development have a high probability of successfully linking into the national dairy marketing system (Figure 3.2.4-4). Further refinements in the production zones were possible using this “trimming” method to better represent actual production zones for smallholder dairying.

3.2.5 Defining Yields from Biophysical Models

After identifying the potential areas of dairy production, regional forage production profiles of existing and potential (new) adoption were modeled to link climatic clusters to provide a geographic identity to areas suitable for production of Napiergrass for forage. Representative farms were selected for intensive survey and characterization of biophysical conditions and livestock/crop enterprises. PHYGROW, a biophysical forage production model, provided the estimates of variation in forage yields and feeding values for each of the Ugandan agro-ecological zones using the conditions observed on the stratified representative farms. The various breeds of cattle used in smallholder dairying were then input into the NUTBAL nutritional balance analyzer to determine the annual crude protein requirements, net energy requirements and dry matter intake reflecting temporal changes in forage quality, environmental conditions and animal physiology. These values were used to produce enterprise budgets and agricultural sector analyses for the assorted production systems in each agro-climatic zone. In addition, many of the major crops grown in Uganda were biophysically simulated with the Environment Policy Integrated Climate (EPIC) model for each of the major production zones as characterized by management practices noted in the representative farms. Nine crops were included in the model: cotton, millet, maize, sorghum, rice, bananas, beans, groundnuts, and simsim.

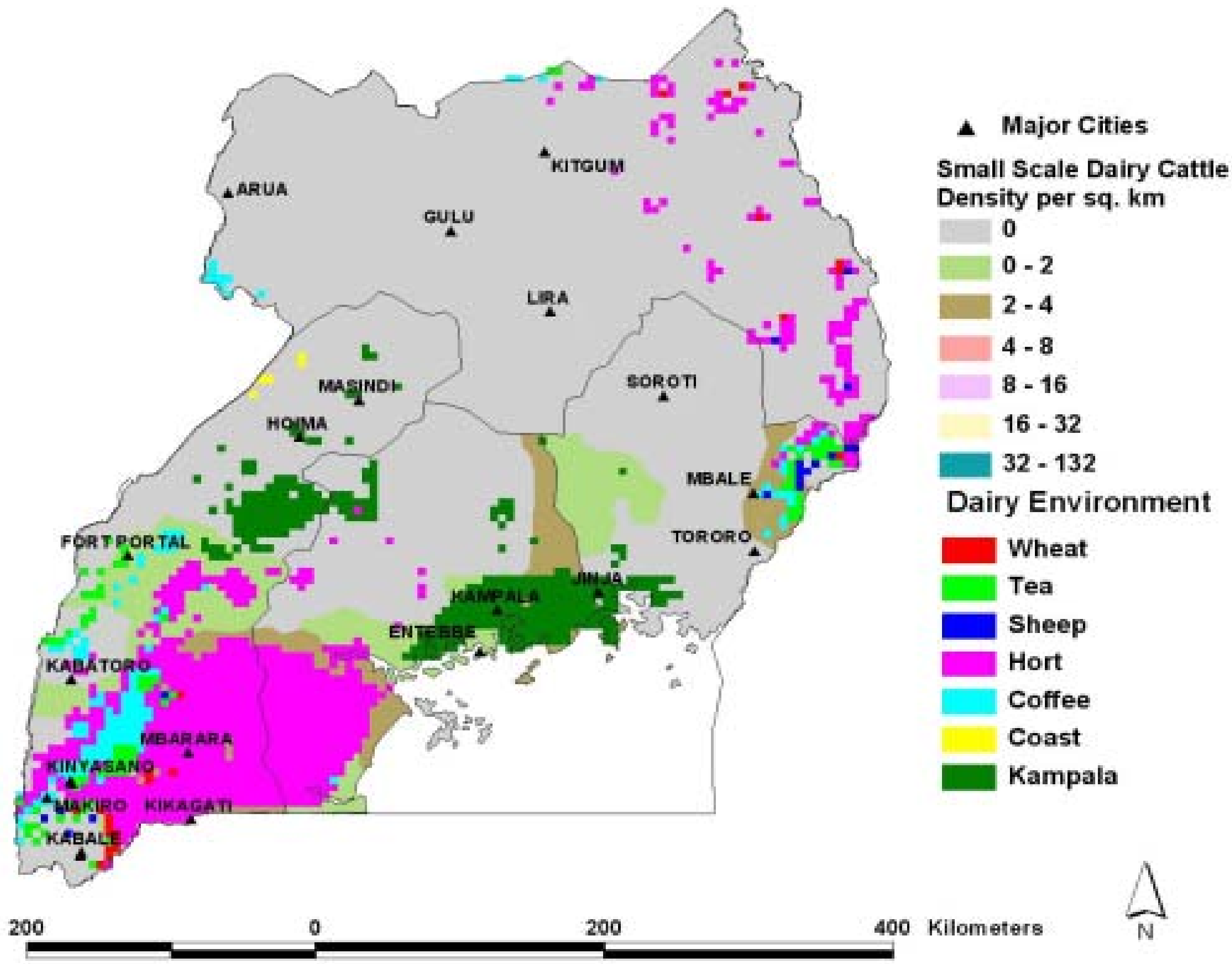


Figure 3.2.4-3. Comparison of Almanac Characterization Tool (ACT) derived small holder dairy environments in Uganda with small scale dairy cattle densities at the regional level.

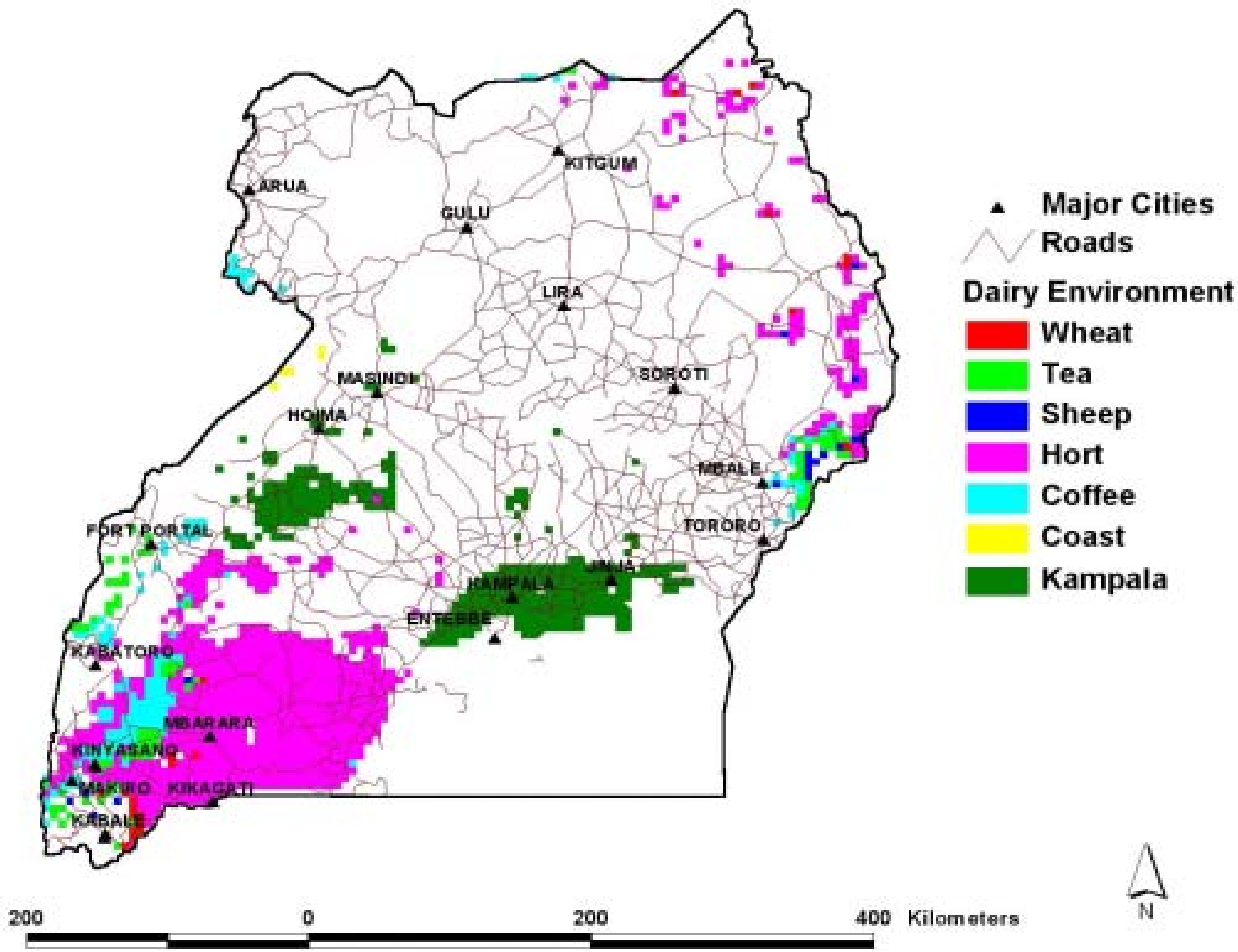


Figure 3.2.4-4. Location of major roads and Almanac Characterization Tool (ACT) derived small holder dairy environments in Uganda.

3.2.6 Economic Impact of Smallholder Dairy Technology in Uganda - Agricultural Sector Model

The purpose of this research was to assess the economic impact of transferring the smallholder dairy intensive zero grazing system and adoption of improved breeding stock now available in Kenya to Uganda. Only mean yields and responses are used in this section.

To perform the macro economic analysis, an agricultural sector model (ASM) for Uganda was developed to estimate the past economic impacts from the adoption of smallholder dairy technologies as well as the potential future impacts of the full adoption of these technologies. Full adoption is defined to be the maximum percentage of herds on dairy farms in each region that would use smallholder dairy technologies. Full adoption does not imply one hundred percent of the producers will adopt the new technologies. Table 3.2.6.1 provides the expected adoption rates by technology, region, and scenario as specified by expert opinion of Ugandan researchers and extension personnel. The maximum adoption rates reflect the best estimate of the maximum percent of producers that will use this suite of technologies.

The Ugandan ASM provided national equilibrium prices and quantities for milk and other commodities resulting from each dairy technology scenario. Equilibrium prices were later used at the farm level to examine income, economic success and risk characteristics of the representative farms in Uganda.

Table 3.2.6.1 Technology Adoption by Region and Scenario

Region and Scenario	Grazing	Fenced	Zero Grazing
Old Northern	100	0	0
Old Eastern	100	0	0
Old Central	100	0	0
Old Western	100	0	0
Existing Northern	97	3	1
Existing Eastern	60	35	5
Existing Central	40	50	10
Existing Western	50	45	5
New Northern	60	15	5
New Eastern	55	40	5
New Central	53	35	12
New Western	45	48	7

3.2.6.1 Results of the ASM Analysis of 3 Smallholder Production Systems

Subnational regional production of crops changed very little from adoption of the improved dairy technologies. Production of maize, robusta and Arabica coffee in the Northern Region each declined by about 1.6% under the existing adoption scenario relative to the old technology scenario. Most other crops had little (0.5% or less) or no change in production. Quantity of milk produced changed significantly among regions (refer to Figures 3.2.6.1-1 and 3.2.6.1-2).

The Central Region produced 47,000 metric tonnes (MT) less milk under the old technology scenario than the existing adoption scenario. The adoption of new technologies resulted in a slight increase in milk production of 2,192 MT in the Central Region's full adoption scenario compared to the existing adoption scenario. In the Eastern province, milk production for the old technology scenario was 2,335 MT less than for the existing adoption scenario. Milk production declines by 13,343 MT under the full adoption scenario relative to the existing adoption scenario. The Northern Region produced 17,343 MT more milk under the old technology scenario than the existing adoption scenario. Production increased, however, in the full adoption scenario by 7,365 MT over the existing adoption scenario. The Western Region produced 3,718 MT less milk under the old technology scenario than the existing adoption scenario. Under the full adoption scenario milk production increases by 14,270 MT relative to the existing adoption scenario. Only the Eastern Region is forecast to reduce milk production as the improved dairy technologies become fully adopted in Uganda.

The shift from traditional to improved smallholder dairy technology under existing adoption rates in Uganda resulted in increased national economic welfare of 21.962 billion Uganda shillings. Urban consumers benefitted by almost 3.0 billion shillings. However, producers and their families gained most from the introduction of the new technology, about 19 billion shillings annually. Full adoption of the dairy technologies would be expected to add 2.031 billion Uganda shillings to the national economic welfare above the existing adoption scenario with the gains about equally shared between urban consumer and rural producers and families. Milk production would increase 1.02 percent, or about 0.43 liter per person. Table 3.2.6.1.1 shows changes in consumer and producer surplus, foreign trade, home consumption benefits, and total economic welfare from adoption of the improved smallholder dairy technologies.

Table 3.2.6.1.1 Summary of Welfare Changes in Uganda With the Introduction of Existing and Future Adoption Rates of Improved Technologies (In Billions of Uganda Shillings).

	Total	Consumer	Foreign	Rural House Hold	Producer Surplus
Existing	21.962	2.960	-0.054	8.796	10.261
Future Adoption	2.031	1.081	0.000	0.710	0.240

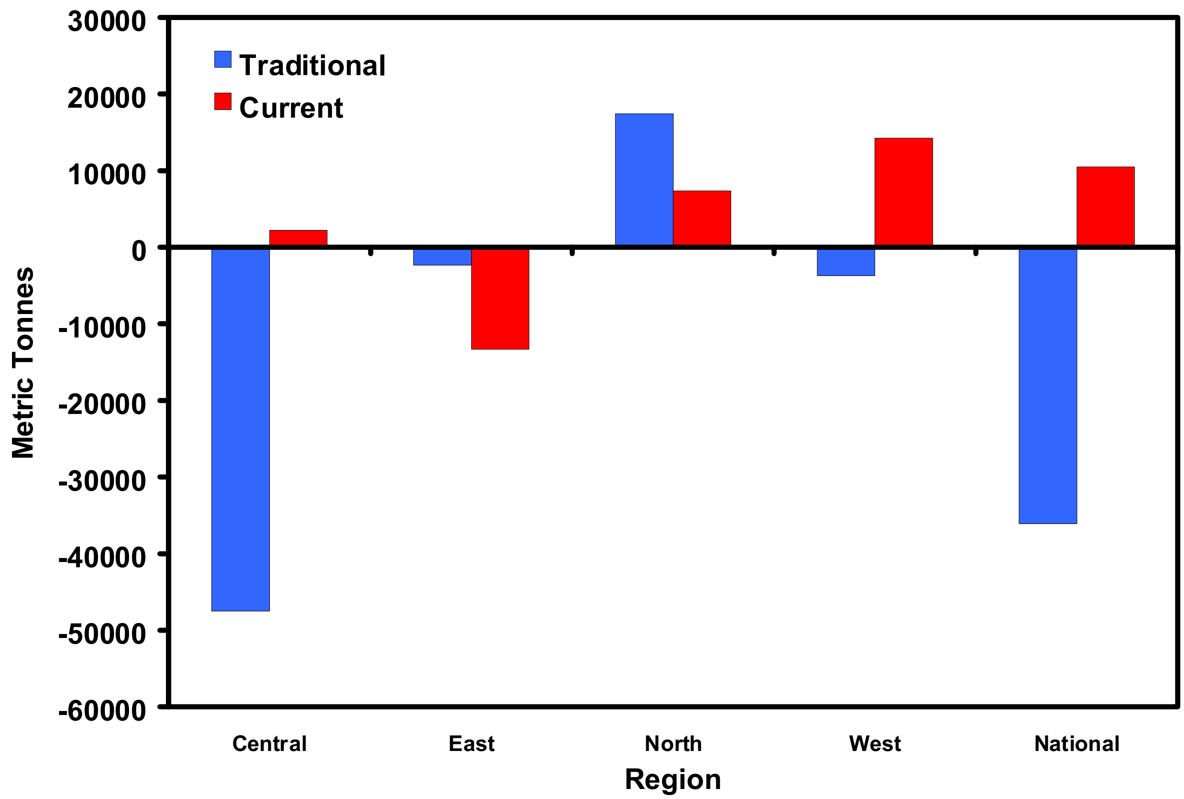


Figure 3.2.6.1-1: Changes in milk production (metric tonnes) by region in Uganda resulting from the adoption of small holder dairy technology.

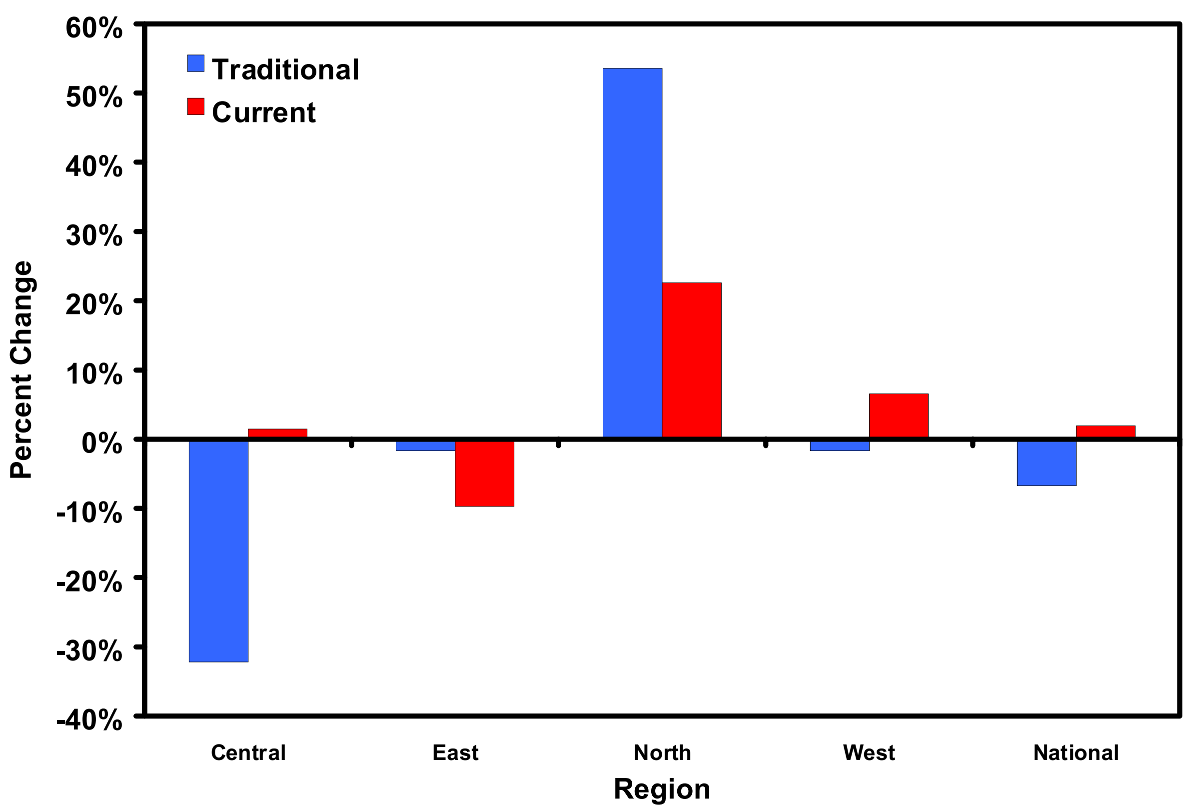


Figure 3.2.6.1-2: Percent change in raw milk production by region in Uganda resulting from the adoption of small holder dairy technology.

3.2.6.2 Potential Impact of Large Scale Dairy Production

A number of aid agencies have participated in promoting rehabilitation and improvement of the Uganda dairy sector including the UNDP, a division of the United Nations Food and Agriculture Organization, the World Food Program, the World Bank, the African Development Bank, and the Danish Aid agency, DANIDA. Since 1994, the Land O'Lakes private sector dairy development project has also assisted. The goal of these public and private institutions is to develop a modern commercial Uganda dairy sector (ILRI).

Part of a modernization strategy for the Uganda dairy sector is growth in large scale commercial dairy enterprises. The Uganda ASM was used to examine the potential economic impacts of the improved smallholder dairy technologies in the presence of a large scale commercial dairy subsector. Milk produced by the commercial sector was treated exogenously in the ASM for this set of scenarios. Percentage increase in herds, numbers of pure bred dairy cattle and production cost per animal for the large scale commercial sector by milk producing region are given in Table 3.2.6.2.1.

Table 3.2.6.2.1 Assumed Pure Bred Dairy Cattle Increase in Large-Scale Commercial Dairy Scenario by Region.

Region	Percent Increase	Number of Animals	Cost of Production Per Animal (USH)
Central	5 %	14,399.00	91,837.00
Eastern	3 %	11,663.00	218,457.00
Northern	1 %	1,440.00	257,417.00
Western	2 %	12,383.00	228,197.00

Production costs for the large scale commercial dairies were estimated at 40% of the cost per animal for the zero grazing dairy technology in each region. The base scenario is the current mix of smallholder dairy technologies without a large scale commercial dairy subsector. Two alternative scenarios were considered: scenario 1 with milk yields for large scale commercial dairies 120% greater than milk yields for smallholder zero grazing dairies, and scenario 2 with milk yields equal in both subsectors. Both scenarios assume milk demand is constant at the base scenario level. Table 3.2.6.2.2 gives expected change in total milk production and raw milk price in the smallholder dairy subsector with existence of a large scale commercial dairy subsector. Milk production from smallholder dairies would decline from the current adoption base scenario by 11.41% and 10.63% in scenarios 1 and 2, respectively. Raw milk price would be 16.10% and 15.97 % lower due to competing supplies in the Uganda milk market from large scale commercial dairies. Labor and land used in smallholder dairy production would be little affected, changing by 1% or less for each scenario. Animal numbers in smallholder dairies would decline proportionately by percentages equivalent to the decrease in milk production for each scenario. (Table 3.2.6.2.3).

Welfare implications of the growth in large-scale commercial dairy subsector would be a reduction in smallholder dairy producer surplus. Rural households would benefit substantively more through reduced food costs than the reduction in producer surplus, resulting in an increase in welfare for rural families. Urban consumers also benefit from the expanded output and reduced price of milk. Total welfare increases by over 30 billion Uganda shillings for both scenarios (Table 3.2.6.2.4).

Table 3.2.6.2.2 Change in Milk Production and Price in Smallholder Dairy Sector Due to the Introduction of A Large-Scale Dairy Enterprise Sector

Scenario	Large Scale Production	Small Holder Milk Production (1,000s liters)	Percentage Change in Small Holder Milk Production	Milk Price (USh)	Percentage Change in Milk Price
Base	0.00	425,564.70	---	486.34	---
Scenario 1	91,214.61	377,022.60	(-11.41)	408.04	(-16.10)
Scenario 2	82,922.37	380,322.20	(-10.63)	408.65	(-15.97)

Table 3.2.6.2.3 Change in Ugandan Smallholder Labor and Dairy Cattle Due to the Introduction of A Large-Scale Dairy Sector

Scenario	Percent Change In Labor Allocated to Dairy Small Holder Activity	Percent Change In Land Allocated to Dairy Small Holder Activity	Percent Change in Small Holder Dairy Cattle Numbers
Scenario 1	(-1.06)	(-0.21)	(-11.41)
Scenario 2	(-0.99)	(0.19)	(-10.63)

Table 3.2.6.2.4 Change in Welfare Due to the Introduction of a Large-Scale Commercial Dairy Sector in Millions of Uganda Shillings

Scenario	Total Welfare	Consumer Surplus	Rural Household	Producer Surplus
Scenario 1	31790.80	16992	1609.3	-1321
(% Change)	(0.36)	(0.21)	(-8.33)	(-0.13)
Scenario 2	30442.3	17976.3	15967.1	-3529.5
(% Change)	(0.35)	(0.23)	(-8.26)	(-0.35)

3.2.7 Economic Impact of Smallholder Dairy Technology in Uganda at the Farm Level (East Africa Farm Level Economic Methodology and Analysis)

To address technology impact at the household level, farms were selected in two broad agro-ecological zones, Kampala and Highland. The Kampala zone was delineated as a "new" region with a substantial milkshed that was not delineated with the Kenya agro-ecological extrapolation. Since the "Horticultural" zone and Kenya dominated the landscape where dairying occurred outside of the Kampala milkshed, all Kenya extrapolations were "lumped" and farms assigned to a "Highland" zone.

A rapid rural appraisal of farms in existing surveys of NARD and Land 'O Lakes was made and six farms selected: Kampala-fenced, Kampala-zero grazing, Highland-fenced, Highland-zero grazing, Kampala-traditional, and Highland-traditional. A cluster analysis similar to that performed in Kenya was used to select farms by ecological strata and farm type.

The old, or base traditional technology, was continuous permanent grazing of indigenous grass with Ankole or Zebu crossbred cattle. Improved technologies included a fenced system with Ankole-Friesian crossbred animals in the highland region and Ankole breed in the Kampala zone with rotational grazing of improved indigenous grass pastures. Zero-grazing in both the Highland and Kampala zones were represented by a Friesian dairy cow fed Napiergrass or Kikuyu grass in a confined feeding system.

Farm size in Uganda was more variable than in Kenya (Table 3.2.7.1). Cropland available ranged from 0.81 to 8 hectares. Pasture land ranged from 0.00 hectares in the peri-urban zone (Kampala-zero grazing) of Kampala to 875 hectares in the rural areas of Kampala (Kampala-traditional). Annual milk yields are higher in Uganda than in Kenya. The lake crescent zone near Lake Victoria encompasses Kampala and its environs, with higher moisture than for areas further removed from the lake. Pastures in this area are more

Table 3.2.7.1 Uganda Representative Farms Profile Under Current Conditions

Variables	Highland/ zerograzing	Highland Frenced	Kampala/ zero grazing	Kampala/ fenced
Latitude	-1.34370	-1.21823	0.33957	0.17003
Longitude	30.01293	29.96008	32.66652	31.64660
District	Kabale	Kabale	Mpigi	Mpigi
Crop Hectares	2.00	2.00	0.81	8.00
Grass Land* Hectares	0.00	12.24	0.00	875
Cattle Type Current Technology	Friesian	Friesian	Friesian	65% Boran 35% Boran./Ankole cross
Current Mean Milk Yields kg./Cow	3434	2112	3184	480
Number of Dairy Cows	1	12	1	50
Cattle Type Old Technology	Ankole Friesian Cross	Ankole Friesian Cross	Ankole Friesian Cross	Ankole
Traditional Mean Milk Yields Kg./Cow	965	593	894	261

Source: Kaitho

productive. Also, the highland zone of Uganda near the Rwandan border has highly productive stream fed pastures.

3.2.8 Results From Farm Level Analysis

In the Ugandan farms studied, the net present value under the current or improved technology increased for all farms except the Highland zero grazing farm compared to the old technology. This was most apparent for the highland fenced producer whose expected net present value for the ten-year horizon increased by 69% (see Table 3.2.8.1). The gains in net present value were negative for the Highland zero grazing unit which declined by -0.93%, the Kampala zero grazing increased NPV by 86.4%, and the Kampala fenced farm's net present value increased by 41.2%. All farms total cash receipts increased. In percentage terms the increases ranged between 38 to 71 %. Total cash costs increased on the two zero grazing farms by 51.3% for the Highland enterprise and 24.0% for the Kampala unit. Costs rose for the Highland fenced unit by 7.8% and 19.3% for the Kampala fenced farm. In these two enterprises the net farm income is positive under both scenarios. The increased feed and maintenance costs associated with the current technology result in increased costs for the producer relative to the old technology (dairy breeds with zero grazing and Napiergrass versus extensive non-fenced dairying on native pastures).

Table 3.2.8.1 Uganda Representative Farms Mean and Standard Deviations of Net Present Values, Total Cash Receipts, Total Cash Costs, Net Cash Farm Income, and Real Net Worth Under the Base (old) and Current Smallholder Dairy Technology in 1,000,000's Uganda Shillings

Farm Type	Net Present Value		Total Cash Receipts		Total Cash Costs		Net Cash Farm Income		Real Net Worth	
	Old	Current	Old	Current	Old	Current	Old	Current	Old	Current
Highland 0 grazing	-6.44[*]	-6.50 (-0.93)[+]	0.98	1.57 (60.20)	1.15	1.74 (51.30)	-0.17	-0.18 (5.88)	-5.48	-5.51 (0.55)
	2.23[**]	3.14	0.103	0.103	0.391	0.391	0.329	0.331	4.974	4.995
Kampala 0 grazing	-6.19	-0.84 (86.4)	1.15	1.97 (59.04)	1.19	1.48 (24.37)	-0.04	0.5 (400)	9.79	12.35 (26.15)
	2.31	4.42	0.057	0.074	0.387	0.257	0.339	0.205	4.957	3.273
Highland Fenced	76.48	129.26 (69.01)	7.52	11.96 (71.30)	1.02	1.1 (7.84)	6.5	10.86 (67.08)	84.13	109.83 (30.55)
	7.34	11.78	0.297	0.495	0.000	0.000	0.297	0.493	20.764	36.383
Kampala Fenced	130.48	184.18 (41.16)	12.94	17.96 (38.79)	3.01	3.59 (19.27)	9.93	14.37 (44.71)	175.89	201.83 (14.75)
	33.01	45.65	1.038	1.398	0.007	0.008	1.034	1.396	37.441	53.890

[+] Number in the parenthesis represents the percentage change between the old and current scenario
[*] Mean in 1'000,000's of Uganda Shillings (Ush)
[**] Standard deviation

Net cash farm income remained negative for only the Uganda highland zero grazing unit. The highland zero grazing units negative net farm income declined by 5.9%. In the other three farms net farm income increased between 44.7 to 125%. The real net worth increased for all farms except in the case of the Highland zero grazing unit which declined by .6%. In the other farms the percentage change in real net worth ranged between 14.8% to 30.6%.

The Kampala zero grazing farm produced a positive net farm income. Both the Highland fenced and Kampala fenced farms had positive net farm incomes over the 10 year planning horizon. The fenced operations had relatively lower costs per animal than their zero grazing counterparts. The same pattern is observed in the Kampala region where the Kampala zero grazing producer's labor costs are higher than the Kampala fenced producer's costs.

The highland zero grazing animal produced 792,000 Ush/cow worth of milk. The highland fenced animal produced 439,200 Ush/cow worth of milk. The Kampala zero grazing enterprise produced 1,340,640 Ush/cow. The Kampala fenced unit produced 171,600 Ush/cow. Each zero grazing enterprise had one cow whereas the highland and Kampala fenced farms had 12 and 50 cows respectively.

Figures 3.2.8-1 to 3.2.8-10 compare the average results of the five economic variables discussed under the old and current scenarios. Figures 3.2.8-11 to 3.2.8-15 describe the distribution of the variables under the two scenarios for Uganda Kampala fenced representative farm as an example.

3.2.9 Summary and Interpretation

Similar to the Kenyan dairy producers the representative Ugandan dairy producers are able to generate positive net farm incomes on an annual basis. The only farm type not obtaining a positive net income was the Highland zero grazing enterprise. The production declined in regions (Northern) that were less competitive relative to other dairy zones and increased in regions more conducive to dairy production in proximity to urban populations. The zero grazing technology with its increased costs was not competitive in the Western highlands though production in the region increased in the ASM analysis. In the Kampala region with its urban population, the price for milk is greater and allows the peri-urban zero grazing unit to operate on a sustainable basis.

When forage and associated crop yield variation and historical milk yield of these farms are introduced as stochastic information in the farm-level analysis, risk associated with adoption of these improved technologies can be assessed. Only the Kampala fenced representative farm had a 100% probability of obtaining a positive net farm income under the traditional technology and the improved technology. The Highland zero grazing farm had a 0.75 probability of obtaining a positive net cash farm income under both technology scenarios. The Kampala zero grazing farm experienced an increase in the probability of obtaining a positive net farm income from 0.45 under the traditional technology to 1.0 under the current adoption improved technology. Although the probability of economic success increased on the Highland fenced farm, it exhibited only a 47% chance of producing a positive net cash farm income with adoption of the improved dairy technologies.

The ASM model indicates that zero grazing could be adopted in more rural regions. However, Table 3.2.6.1, describing the expected adoption level of zero grazing suggests that only 5% of the total dairy producers in the Western province would use this system based on expert opinions. Investments in cross-fencing with some strategic infusion of improved grass and upgrading Ankole cattle with Friesian dairy breeds appears to be the most viable means of improving producer welfare and meeting urban demands for milk. However, expansion of the apparently more viable commercial dairying near peri-urban centers will place even greater economic pressures on the less variable farm-types in both the Highland and Kampala regions of Uganda. Seeking the right balance between investments in smallholder fenced systems and fostering the commercialization of dairying will be the challenge for policy makers in Uganda.

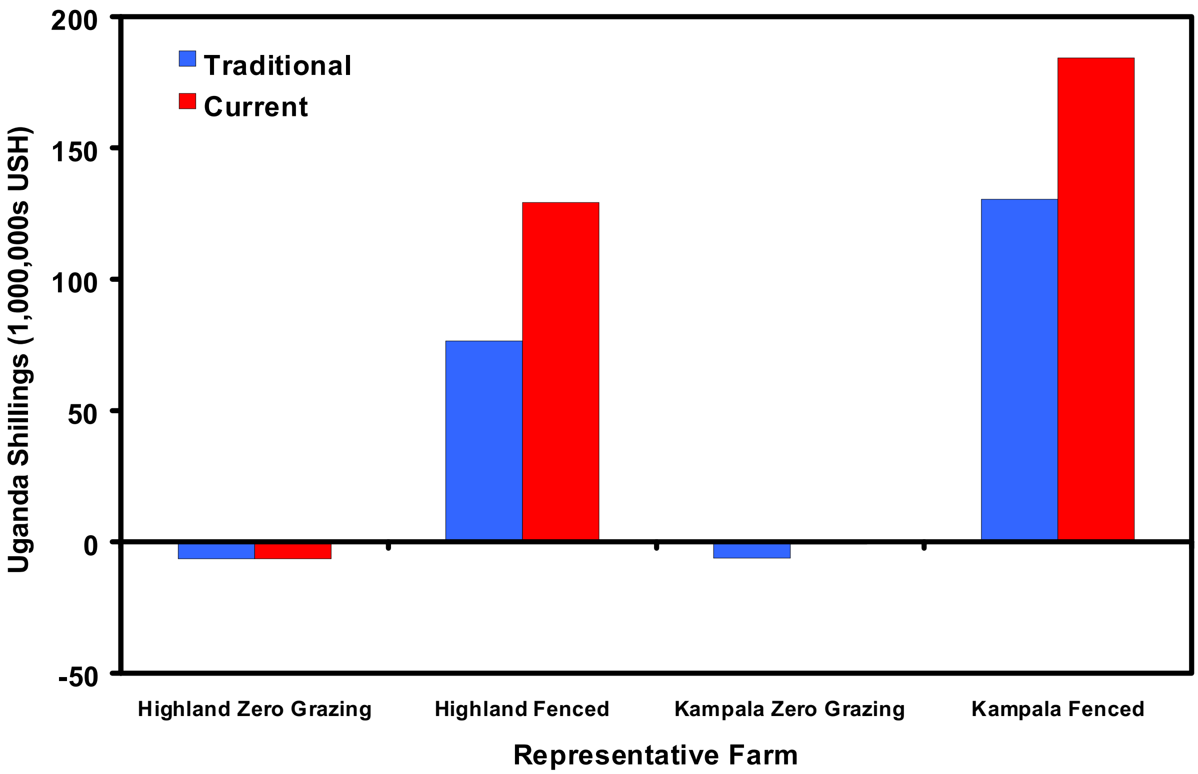


Figure 3.2.8-1. Net present value (NPV) for Ugandan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

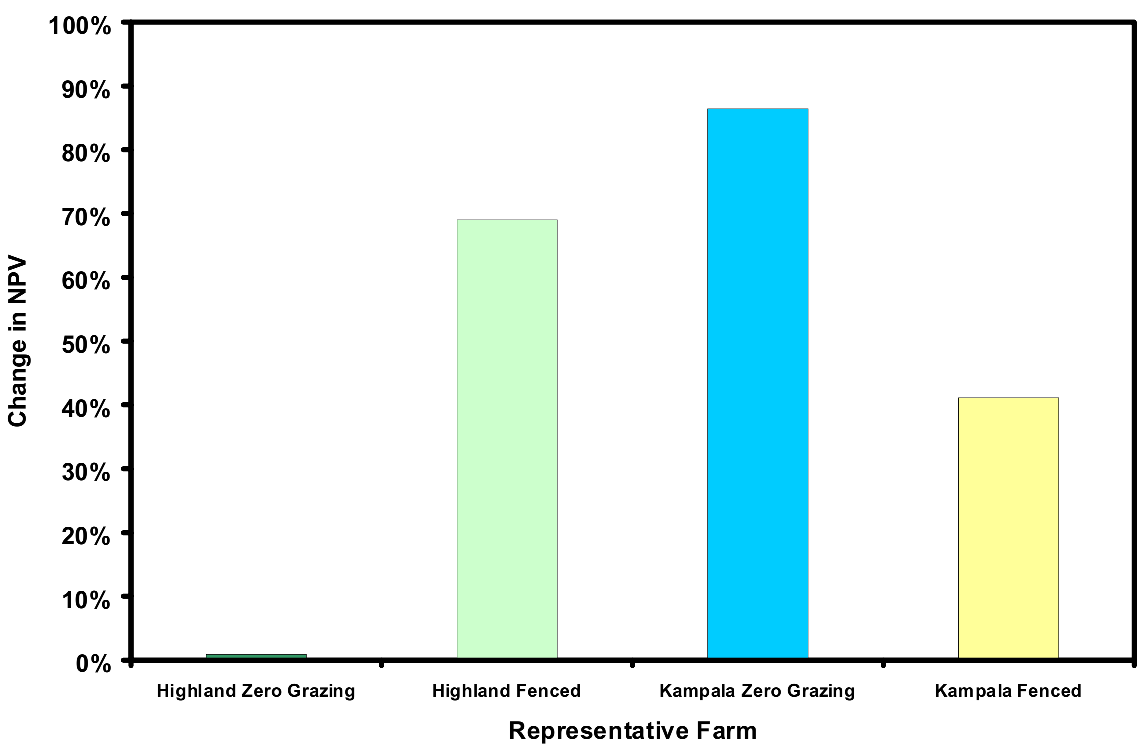


Figure 3.2.8-2. Percentage change in net present value (NPV) for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in four dairy environments in Uganda under the stochastic scenario.

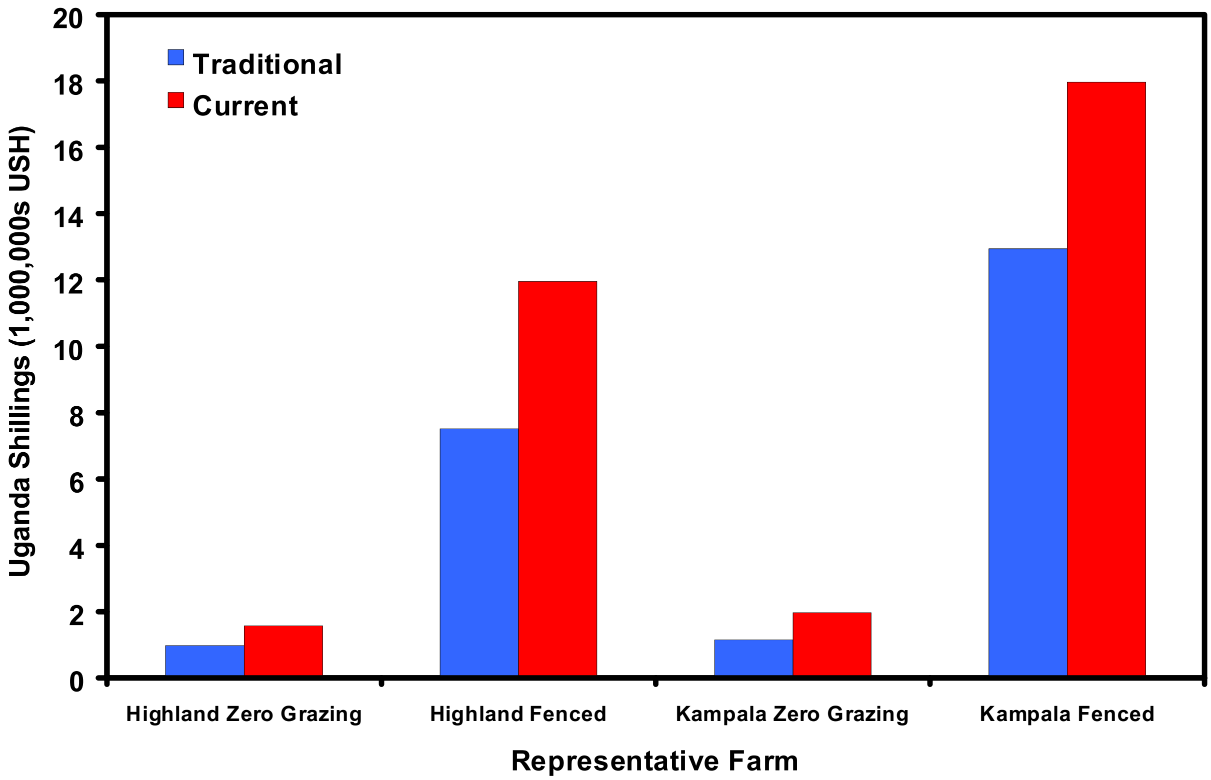


Figure 3.2.8-3. Total cash receipts for Ugandan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

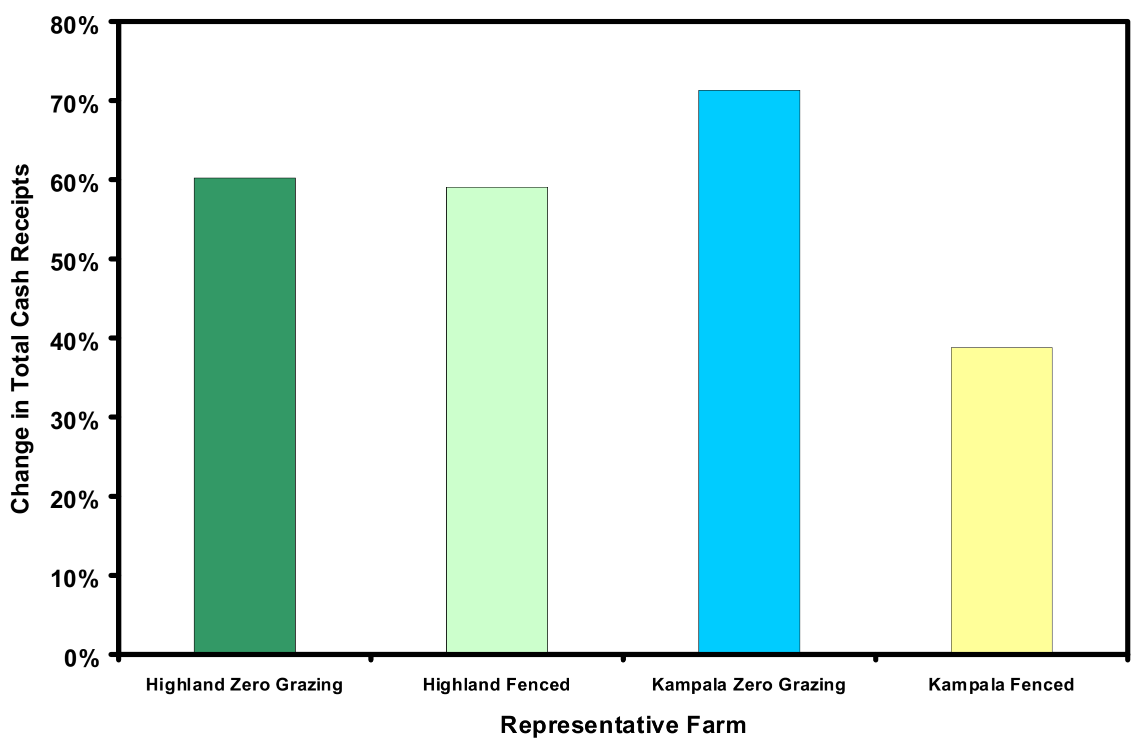


Figure 3.2.8-4. Percentage change in total cash receipts for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in four dairy environments in Uganda under the stochastic scenario.

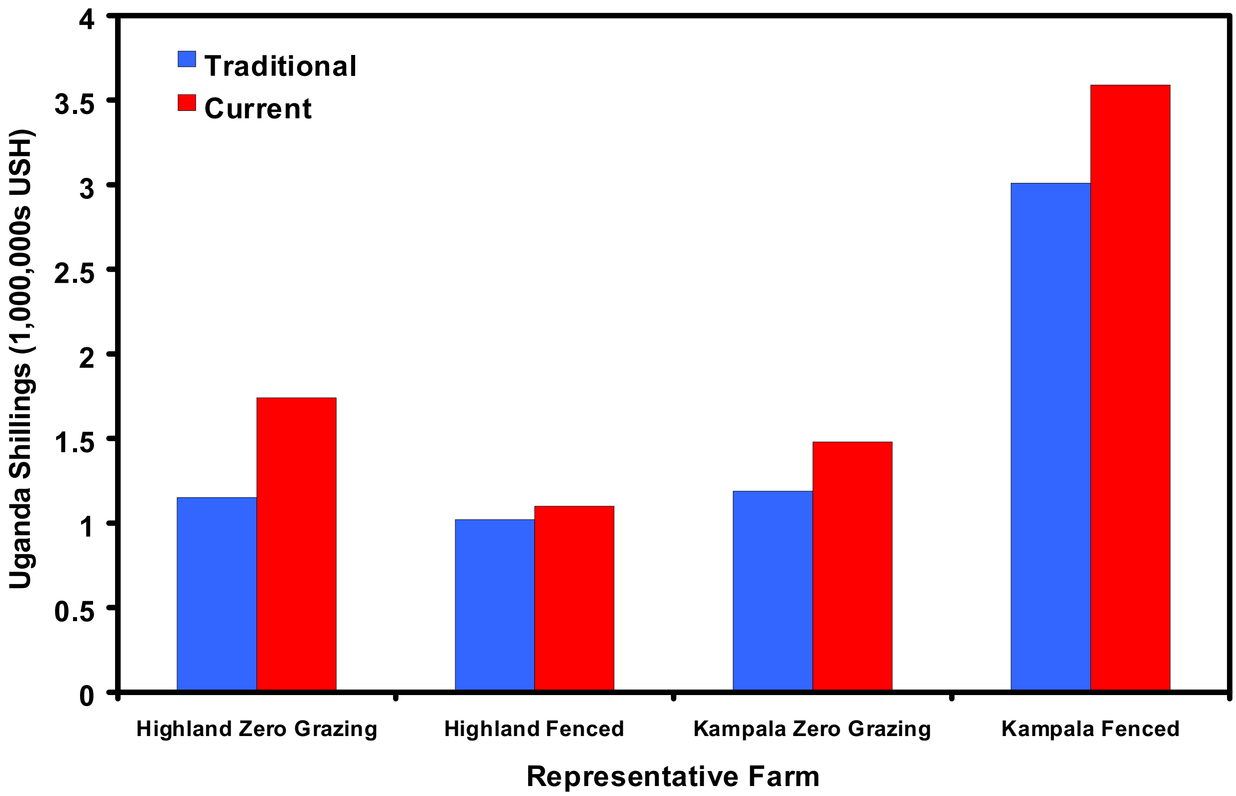


Figure 3.2.8-5. Change in total cash costs for Ugandan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios

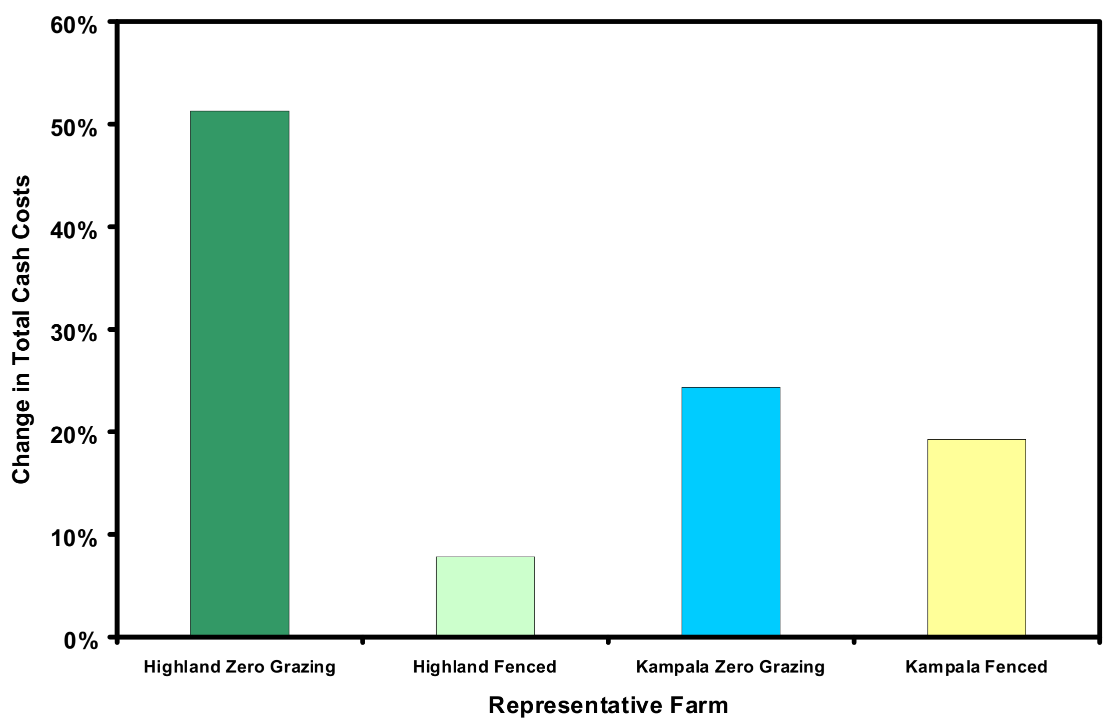


Figure 3.2.8-6. Percentage change in total cash costs for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in four dairy environments in Uganda under the stochastic scenario.

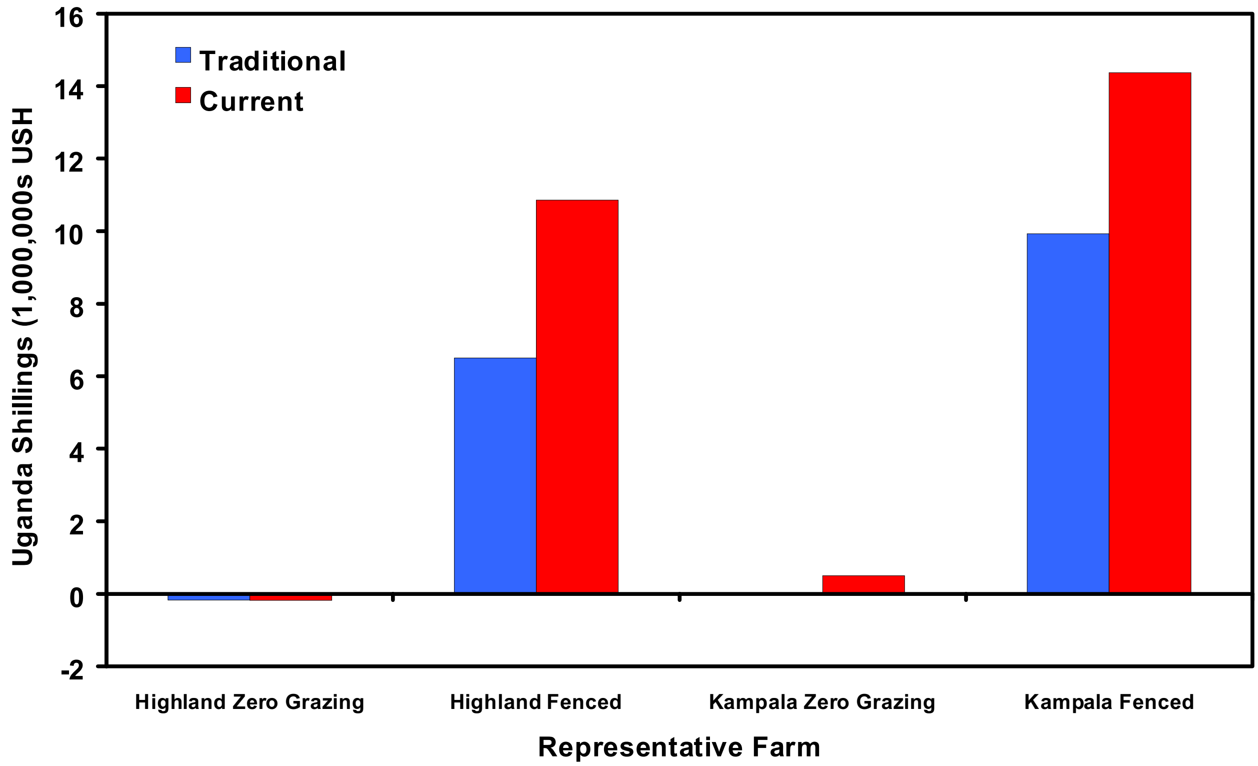


Figure 3.2.8-7. Mean net cash farm income for Ugandan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

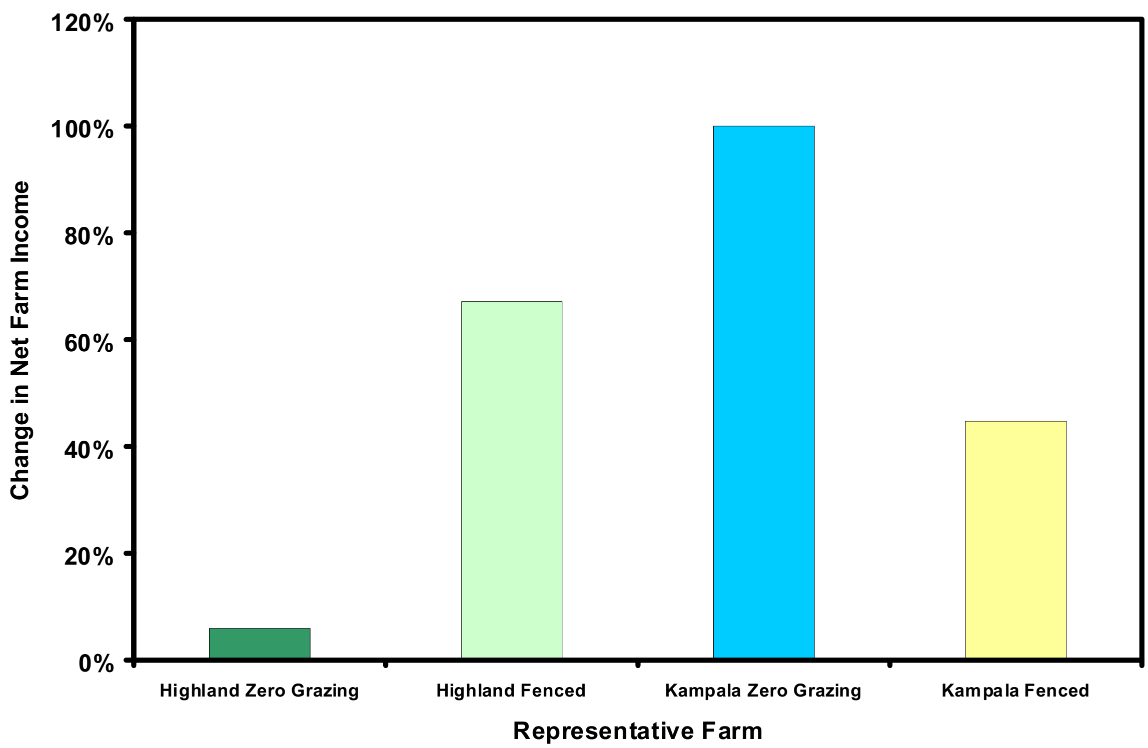


Figure 3.2.8-8. Percentage change in net farm income for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in four dairy environments in Uganda under the stochastic scenario.

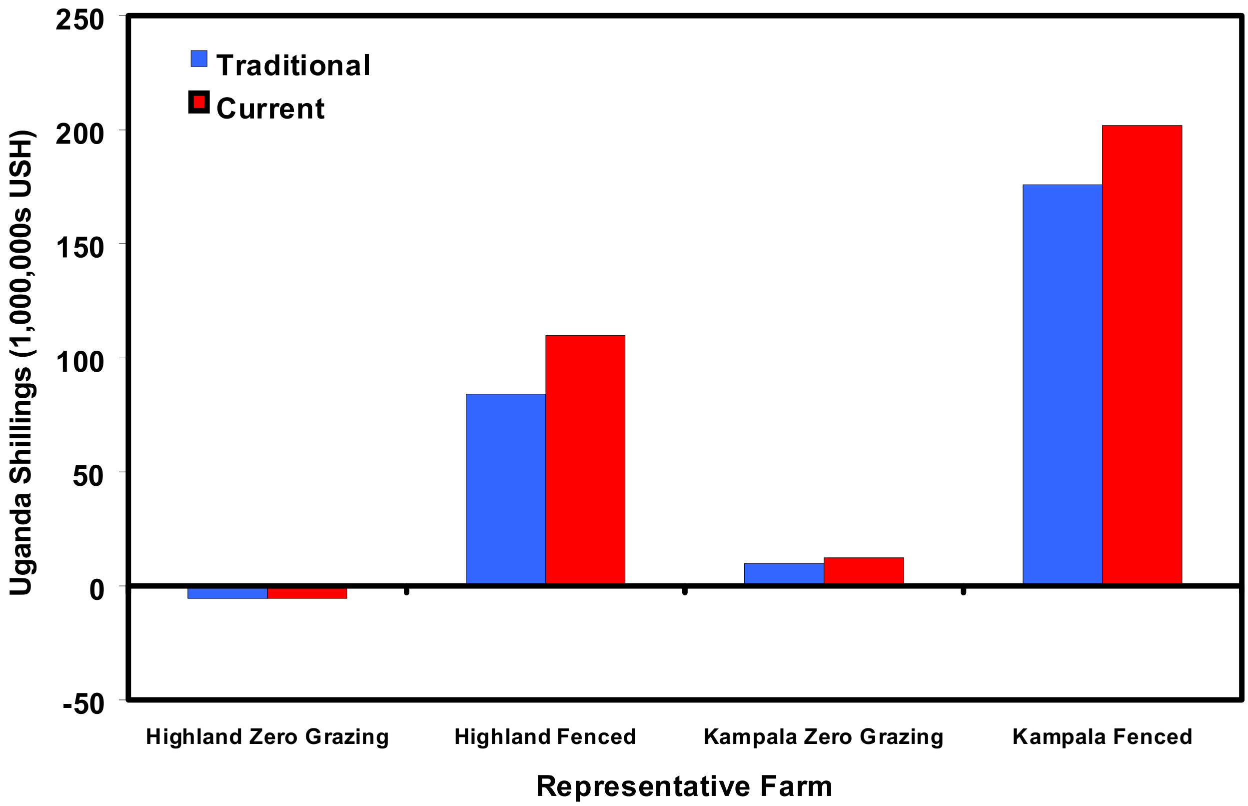


Figure 3.2.8-9. Mean real net worth (RNW) for Ugandan representative farmers under the traditional (zebu cattle/native forage) and the current technology, stochastic scenarios.

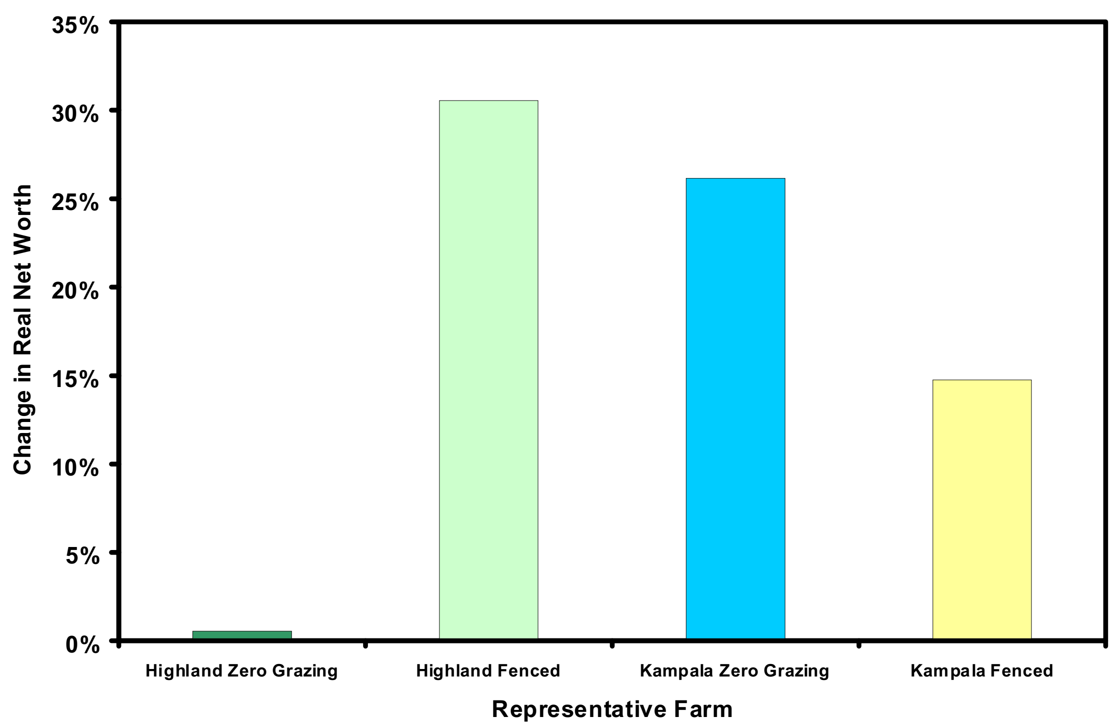


Figure 3.2.8-10: Percentage change in real net worth (RNW) for representative small holder dairy farmers changing from traditional (zebu cattle/native forage) to current technology for farms in four dairy environments in Uganda under the stochastic scenario.

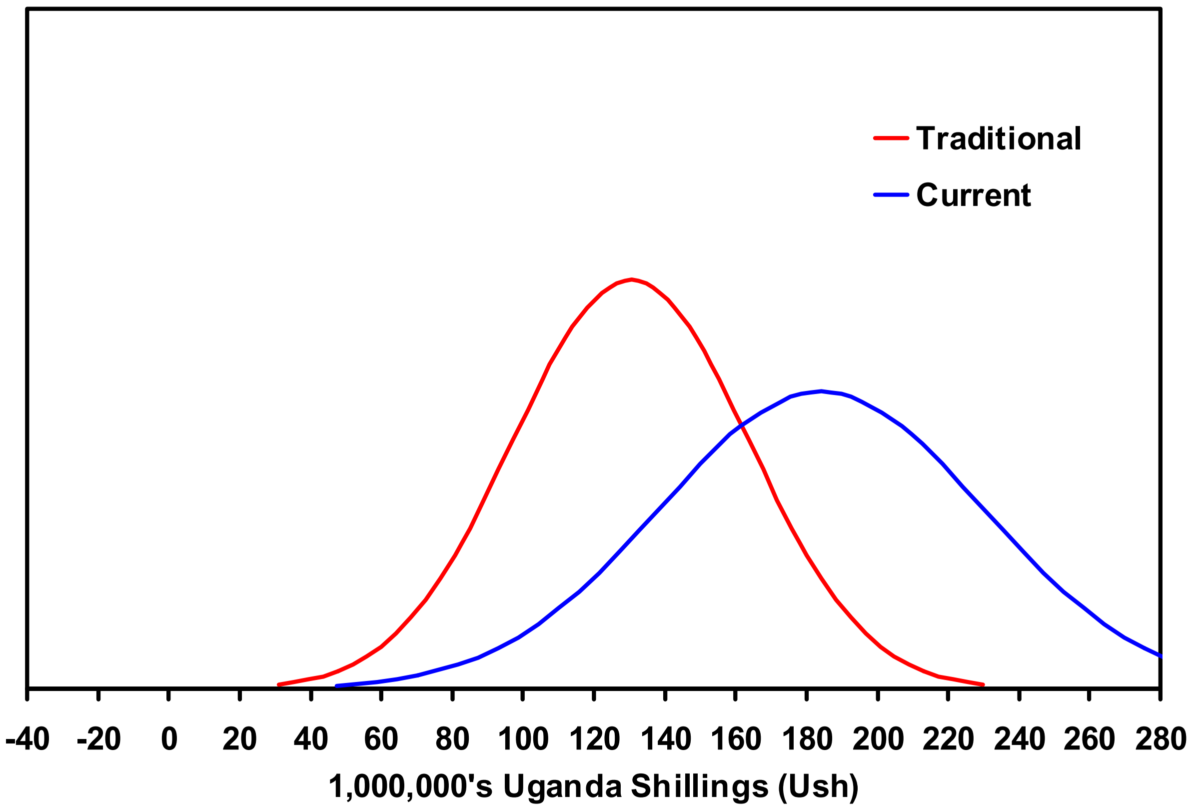


Figure 3.2.8-11. Distribution of net present value (NPV) under traditional and current small holder dairy technologies on a representative Kampala Fenced farm in Uganda.

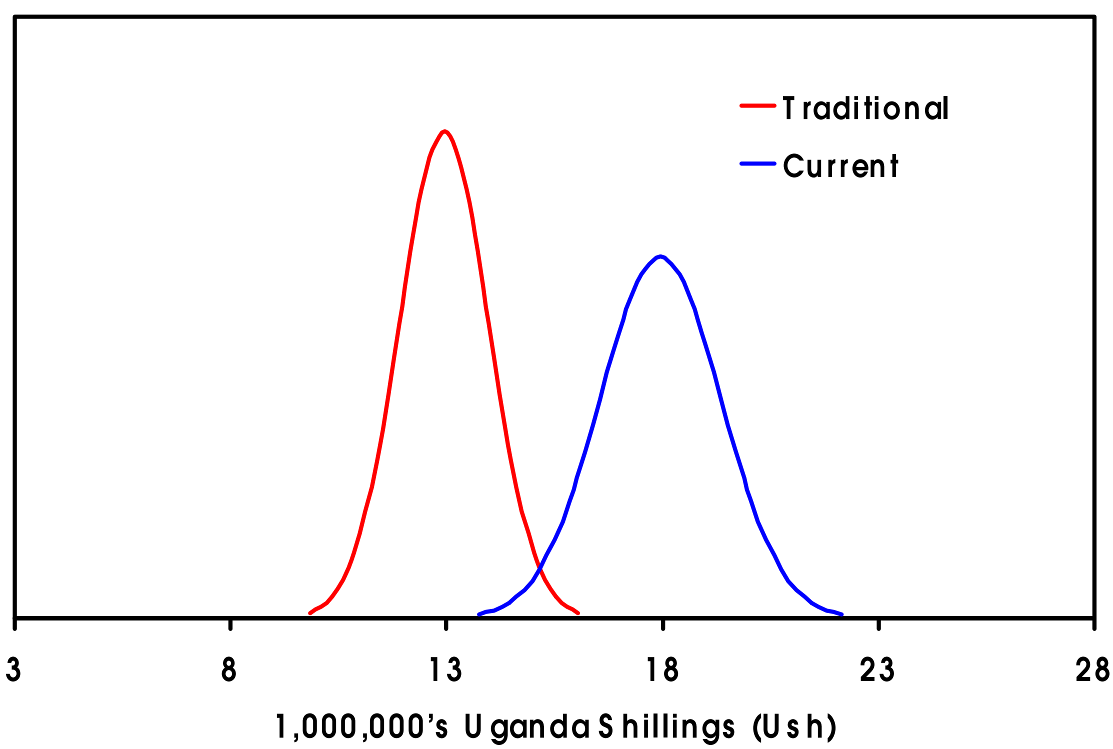


Figure 3.2.8-12. Distribution of total cash receipts under traditional and current small holder dairy technologies on a representative Kampala Fenced farm in Uganda.

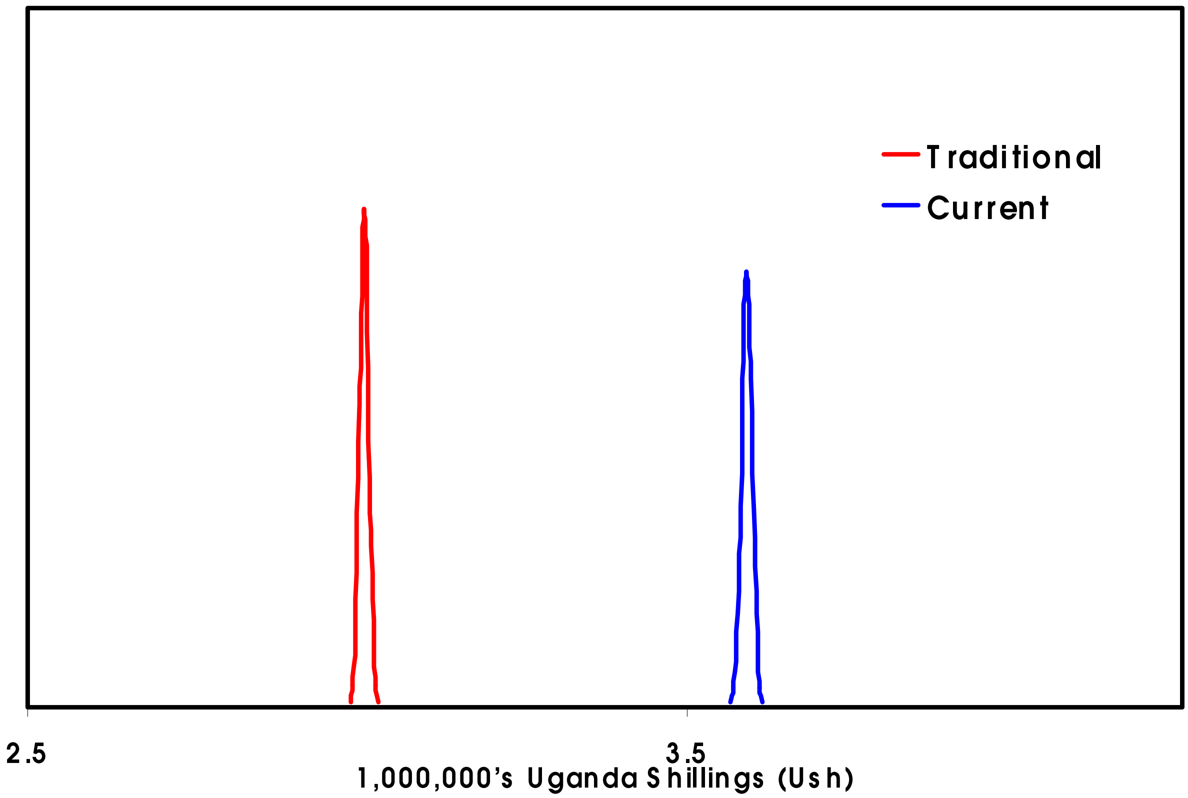


Figure 3.2.8-13. Distribution of total cash costs under traditional and current small holder dairy technologies on a representative Kampala Fenced farm in Uganda.

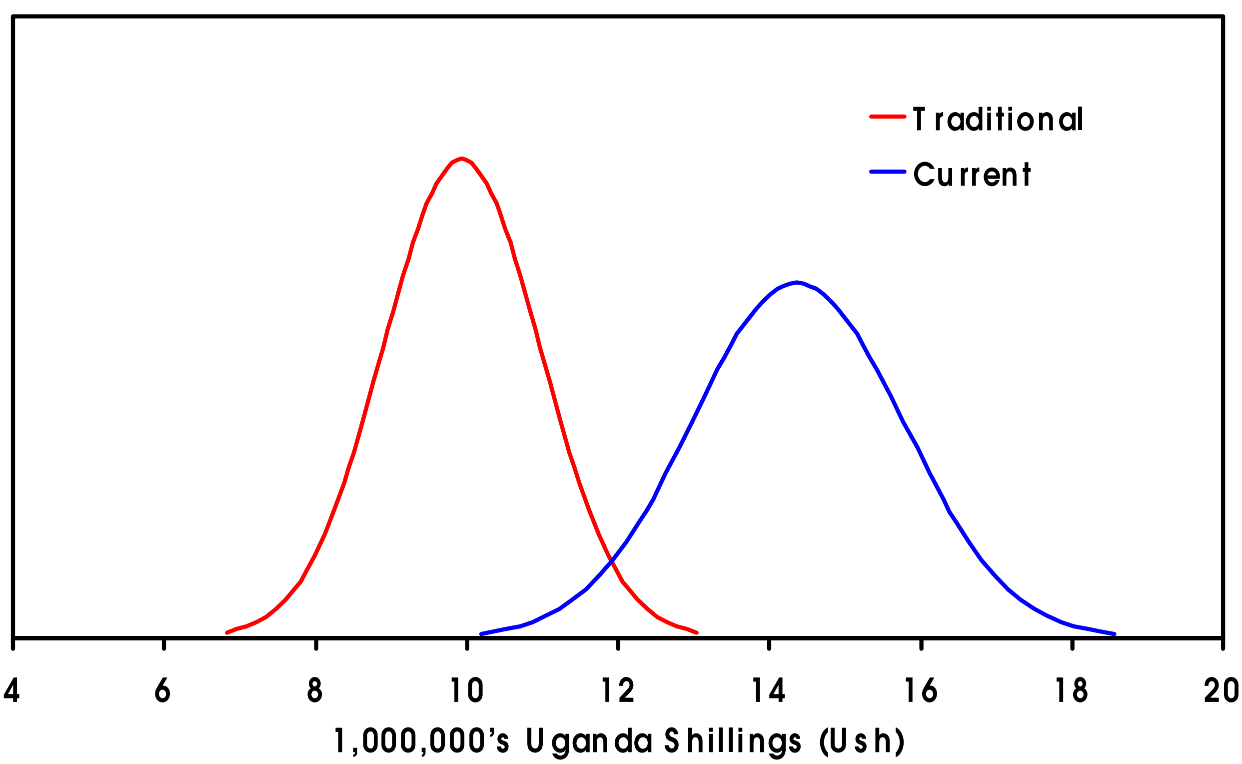


Figure 3.2.8-14. Distribution of net cash farm income under traditional and current small holder dairy technologies on a representative Kampala Fenced farm in Uganda.

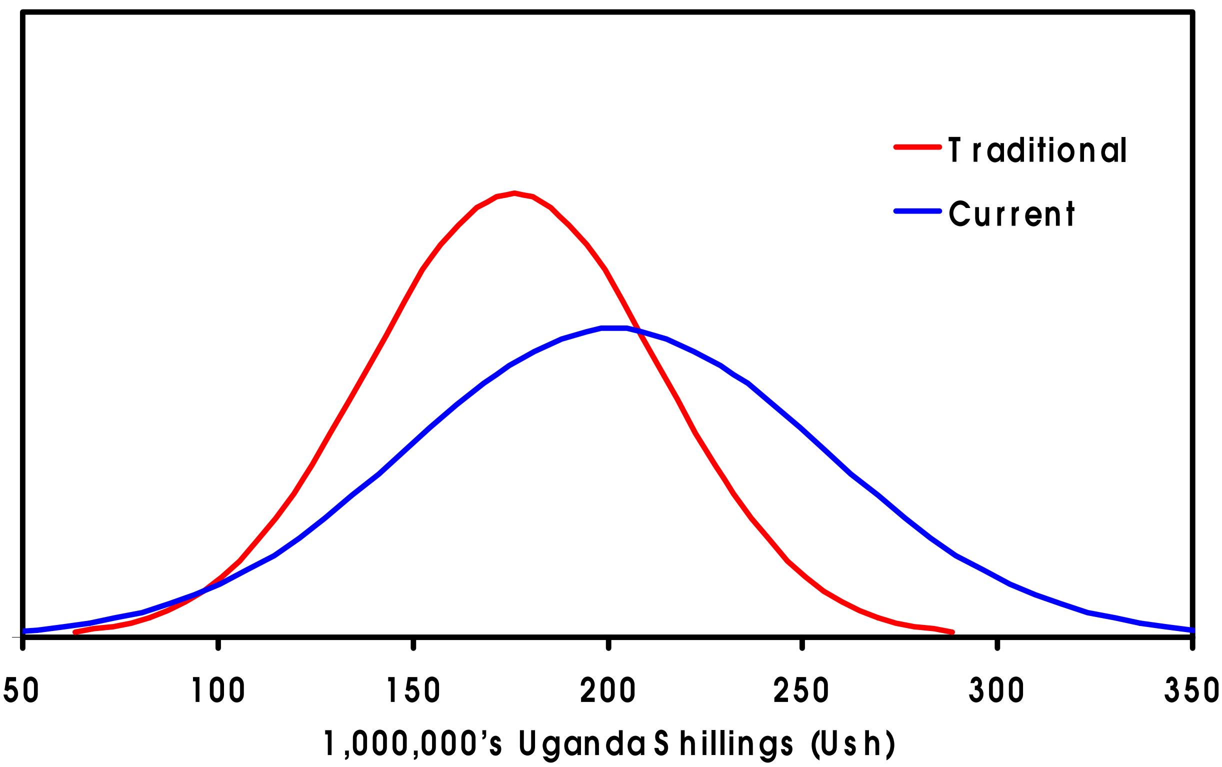


Figure 3.2.8-15. Distribution of real net worth under traditional and current small holder dairy technologies on a representative Kampala Fenced farm in Uganda.

The methods developed and evaluated in this part of the study appear to correspond in a clear and coherent mannner. The trends and projections of results of adopting various scenarios are generally internally consistent between farm and sector level models. The spatial extrapolation of geographic equivalence between Kenya and Uganda is generally convergent, with variations having a reasonable basis in non-modeled factors. The model outputs are reasonably correlated to the opinion of national experts.

3.3 Tanzania

3.3.1 Introduction and Characterization of the Dairy Industry

Smallholder dairying is much more disaggregated in Tanzania; isolated milksheds are associated with market concentrations near Dar es Salaam, Arusha, Morogoro/Dodomo, Mwanza and the southwestern border areas of Tanzania. This is a reflection of the size of the country, distribution of urban populations, road networks and disease constraints as it applies to successful smallholder dairying.

Like Uganda, Tanzania producers' milk yields were higher than those observed in Kenya. Like the Kenyan coastal representative farm the Tanzanian coastal sites, Tanga, and the Peri-urban Dar Es Salaam site face high disease pressures. The Kilimanjaro site is unique in that it is situated at the base of Kilimanjaro,a former volcano. The mountain produces a special climatic zone with a particularly fertile soil base due to the volcanic source of the soil. Unlike Kenya and to a lesser degree Uganda private land ownership is not well defined. The marketing infrastructure is developing in response to on going market reforms but is still less advanced than Kenya..

3.3.2 Analysis Relating Adaptation to Adoption

In an attempt to address the issue of adaptation and adoption, we used the Tanzania extrapolation to test methods for better refining the issues of where a technology would be adapted verses areas where it will be adopted. Tanzania was particularly challenging because of the wide dispersion of dairying as noted in the previous section. Efforts to target similar biophysical situations rely upon empirical observations of where dairies exists and identification of similar situations. Refinement of this 'adaptation' zone – adaptation because the characteristics of the zone (so far)- addresses only part of the issue surrounding the adoption and use of innovative technologies to improve the economic and sustainable well-being of smallholder dairy farmers. Refinements to the target 'adaptation' zones can be accomplished by using additional information and spatial information technologies.

Table 3.3.2.1 Area and 1990 population for dairy zones in Tanzania

Dairy Zone	Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/ (km^2)	Population Density in Areas having >16 people/ (km^2)	Total Area (km^2) with Population <16 people/ (km^2)	Population Density in Areas having <16 people/ (km^2)
Horticultural	93742	1963985	31245	1797335	62496	166650
Tea	35145	1758402	25287	1704598	9858	53804
Coast	23438	682280	6011	657557	17427	24723
Mt. Kilimanjaro	20292	614382	10184	577021	10108	37361
Coffee	6317	498282	4232	496420	2084	1861
Wheat	8420	368852	5523	344743	2897	24108
Sheep	3588	162265	1550	147882	2038	14383

Several additional databases were incorporated into the ACT to add further precision to the extrapolation based on geographic equivalence between Tanzania and Kenya. These included the Tanzania's dairy zones, recent updates of ILRI's disease distribution data, and the human population database from Diechman. These data allowed us to move from adaptation zones defined by the geographic equivalence extrapolation to estimates of adoption zones, based on a more detailed and realistic assessment. For example, in Tanzania the 'Horticultural' dairy type ecology derived in Kenya was the most widespread. Table 3.3.2.1 provides a breakdown of the smallholder dairy adaptation zones in Tanzania ranked by area and sorted by population density. We chose 16 persons per square kilometer as a reasonable split between low population density where support for a smallholder dairy would be less viable and areas with higher populations and thus more of a market for smallholder dairy products. Using the ILRI livestock disease database, we could further refine the smallholder dairy target environments.

We examined the Tanzanian 'Horticultural' type ecology first. The data in Table 3.3.2.2 have been sorted by total population. The Dicheman population density database utilized the best available road, town, market, city and natural areas (parks, reserves etc.) database to distribute population data from the census (political unit) across the landscape. The data in Table 3.3.2.2 shows that most people in the horticultural zone live in a relatively small percentage of the area of the zone. This high population area would be a logical target for further sampling of smallholder dairy. We already know something about the biophysical conditions and thus the production opportunities and constraints and we now know that there are sufficient people to generate a 'market' for milk consumption. Furthermore, having crossed the 'Horticultural' type ecologies with the database of disease pressure, we know even more about the kinds of constraints that will most likely affect smallholder dairy production. To illustrate this, the map in Figure 3.3.2-1 shows the area within Tanzania corresponding to the first six rows of data in Table 3.3.2.2.

The mapped data from ILRI have a scale limitation that becomes apparent during this spatial analysis. The 'expert opinion' that supports the disease distribution map was not supported by the level of detail available in the ACT. Therefore, it is inevitable that small areas of specific, unique, disease pressure exist. We provide these data to complete the tables recognizing that the information used to generate these isolated cells in the table likely does not support their unique characteristics. Spatial analysis often confronts this issue when integrating data from different sources and often from different scales. The value in reporting the complete

Table 3.3.2.2: Tanzania Hort (Termperate/Dry) Dairy Zone

	Parva (ECF)	Tstete								
Ticks Present?	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?	Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/ (km^2)	Population Density in Areas having >16 people/ (km^2)	Total Area (km^2) with Population <16 people/ (km^2)	Population Density in Areas having <16 people/ (km^2)
Yes	Antibodies	No	No	No	9797	497185	7853	486332	1944	10853
Yes	Antibodies	No	Yes	No	7719	320059	5171	308244	2548	11815
Yes	No	No	No	No	7866	249078	4397	231811	3469	17267
Yes	No	No	Yes	No	9297	229739	3950	205290	5347	24449
No	No	No	Yes	No	40698	122278	1970	61970	38728	60308
No	No	No	No	No	9719	105660	2141	78395	7578	27265
Yes	No	Yes	No	No	1796	99685	1452	96922	344	2763
Yes	Antibodies	Yes	Yes	No	987	84762	879	83977	108	785
Yes	Antibodies	Yes	No	No	408	77789	357	77632	51	157
No	Antibodies	No	Yes	No	2158	69633	1335	64819	823	4814
No	Antibodies	No	No	No	1250	38943	1017	37051	233	1892
Yes	No	Yes	Yes	No	652	29042	186	25964	466	3078
No	Antibodies	Yes	Yes	No	345	21126	290	21002	55	124
No	Antibodies	Yes	No	No	60	10357	59	10346	1	11
No	No	Yes	Yes	No	215	5557	114	4966	101	591
No	No	Yes	No	No	135	1798	27	1366	108	432
Yes	Antibodies	No	Yes	Yes	10	855	10	855		
Yes	No	No	Yes	Yes	37	427	4	372	33	55
No	No	No	No	Yes	2	0			2	0
No	No	No	Yes	Yes	719	0			719	0

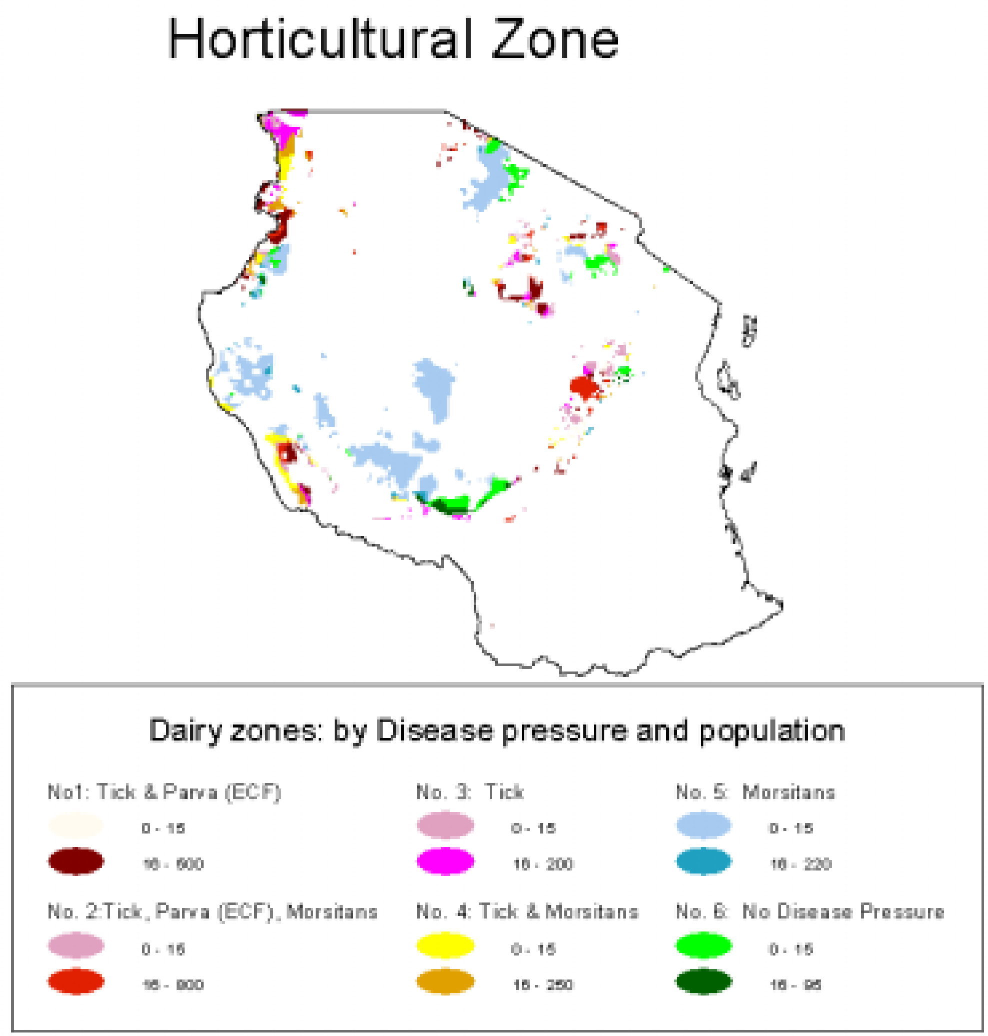


Figure 3.3.2-1. Characterization of the "Hort" dairy environment in Tanzania based on disease pressure and population density.

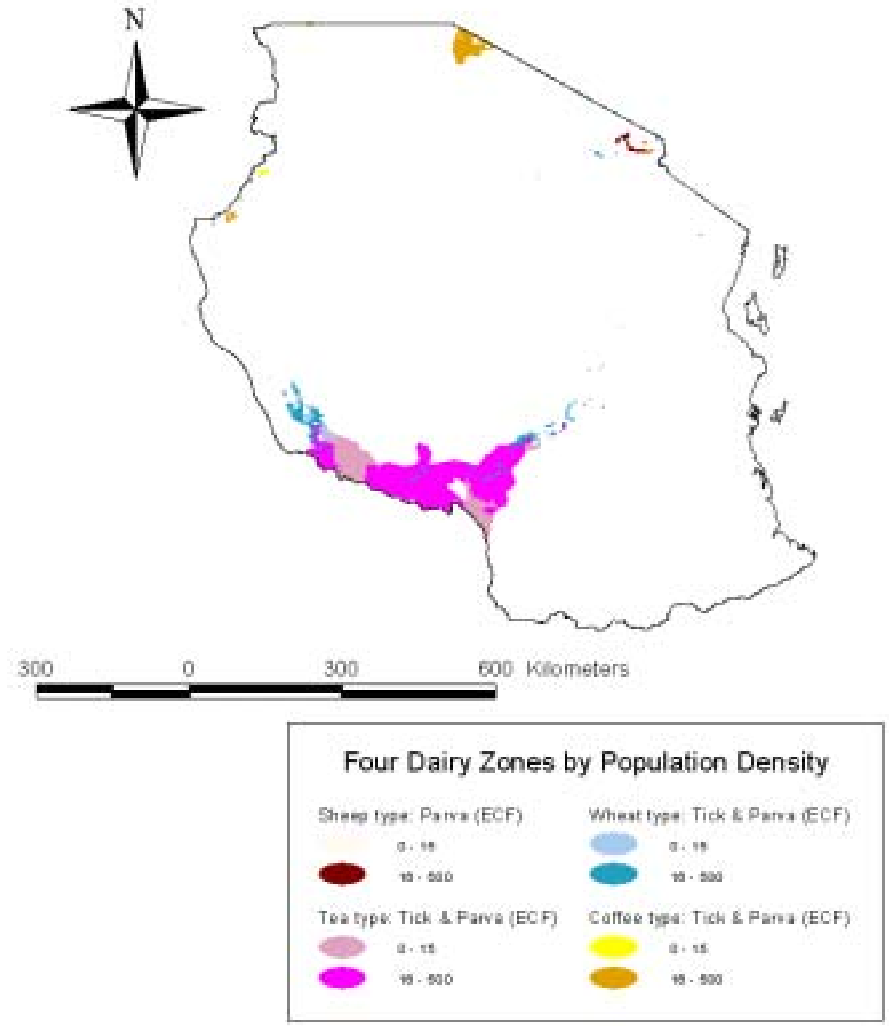


Figure 3.3.2-2. Sheep, Wheat, Tea, and Coffee type dairy ecological types, by population density (first line of corresponding table only) Characterization of the "Sheep", "Wheat", "Tea", and "Coffee" dairy environments in Tanzania based on disease pressure and population density. (First lines in Tables 3.7.5.5, 3.7.5.6, 3.7.5.7, and 3.7.5.8.

analysis is the feedback it provides to the scientists whose polled opinions created the initial disease distribution databases. Udates to the map can be made utilizing the data now available in a GIS, and the description of disease distribution will become more accurate.

Characterization procedures outlined here allowed targeting of environments to be far more specific than was possible using analogue (paper maps) methods. We are able to mix spatial data of both qualitative and quantitative origin, of various scales, and from multiple sources and disciplines. Our results have sufficient spatial resolution to greatly facilitate implementation steps for the transfer of technology and for the evaluation of technology developed in one place carried to another, similar locations.

The following tables (Table 3.3.2.3 to Table 3.3.2.8) serve to describe the other smallholder dairy zones with respect to their area, disease pressure, and the population split into high and low density groups. The lines in bold are then mapped in Figure 3.3.2-2. This is a rich digital database environment. We could look at one zone and map many subdivisions of that zone (by disease, population density, soil, precipitation and

Table 3.3.2.3 Tanzania Coastal Zone

	Parva (ECF)	Tstete								
Ticks Present?	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?	Total Area	Total Population	Total Area (km2) with Population >16 people/ (km^2)	Population Density in Areas having >16 people/ (km^2)	Total Area (km^2) with Population <16 people/ (km^2)	Population Density in Areas having <16 people/ (km^2)
No	Antibodies	Yes	Yes	No	481	349969	479	349969	2	0
No	No	No	Yes	No	16100	140938	3196	129794	12903	11144
No	Antibodies	No	Yes	No	448	70293	448	70293		
No	Antibodies	Yes	No	No	18	25691	18	25691		
No	No	No	No	No	2435	29671	507	25548	1928	4124
No	No	Yes	Yes	No	2003	28214	336	22284	1666	5930
Yes	No	No	Yes	No	432	9082	276	8327	157	756
Yes	No	No	No	No	1014	10132	244	7363	770	2769
Yes	No	Yes	Yes	No	182	7291	182	7291		
Yes	Antibodies	Yes	No	No	145	4447	145	4447		
Yes	No	Yes	No	No	88	2609	88	2609		
Yes	Antibodies	No	No	No	78	2075	78	2075		
Yes	Antibodies	Yes	Yes	No	14	1841	14	1841		
No	No	Yes	No	No	1	29	1	29		

Table 3.3.2.4 Tanzania Mt. Kilimanjaro Zone

Ticks Present?	Parva (ECF)	Tstete			Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/(km^2)	Population Density in Areas having >16 people/(km^2)	Total Area (km^2) with Population <16 people/(km^2)	Population Density in Areas having <16 people/(km^2)
	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?						
Yes	Antibodies	No	No	No	7386	323282	6286	311704	1101	11578
Yes	Antibodies	Yes	Yes	No	898	68599	807	67524	90	1074
Yes	Antibodies	No	Yes	No	1380	56815	858	55059	522	1756
Yes	No	Yes	Yes	No	1627	42406	493	35862	1134	6544
No	No	No	Yes	No	1012	25392	223	24930	789	462
Yes	No	No	No	No	1799	19084	565	16665	1234	2419
Yes	Antibodies	Yes	No	No	77	13838	46	13663	31	175
Yes	No	No	Yes	No	2161	13436	287	8353	1873	5083
No	Antibodies	Yes	No	No	271	11222	101	10225	169	997
No	Antibodies	Yes	Yes	No	61	11031	58	11011	3	20
No	No	Yes	Yes	No	200	9689	107	9215	93	473
No	No	No	No	No	2667	7251	76	2409	2592	4843
No	Antibodies	No	No	No	369	5597	159	4145	209	1452
No	Antibodies	No	Yes	No	236	5590	91	5283	145	307
No	No	Yes	No	No	63	1058	28	972	35	87
Yes	No	Yes	No	No	86	91			86	91

Table 3.3.2.5 Tanzania Sheep (Dry/Cool) Dairy Zone

Ticks Present?	Parva (ECF)	Tstete			Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/(km^2)	Population Density in Areas having >16 people/(km^2)	Total Area (km^2) with Population <16 people/(km^2)	Population Density in Areas having <16 people/(km^2)
	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?						
No	Antibodies	No	No	No	1641	92327	602	84830	1039	7497
Yes	Antibodies	No	No	No	865	33952	522	30657	343	3295
Yes	Antibodies	No	Yes	No	154	9841	66	9069	89	772
Yes	Antibodies	Yes	Yes	No	111	9633	104	9544	7	89
Yes	Antibodies	Yes	No	No	161	3476	50	2356	111	1121
No	No	No	No	No	147	2839	69	2381	78	459
No	Antibodies	Yes	No	No	31	2836	14	2716	17	120
Yes	No	No	No	No	311	2596	36	1726	274	869
No	Antibodies	No	Yes	No	52	2061	25	2004	28	57
No	No	No	Yes	No	56	1599	25	1599	31	0
Yes	No	No	Yes	No	42	823	31	752	11	71
No	No	Yes	Yes	No	18	281	7	248	11	33

Table 3.3.2.6 Tanzania Tea Dairy Zone

	Parva (ECF)	Tstete									
Ticks Present?	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?	Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/ (km^2)	Population Density in Areas having >16 people/ (km^2)	Total Area (km^2) with Population <16 people/ (km^2)	Population Density in Areas having <16 people/ (km^2)
Yes	Antibodies	No	No	No	34023	1735643	24930	1685883	9092	49760
Yes	Antibodies	Yes	No	No	87	5261	56	4973	31	287
Yes	No	No	No	No	93	3974	40	3755	53	220
Yes	Antibodies	No	Yes	No	217	3181	97	2299	121	882
No	Antibodies	No	No	No	208	2538	56	1899	152	639
Yes	Antibodies	Yes	Yes	No	30	2526	30	2526		
No	No	No	Yes	No	240	1625	15	706	225	918
No	Antibodies	No	Yes	No	29	1300	29	1300		
No	No	No	No	No	156	866	10	236	145	630
Yes	No	No	Yes	No	42	649	4	181	39	468
Yes	No	Yes	Yes	No	11	610	11	610		
Yes	Antibodies	No	No	Yes	7	130	7	130		
No	Antibodies	Yes	Yes	No	1	55	1	55		
No	No	Yes	Yes	No	1	45	1	45		

Table 3.3.2.7 Tanzania Wheat Dairy Zone

	Parva (ECF)	Tstete								
Ticks Present?	Theileriosis Present?	Fusca Present?	Morsitans Present?	Palpa Present?	Total Area (km^2)	Total Population Density	Total Area (km2) with Population >16 people/ (km^2)	Population Density in Areas having >16 people/ (km^2)	Total Area (km^2) with Population <16 people/ (km^2)	Population Density in Areas having <16 people/ (km^2)
Yes	Antibodies	No	No	No	5687	231096	4134	217294	1552	13802
Yes	Antibodies	Yes	Yes	No	333	58842	286	58423	47	420
Yes	Antibodies	No	Yes	No	760	31465	523	28992	237	2473
No	Antibodies	No	Yes	No	144	12577	144	12576	0	1
No	Antibodies	No	No	No	200	8712	125	8131	75	581
Yes	No	No	No	No	567	7794	97	4453	471	3341
Yes	Antibodies	Yes	No	No	53	6724	34	6569	19	155
Yes	No	No	Yes	No	225	5190	67	3536	158	1654
No	No	No	Yes	No	316	4294	53	3175	262	1120
Yes	No	Yes	Yes	No	61	1047	28	756	33	291
Yes	No	Yes	No	No	33	864	31	838	2	26
No	Antibodies	Yes	No	No	37	225			37	225
No	Antibodies	Yes	Yes	No	3	21			3	21

Table 3.3.2.8 Tanzania Coffee Dairy Zone

	Parva (ECF)	Tstete								
Ticks Present?	**Theileriosis Present?**	**Fusca Present?**	**Morsitans Present?**	**Palpa Present?**	**Total Area (km^2)**	**Total Population Density**	**Total Area (km2) with Population >16 people/ (km^2)**	**Population Density in Areas having >16 people/ (km^2)**	**Total Area (km^2) with Population <16 people/ (km^2)**	**Population Density in Areas having <16 people/ (km^2)**
Yes	Antibodies	No	No	No	3588	374110	3294	372525	294	1584
Yes	Antibodies	Yes	No	No	89	29202	80	29151	9	51
Yes	No	Yes	Yes	No	46	28663	46	28663		
Yes	Antibodies	Yes	Yes	No	47	28518	47	28518		
Yes	No	No	No	No	93	8114	84	8038	9	76
Yes	Antibodies	No	Yes	No	251	6355	193	6310	58	44
No	Antibodies	No	Yes	No	179	5813	179	5813		
No	Antibodies	No	No	No	75	5548	75	5548		
Yes	No	No	Yes	No	221	3685	61	3588	160	97
Yes	Antibodies	No	Yes	Yes	41	2851	41	2851		
No	No	No	Yes	No	1544	511	119	511	1425	0
No	No	No	No	No	10	203	9	198	1	5
Yes	No	No	No	Yes	31	104	5	104	26	0
No	No	No	Yes	Yes	102	3			102	3

temperature gradients, etc.) or we could map multiple zones for similar disease etc. We have elected to map, split by population density, the largest 'homogeneous' group from each ecology as defined by disease pressure. However, the user could elect to view any particular grouping of data without facing the obvious limitation of creating a paper map with each query if properly represented in the ACT.

3.3.3 Assessment of Impact of Smallholder Dairy Technology in Tanzania: Analysis of Representative Farms

Three milksheds were selected to conduct on-farm surveys: Dar es Salaam peri-urban, Tanga, and Kilimanjaro milksheds. Both Dar es Salaam and Tanga are representative of the "Coast" ecological zone identified in the Kenya analysis. They also represent the highest population in Tanzania. Given its uniqueness to Tanzania, we chose to conduct on-farm surveys in the Kilimanjaro milkshed. Due to limitations in resources, the results from assessments of impact in the horticultural zone of Kenya were used in the Tanzanian analysis. However, baseline information is available for our Tanzania partners to pursue these analyses if so desired. There were no ASM analyses conducted for Tanzania but the framework for both the Kenya and Uganda ASM are available to Tanzania if required.

Interviews of both the Tanga and Dar es Salaam farms were structured in a similar manner as the interview farm in the Coast region of Kenya. The Dar es Salaam farm was more zero-grazing based and had a higher reliance on purchased feed than the Tanga farm. The Kilimanjaro farm also had more reliance on purchased fodder even though it was in a less disease-risk area, similar to the Highland farms in Kenya.

Commodity prices for use in the farm-level analysis in Tanzania were obtained from FAO data since no ASM analysis was conducted to generate commodity prices. Technologies evaluated encompassed improved cattle breeds and forage management practices, the same as done in the Kenya analysis.

With adoption of the improved technologies, the representative farms in the Coastal region increased their

Table 3.3.3.1 Tanzania Representative Farms Mean and Standard Deviations of Net Present Values, Total Cash Receipts, Total Cash Costs, Net Cash Farm Income, and Real Net Worth Under the Base (old) and Current Smallholder Dairy Technology in 1,000,000's Tanzania Shillings

	Net Present Value		Total Cash Receipts		Total Cash Costs		Net Cash Farm Income		Real Net Worth	
Farm Type	**Old**	**Current**	**Old**	**Current**	**Old**	**Current**	**Old**	**Current**	**Old**	**Current**
Kilimanjaro	610.0*	-1360.0 (-144.9)	700.0	1100.0 (48.0)	640	1230.0 (48.0)	60	-140.0 (-142.9)	-1540.0	-2570.0 (-40.1)
	241.0**	386.0	90.0	110.0	24.0	29.0	180.0	200.0	2910.0	3510.0
Tanga	5500.0	7960.0 (30.9)	620	860 (25.0)	90.0	120.0 (25.0)	530.0	740.0 (28.4)	2070.0	3290.0 (37.1)
	22.33	22.58	20.0	40.0	10.0	10.0	20.0	40.0	350.0	1080.0
Dar Es Salaam	-2322.0	-1580.0 (54.0)	2460.0	6700.0 (63.3)	4780.0	8210.0 (41.8)	-2320.0	-1510.0 (53.6)	-1454.0	-1149.0 (26.6)
	8.38	20.61	270.0	520.0	850.0	690.0	680.0	250.0	1064.0	8250.0

* Mean in 1'000,000's of Tanzania Shillings (TSH)
**Standard deviation

net present value (Tanga and Dar Es Salaam) though in the case of the Dar Es Salaam farm in the peri-urban environment, the increase meant the net present value became less negative. The increase ranged between 30.9 to 54.0 percent. In the case of the Kilimanjaro farm its net present value declined by over 144.9% (Table 3.3.3.1).

All the Tanzanian representative farms studied increased their cash receipts with the adoption of the current technology (improved dairy breeds, improved forages). The percent changes ranged between 25.0 to 63.3 percent which is congruent with the increased production expected to occur with the adoption of the improved varieties. Cash costs increased by 25.0 to 48.0 percent across the same enterprises due to the increased feed costs.

Only the Tanga enterprise mean net cash farm income is positive with an increase of 28.4%. Both the Kenyan and Tanzanian coastal producers have access to the high coastal population density and more developed market channels. The Tanga producer also has an advantage that the Kilimanjaro and Dar Es Salaam producers do not have. That advantage is sufficient land to feed his cattle without the need of purchasing feed and paying labor to feed the animals. Consequently the coastal producer in Tanga like the Kenya counterpart has a positive NPV and RNW. The Kilimanjaro enterprise net cash farm income declined by 142.9% while the Dar Es Salaam cash farm income increased by 53.6%.

The real net worth of representative farms in the Coastal zone (Tanga and Dar Es Salaam) increased under the current technology. Again in the Dar Es Salaam farm still had a less negative real net worth with new technology. The percentage changes ranged between 26.6 to 37.1 percent. The Kilimanjaro farm was projected to have a decrease in real net worth of 40.1% with new technologies.

Producer profitability, NPV, and RNW for the Kilimanjaro farm declined with the adoption of the new technology. A major problem faced by the producer is the need to purchase a significant portion of the herd's feed off the farm which combined with the relatively low price for milk in Kilmanjaro lead to the net decline in the projected net real worth over the ten-year period.

The analysis does not predict a positive net farm income for the the Dar Es Salaam farm. Herd size relative to land holding was the largest of the three Tanzanian farms analyzed which raised feed costs significantly. The farm did have one advantage in that Dar Es Salaam has the highest milk price in Tanzania due to its high population density (MOAC. et al.). This contributes to the farm's net present value and real net worth though negative becomes less negative with the adoption of the new technology. The improvement in revenues were significant but not sufficient to offset the increased costs.

The representative farm in the Dar Es Salaam zone in Tanzania had a zero probability of obtaining a positive net cash farm income under both scenarios. The Kilimanjaro farm experienced a decline in the probability of obtaining a positive net cash farm income from 0.6 under traditional technology to 0.20 under the improved technology. The Tanga farm had a 100% probability of obtaining a positive net cash farm income under both technology scenarios.

3.4 Regional Economic Differences in Smallholder Dairy Technology Impact

In general, the representative farms in all the dairy zones in Kenya experienced improvements in NPV, net cash farm income and RNW through adoption of the improved dairy technologies. Only the representative farm in the coffee zone continued to exhibit relatively low probability of economic survival under the improved technology scenario. The improved dairy technologies if adopted in Uganda would appear to be most economically successful in the Kampala dairy zone for both the fenced and zero grazing representative farms. The Highland zero grazing farm would likely be the least affected by adoption of the improved technology. NPV, net cash farm income, and RNW are little affected by the improved technology as compared to the traditional technology.

In these analyses, only the Tanga representative farm in Tanzania would experience economic success through adoption of the improved dairy technologies. NPV, net cash farm income and RNW decline for the Kilimanjaro representative farm with adoption of the improved dairy technology. Hence, little incentive exists to adopt. Although values for these economic variables increase for the representative farm in the Dar Es Salaam zone, mean values remain negative, resulting in little chance for economic success on this farm even with adoption of the improved dairy technology. The probabilities of obtaining positive NPV, net cash farm income and RNW on farms define the dairy zones in each county where improvements in dairy technology are likely to foster technology adoption and expansion of the smallholder dairy industry.

3.5 Interpretation of Methodological Results for Regional Extrapolation

The use of the geographic equivalence was demonstrated in these analyses as a method of making first order approximations of where technology developed and evaluated in Kenya might be applied to Uganda and Tanzania. The utility was shown to be improved by including in the assessment other relevant variables that are not modeled in the first level extrapolation from Kenya, which was based only on temperature, soil, and precipitation patterns. The more relevant layers of the descriptive GIS that can be provided, the more useful the extrapolation.

The importance of relative site specificity of both natural resource and economic factors affecting the adoption of new technology was demonstrated in these studies. The extrapolation of use of new technology was limited to relatively general interpretations with specific assessments based on local conditions. Nonetheless, the general principles of geographic equivalence were demonstrated and the correspondence to the "real world" was encouraging. These methods should be useful in ex ante planning of research investments, in evaluation of ongoing and completed research, and in evaluating the impact of alternative policy scenarios affecting agriculture and the use of natural resources.

While no specific environmental analyses were conducted in Uganda and Tanzania, the general methods developed and demonstrated in the Kenya Sondu river basin analysis and the use of the EPIC model to assess run off and erosion will be equally applicable to these countries.

National policies on critical issues such as land tenure and market policies and regulations obviously can have as large or larger effects on the success of agricultural enterprises as the use of new technology.

These studies highlight the potential inherent conflict between the emergence of larger commercial dairies and the health of small holder dairy enterprises. It draws attention to the difference in benefits between consumers and producers. It notes that farm households represent both producer and consumer interests as home consumption by farmers of dairy products is considered.

The studies in Uganda and Tanzania do not deal with the impact of projected population growth on future demand for dairy products. These studies do not clearly address the possibility that small local markets will continue to provide sustainable income for smallholder dairies in these marketsheds, even in the face of commercialization of the industry to serve larger population centers.

The development of agricultural sector models for Kenya and Uganda and the demonstration of the use of farm level models in all three East African countries studied, along with the databases that were acquired, provide a resource for further use in these countries. These models and methods are usable for assessment of technology and policy options that apply to the major agricultural commodities of these countries. The smallholder dairy technology assessment was chosen as a test platform to develop these general models.

In section 6.2 of this report, we discuss the application of new technology using the terms adaptation and adoption. We have used geographic equivalence as the first order approximation of extrapolation of technology from one location to another. With further more site-specific analysis, we have suggested that prediction of actual adoption of the technology or policy option can be undertaken. For the East Africa scenario, we believe the potential utility of this method has been demonstrated and that the ancillary factors that must be considered have been identified.

We recognize that a pacing factor in the utility of the IMPACT suite in East Africa will be the development of capacity to use the models. We have proposed joint efforts with FAO to continue to this work by developing more "user-friendly" renditions of the models in a networked system that will be easily accessible by national users. We have included in this proposal the further building of national capacity through long term training and ongoing workshops.

Section 4: Assessment of the Impact of INTSORMIL and Peanut CRSPs Technology in Mali

The second major element of the IMPACT development was conducted in West Africa and used the impact assessment of a sorghum production system as a case study or platform for development of the suite of models. The improved production system included enhanced germplasm, a water conservation scheme involving ridge tilling, and improved fertilization. The system was developed under the INSORMIL CRSP with collaborators from the Malian Institute of Rural Economy, several U.S. university collaborators, and ICRISAT. In addition, a smaller study was done to assess the impact of improved peanut germplasm developed by U.S. and West African researchers under the Peanut CRSP.

This evaluation was based on data derived from experimental trials and extension and farmer demonstrations of the components of the production system as well as data from secondary economic statistics and information on relevant natural resources and weather data.

In this section, the evaluation of sorghum production system in Malis is reported. In the next section, the evalution of the system in Senegal and Burkina is reported.

Summary of Methods and Outputs

Activity	*Purpose*
4.1 Summary of Sorghum and Millet Production in Mali	Background for the analysis of the impact of technology
4.2 Sorghum Production Systems Evaluated	Description of the five production systems currently practiced in sorghum and pearl millet production in Mali
4.3 Spatial Characterization of Agro-Environmental Zones	Establish a geographic basis for modeling performance of production system
4.4 Biophysical Inputs for Agricultural Sector Model (ASM)	Characterization of agricultural climatic zones used in EPIC model to predict yields followed by spatially explicit analysis to develop “simulation environments.” Then, 20-year simulations were run with EPIC model.
4.5-4.6 Agricultural Sector Model (ASM) Analysis of Mali	Assessment of impact of the production system at national and regional levels, input to household economic and environmental models.
4.7 Economic Impact at Farm or Household Level	Develop decision aides to be used at local levels for planning, input data for the ASM
4.8 Environmental Impact of INTSORMIL Technology in Mali	Use of EPIC and related models to predict erosion and runoff

4.1 Summary of Sorghum and Millet Production in Mali

Sorghum, pearl millet, rice, maize, cotton, peanut, and cowpea are the major crops produced in Mali. Sorghum and pearl millet are the most important cereal crops in terms of area planted, production, and per capita consumption. For example, harvested area for pearl millet in 1996/97 was 935 thousand hectares, or about 36% of total harvested agricultural area. Sorghum occupied about 21%, and cotton, a major cash crop for export, accounted for about 16% of total area harvested.

Cereal yields in Mali and neighboring countries, Burkina Faso and Senegal, have been stagnating over the last 30 years (Sanders, Shapiro and Ramaswamy). A number of reasons exist for this phenomenon, including agronomic practices that do not maintain soil fertility and cereal breeding programs that have not accounted for the micro variability observed across the region. Demand for food was forecast to increase between 1988 and 2000 by 4% to 4.2% in Mali, 3.6% to 4.1% in Burkina Faso, and 2.7% to 4.4% in Senegal. To meet this demand and retain national sufficiency, producers would need to increase cropped acreage and/or yields.

There is a well documented positive contribution of new technology, especially germplasm, to the goal of enhancing food security. Improved crop varieties and production practices have the potential to meet some of the increased demand for food. The impact of adopting new sorghum technologies in Mali was examined as a case study for developing the spatial analysis tools, biophysical models, and national and farm-level economic analyses. Both environmental and welfare impacts were evaluated.

The available crop production and budget data indicated that sorghum and pearl millet production occurs primarily in the Kayes, Koulikoro, Sikasso, Segou, and Mopti regions. The Kayes, Koulikoro, and Sikasso regions are major sorghum production areas, while the Mopti and Segou regions followed by the Koulikoro and Sikasso regions are principal producers of pearl millet. Cotton production is concentrated primarily in the Sikasso Region with somewhat less production in the Koulikoro and Segou regions.

4.2 Sorghum Production Systems Evaluated

The sorghum varieties investigated in this assessment were a suite of local varieties and improved varieties from the IER/INTSORMIL CRSP. Additionally, two new varieties, N'Tenimissa and the Seguetana Cinzana, were evaluated. The N'Tenimissa variety is a high-yielding, white-seeded, tan-plant, guinea-type variety tolerant of sorghum head bugs. It is ideal for processing into white flour mixes and value-added products sold in urban areas, including breads, biscuits, confectioneries, sorghum crunch, and composite flours. INTSORMIL and IER researchers in Mali have been encouraged by results of consumer tests by of value-added products developed from this variety. In addition, the variety performed well in evaluations at on-farm sites in Mali by World Vision International and on test plots at the Cinzana Station in 1996, 1997, and 1998. N'Tenimissa was included in the West and Central Africa Sorghum Research Network (WCASRN) trials across West Africa in 1996, 1997, and 1998. In the sorghum variety trials for 1996 and 1997, N'Tenimissa had adjusted yields in Mali that were 25% to 33% higher than the local varieties in the improved and traditional cropping systems, respectively. The 1996-97 yields for N'Tenimissa and the local check varieties are presented in Table 4.2.1, along with the numerical and percentage yield differences for the various cropping systems.

Table 4.2.1. Adjusted Yields and Yield Differences for N'Tenimissa and Seguetana Cinzana Sorghum Varieties and Local Check Cultivars

Cropping System	Variety	Adjusted Grain Yield (kg/ha)		Adjusted Yield Difference (kg/ha)	Adjusted Yield Difference (%)
LORDG (1) TEMRDG (6)	Local check N'Tenimissa	930 1274	>	344	37
LOMANRDG (2) TEMMANRDG (7)	Local check N'Tenimissa	992 1240	>	248	25
LOFERRDG (3) TEMFERRDG (8)	Local check N'Tenimissa	992[a] 1240[a]	>	248[a]	25[a]
LOMANRDG (2) SEGMANRDG (9)	Local check Seguetana Cinzana	[b] [b]	>	600[b]	33[b]
LOFERRDG (3) SEGFERRDG (10)	Local check Seguetana Cinzana	[b] [b]	>	800[b]	33[b]

[a] Experiments and on-farm trials using inorganic fertilizers were not conducted. Expert opinion of the researchers who developed and tested N'Tenimissa was that relative yield levels and yield differences should be about the same as with use of manure.

[b] Yield differences provided by researchers who developed Seguetana Cinzana from a nonStriga-tolerant parent cultivar at the Cinzana Station. The percentage differences were used to adjust the current adoption scenario yields in the Mali ASM to reflect the relative yield increase for the two varieties.

Seguetana Cinzana is a Striga-tolerant, guinea-type variety, selected from a local cultivar, with good head bug resistance. It has performed well relative to the local cultivar in test plots at the Cinzana Station in 1996 and 1997 and at on-farm sites near Bla. Seguetana Cinzana had adjusted yields of 600 to 800 kg/ha more grain production than the nonStriga-tolerant variety at the Cinzana Station trials in 1996-97, reflecting a 33% increase in grain yield when grown with an improved cropping system consisting of manure and ridge tillage (Table 4.2.1).

In major sorghum producing areas of the Sudanian Zone of southern Mali, a pervasive use of animal traction has enabled farmers to use a plow to construct ridges, either with a straight furrow throughout the field or on the contour. This technique has been combined with increasing use of manure mixed with straw from pearl millet and sorghum residues, resulting in improved water retention. This has allowed for the introduction of new sorghum, pearl millet, and cowpea cultivars. These two improved sorghum varieties were evaluated in this assessment. Both varieties are guinea-type sorghums adapted to rainfall zones of 600 mm and greater or to areas where guinea-type sorghums are commonly grown. Other improved varieties of sorghum and millet were also analyzed along with the tillage and fertility components of the cropping systems.

Technologies currently in practice that were considered in this assessment included use of ridge tillage, animal and household manure, and inorganic fertilizers in combination with local or improved, higher-yielding sorghum and pearl millet varieties. The following is a list of current production systems:

LORDG - Local varieties with ridge tillage
LOMANRDG - Local varieties with manure fertilizer and ridge tillage
LOFERRDG - Local varieties with inorganic fertilizer and ridge tillage
IMMANRDG - Improved varieties with manure fertilizer and ridge tillage
IMFERRDG - Improved varieties with inorganic fertilizer and ridge tillage

4.3 Spatial Characterization of Agro-environmental Zones

Many agro-ecological zones schemes have been used to describe the region. For example, Gorse and Steeds (1987) described four climatic zones of semiarid west Africa based on annual precipitation: Sahelian (northern crop limit to 350 mm), Sahelo-Sudanian (350 mm-650 mm), Sudanian (650 mm-800 mm), and the Sudano-Guinean (>800 mm) ((Figure 4.3-1). These zones represent crop growth, yield potential of land and climate resources. Following is a brief description of each zone.

The Sahelian Zone is characterized with a southern boundary of annual average rainfall during the rainy season of 400 mm (90% probability) to the northern limit of cultivation with annual average rainfall of about 200 mm. Length of the rainy season is generally less than 90 days (Figure 4.3-2). This zone has extremely poor soil fertility, low soil water-holding capacity, high production risk, and land with the lowest agricultural potential. Within this zone, population density is low, and livestock production is the major activity. The Sahelian Zone contributes less to national crop production than the other three zones. The cropping system is primarily subsistence pearl millet and cowpea.

The Sahelo-Sudanian Zone has annual rainfall averaging 400 mm to 600 mm and a rainy season that lasts between 90 and 120 days. The northern portion of this zone is very similar to the Sahelian Zone, characterized by poor soil fertility, low soil water-holding capacity, and high production risk. Pearl millet-cowpea intercropping, some sorghum, and nomadic grazing of livestock are the major activities in the northern portion of the zone. Population density is still somewhat sparse but increases substantially farther south. Sorghum, pearl millet, maize, cowpea, vegetables, and some cotton are produced in the southern portion of this zone. The sorghum production systems are predominate on heavier soils. Pearl millet is the primary cereal crop on lighter, sandier soils. A mix of sorghum and pearl millet is found on intermediate soils.

The Sudanian Zone has annual rainfall averaging 600 to 800 mm during the rainy season with a length of 120 to 150 days. This zone has spatial and temporal variability, more land with higher agricultural potential than the Sahelian or the Sahelo-Sudanian zones, and high population density. Sorghum, pearl millet, maize, cowpea, vegetables, and some cotton are major crops. This zone has much higher prospects for improved crop technology development and adoption than the Sahelian or Sahelo-Sudanian zones; however, the potential for developing crop technology is relatively moderate.

The Sudano-Guinean Zone is characterized with an annual average rainfall of 800 to 1200 mm during the rainy season and a growing season greater than 150 days. This zone has the most advanced agricultural technology and highest contribution to total cash crop production. Sorghum and maize are major rain-fed crops, and cotton and peanut are major cash crops. Cropping systems also include pearl millet, vegetables, cowpea, and rice. Livestock production is a major activity in this zone. Population density is low because historically there was high disease risk to residents, but the risk is less today because of improved public health and investment in infrastructures. This zone has high potential for crop technology, including well diversified, high-input production systems.

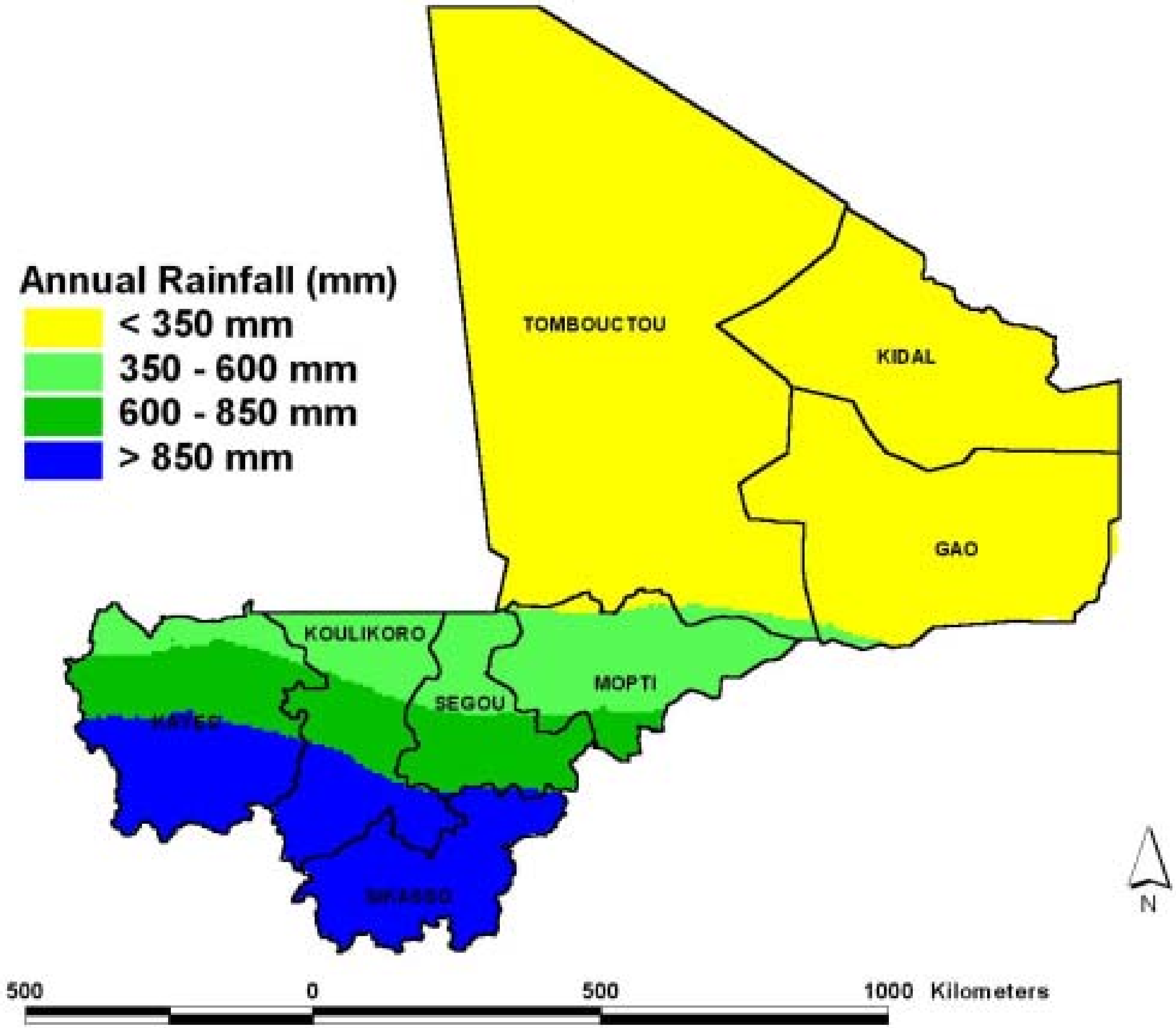


Figure 4.2-1. Rainfall zones in Mali

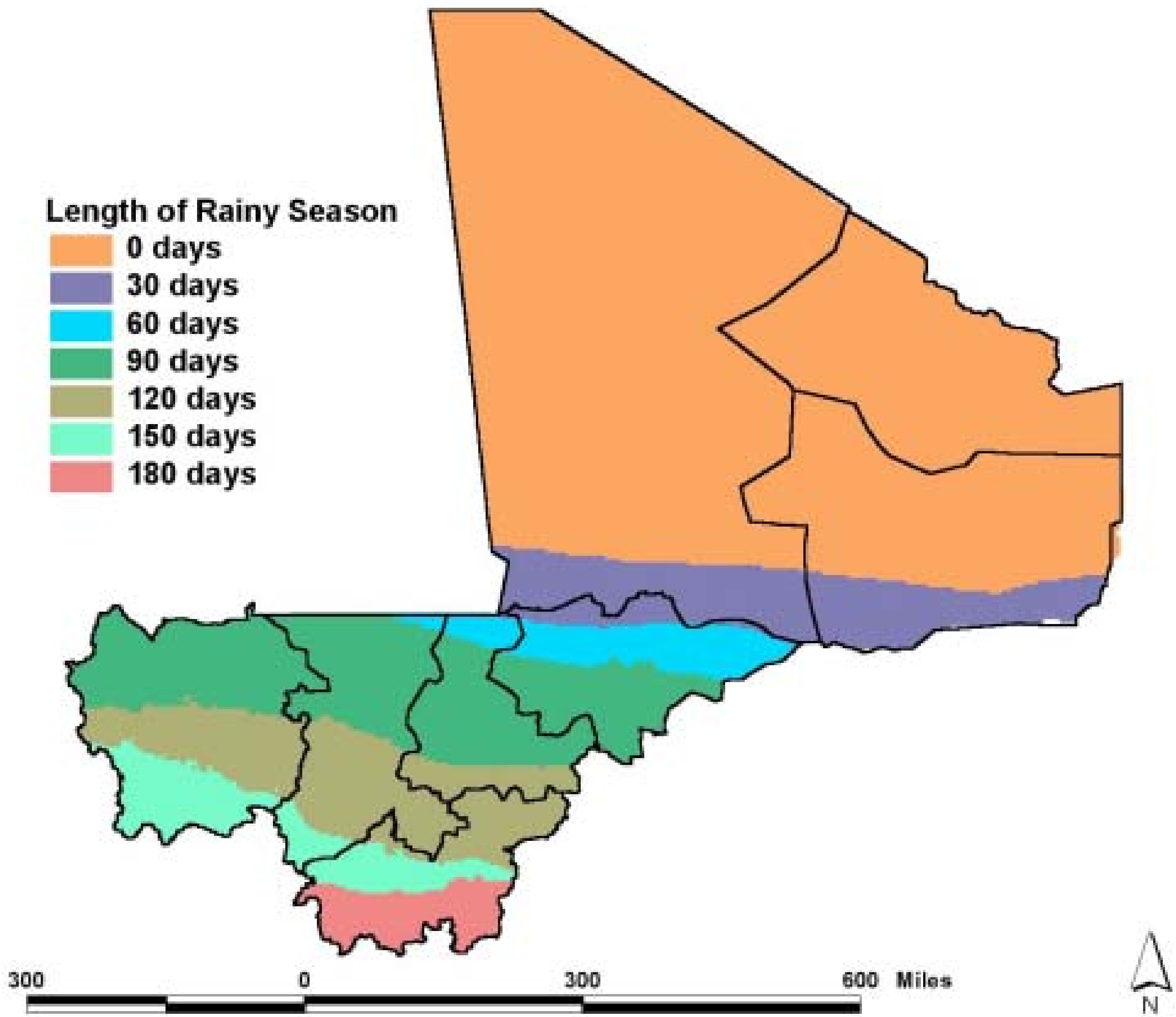


Figure 4.3-2. Length of rainy season in Mali

A spatial analysis framework was developed to identify sites with similar environmental characteristics in which the impact of new technologies would be evaluated. This framework also helped identify areas from which representative farms or households should be selected for more detailed study using farm-level economic models. Using the concept of geographic equivalence, we could also locate areas with similar agro-ecological characteristics, which show potential for adapting new technologies.

To define the zones of geographic equivalence, a spatially explicit analysis employing clustering techniques (Ward's minimum variance) on interpolated (monthly) climate surfaces was used in conjunction with regional soils data. The result of this analysis was a GIS that identified spatially explicit polygons containing unique climate/soil combinations, which were defined as agricultural climatic zones.

Spatial sampling methods were used to link biophysical simulation models and economic models. The relevant historical data for economic models are generally stratified by political boundaries in which they are collected. Biophysical models that produce information on the performance of various crops and rangelands are not defined by political boundaries but by geographic zones characterized by their environments and natural resources. Therefore, a systematic method of aggregating biophysical model output by geographic zones, which included both crop yield and environmental impact estimates, was developed so that these outputs could be compared to data reported at various administrative levels in Mali.

4.3.1 Definition of Simulation Environments

Methods were developed to estimate the performance of the sorghum production system in areas other than where experimental data exist. A two-step process was used. First, a set of unique polygons defined by climate and soil, was developed using the Almanac Characterization Tool (ACT). In each polygon, the yields of various crops, including sorghum, were estimated using the EPIC model. The results of this bio-physical analysis were summarized as weighted average yields for politically defined districts so that they could be used as input to economic models, since other data for these models is collected and reported by these districts. The method was also used to define areas of geographic equivalence in other locations, including Senegal and Burkina Faso, where the sorghum production system was presumed to be adaptable.

ACT foundation data include significant climatic information generated from a procedure that interpolates historical weather station point data to continuous surfaces (ANUSPLIN procedure, Hutchinson 1991, 1995). The ANUSPLIN procedure fits trivariate thin plate spline functions based on location and elevation to climate station data. For Africa, mean monthly values of rainfall and potential evapo-transpiration (PE), monthly minimum and maximum temperatures were collected from more than 6,000 precipitation and 1,500 temperature stations from the period 1920-1980. A separate FAO database provided over 1,200 stations with calculated potential evapo-transpiration. The surface fitting programs determine the optimal tradeoff between goodness of fit and surface smoothing by minimizing the generalized cross validation and also allow for the weighting of stations, roads, towns, markets, rivers, elevation (and its derivatives), census data, soils, and soil attributes, and any other appropriate, available information.

After creation of the interpolated climatic surfaces, a growing season model was created to identify the five consecutive months that maximize water availability in the environment (Corbett and O'Brien, 1998). This growing season model has been shown to be quite effective in the identification of the growing season in Africa where water is the main limiting factor. A cluster analysis was run (Wards Minimum Variance method

– SAS software) with the input variables being the climatic characteristics of each month of the growing season (maximum and minimum temperature, precipitation, potential evapotranspiration). The results of this cluster analysis identified areas designated as "effective environments," which are areas of highly similar climatology during the growing season (Figure 4.3.1-1).

After generating statistics describing each effective environment, those receiving less than 300 mm of rainfall during the five consecutive wettest months were eliminated from further consideration. After this elimination, 31 unique effective environments were identified across the three countries. These were then crosstabulated with a soil map of the region (Figure 4.3.1-2, FAO source, as modified by the World Soils Resource Group) that consisted of 15 soil sub-orders.

The results of this spatial cross-tabulation (overlay) identified 191 spatially explicit areas that were designated as "simulation environments." These simulation environments (Figure 4.3.1-3) express both climate and soil characteristics but are independent of the administrative boundaries for the region. They serve as a "sampling frame" for the biophysical models in this evaluation in Mali and were later used to evaluate the potential impact in areas where the technology could be adapted.

4.4 Biophysical Inputs for Agricultural Sector Model (ASM)

The biophysical characteristics of each of these simulation environments (i.e., climate, soils, topography, etc) were used as variables in the Erosion Productivity Impact Calculator (EPIC) model. EPIC is used to predict yields for six major crops — pearl millet, grain sorghum, maize, cowpea, peanut, and cotton.

The model was run for each combination of crop/technology scenarios and simulation environments. The EPIC model is a continuous, daily time-step model designed to provide simulation output summaries on a daily, monthly, annual and/or multi-year basis. It can be run for long sequences of years allowing for development of frequency distribution output statistics for many simulated attributes. The model is frequently used for 50- to 100-year simulations or longer. In this evaluation, 20-year simulations were used because this was the length of reliable weather data for the region. The drainage area considered by EPIC is generally a field-sized area, up to 100 ha. The major components and processes simulated by the model are hydrology, erosion-sediment, nutrient cycling, plant growth, aluminum toxicity / lime, soil temperature, tillage, economics, and plant environment control (management). More detailed descriptions of the model and component parts are found in articles and publications listed in the references.

The EPIC model uses a weather generator (WxGEN) which was fed the climatic monthly means for each of the simulation zones. For distribution of precipitation, a vitally important factor, the nearest WMO daily weather station was selected to provide the wet day-dry day statistics. Because of the strong north-south precipitation gradient, a routine was used that selected the stations at a 3:1 ratio of east-west distance relative to north-south. Data regarding quantities and prices of commodities produced and consumed nationally and regionally, imports, exports, crop mixes, land resources, labor availability on farms, wage rates, etc. were obtained from published abstracts of the Mali economy.

Most of the cultural practice, soils information, and variety information used in the simulations were obtained from a study by Purdue University and Winrock International conducted in Burkina Faso (Lowenbberg-

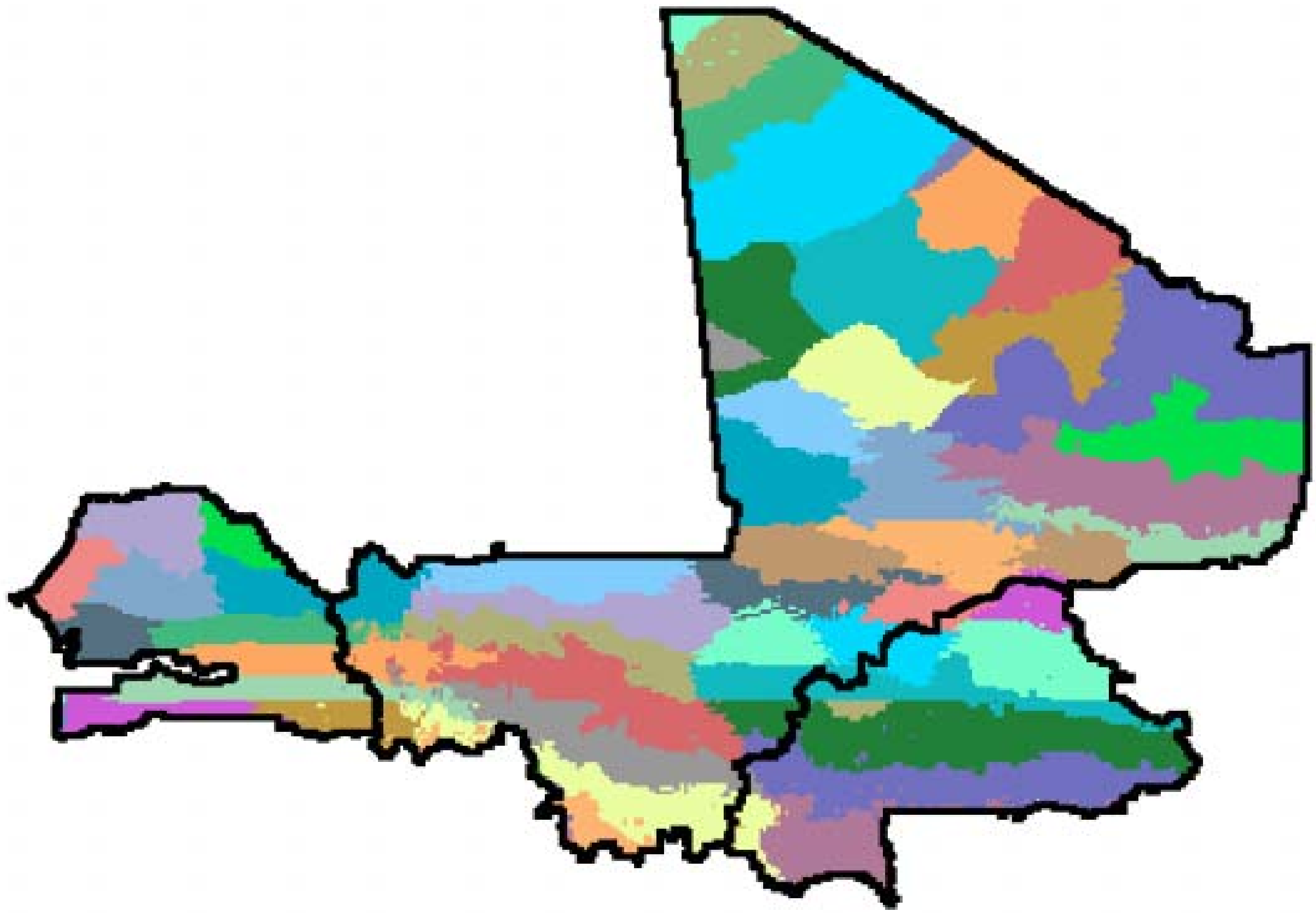


Figure 4.3.1-1. Effective environments in Senegal, Mali, and Burkina Faso were derived using a clust analysis (Ward's minimum variance) on interpolated (monthly) climate surfaces using the 5 consecut months that maximize water availability.

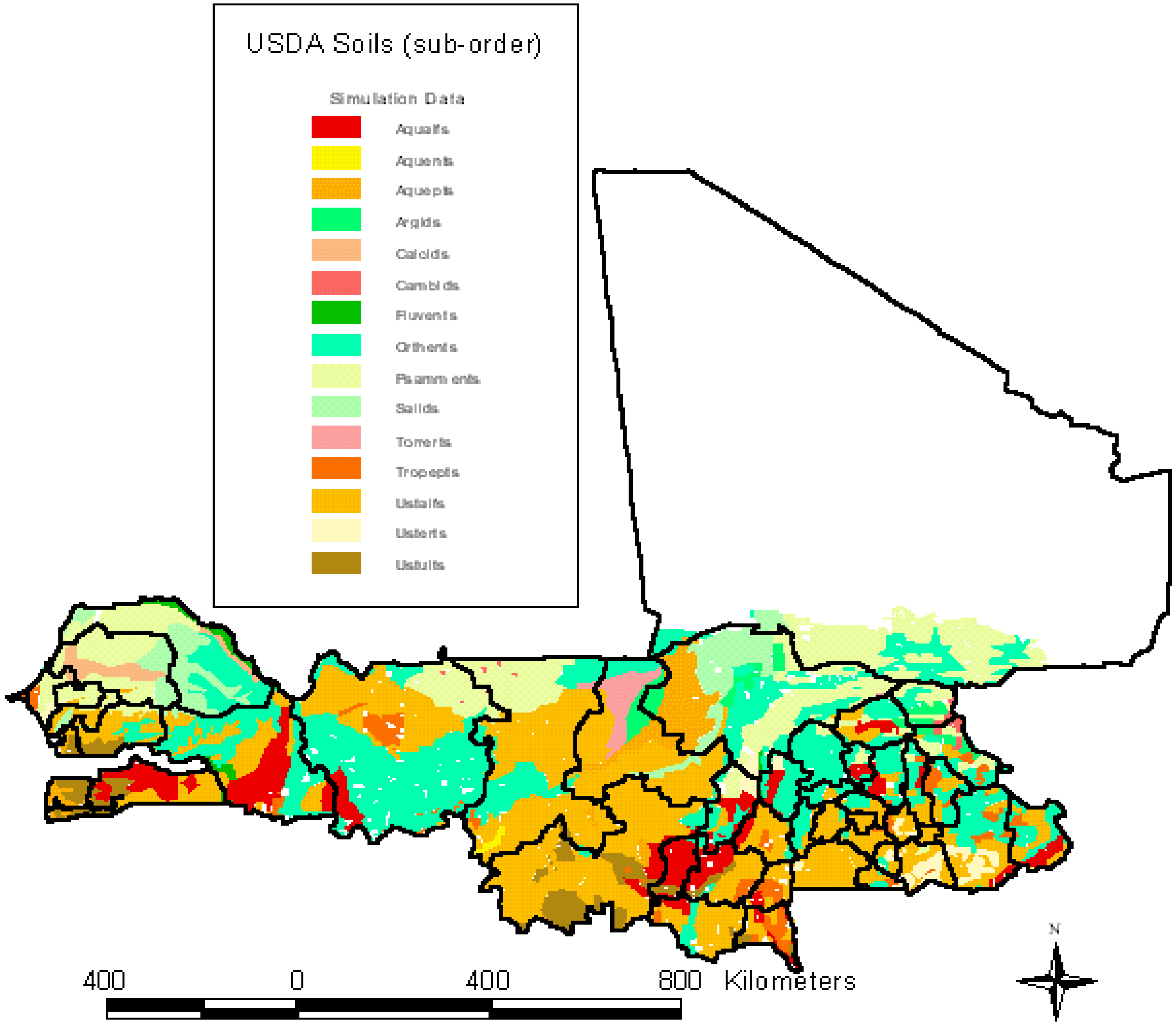


Figure 4.3.1-2. United States Department of Agriculture (USDA) soil suborders in Senegal, Mali, and Burkina Faso that were linked spatially to effective environments to create simulation environments.

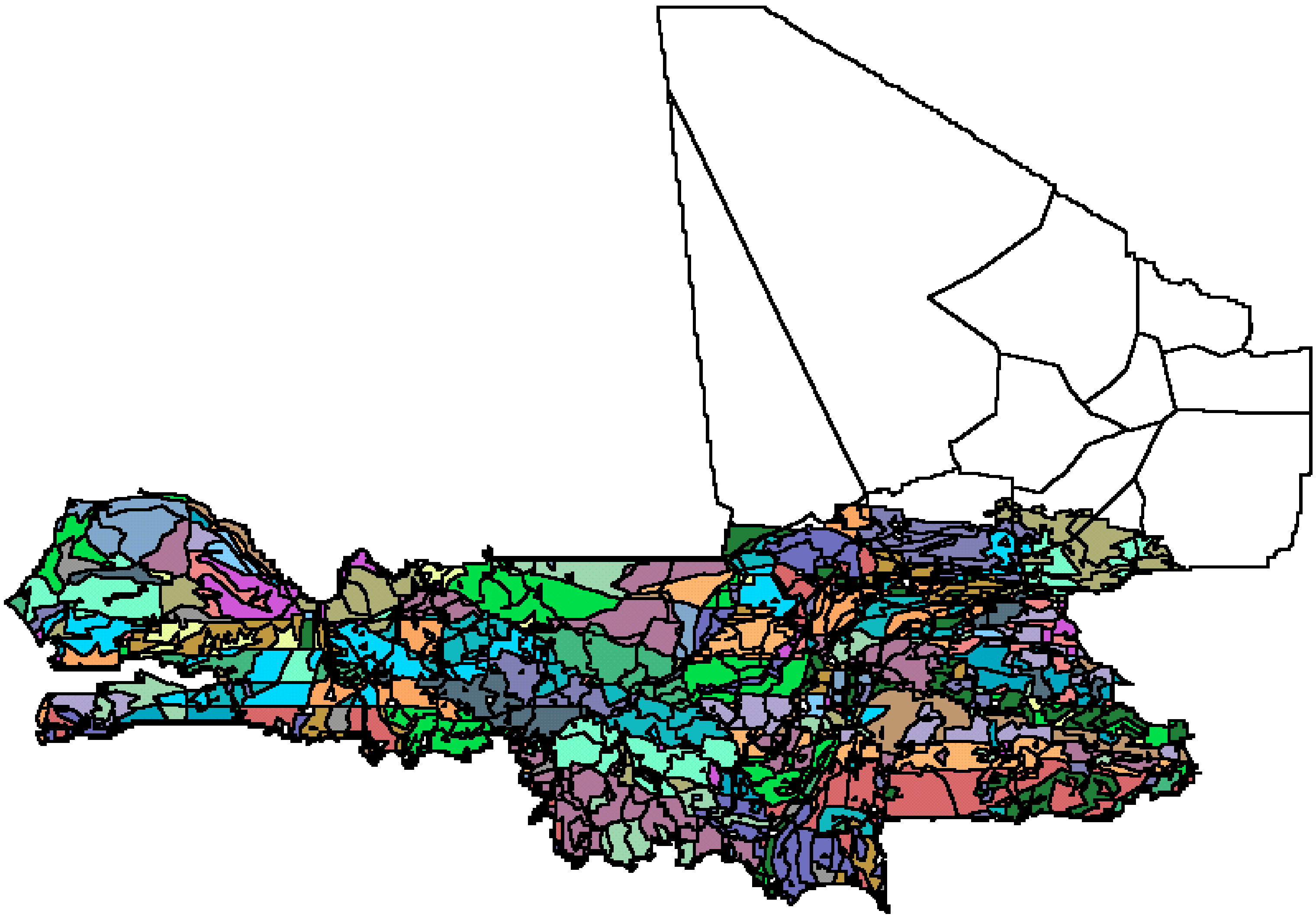


Figure 4.3.1-3. Effective environments and soil suborders were combined to create unique simulation environments for Senegal, Mali, and Burkina Faso. The monthly climate data for each simulation zone and its soil type were input into the EPIC model for the crop simulations.

DeBoer, et al, 1994). One of the most difficult set of parameters to obtain for the simulations were the soil attributes needed by the model. These attributes were extracted from the above reference and various other in-house databases and reports. Of particular difficulty and sensitivity was the estimate of plant extractable water. After several simulation attempts and conversations with soil scientists familiar with the soils in the area, a determination was made that the majority of soils of West Africa have very low water-holding capacity. For the final simulations, values of 4% to 7% plant extractable water were used. These values seemed to provide reasonable tracking of the soil water conditions expected for this area and are consistent with the limited available information. However, further research and testing is needed to verify these coefficients.

The following is a summary of the technology scenarios that were evaluated for each of the crops simulated by the EPIC Model:

Grain Sorghum
Five scenarios were simulated for grain sorghum: These include:

- Striga with low fertility (nitrogen level of 10kg/ha)
- No striga with low fertility (nitrogen level of 10kg/ha)
- Striga with medium fertility (nitrogen level of 37kg/ha)
- No striga with medium fertility (nitrogen level of 37kg/ha)
- No striga with high fertility (nitrogen level of 50kg/ha)

Characteristics of the Striga Grain Sorghum used in the model were as follows:

- Striga simulated as a plant growing with grain sorghum
- Grain sorghum -115 day maturity
- Lower grain to biomass ratio
- Lower photosynthetic efficiency

Characteristics of the No Striga Grain Sorghum used in the model were:

- Grain sorghum- 95 day maturity
- Higher grain to biomass ratio
- Higher photosynthetic efficiency

Maize
Two scenarios were simulated for maize. These include:

- Maize with low fertility (nitrogen level of 10kg/ha)
- Maize level with medium fertility (nitrogen level of 37kg/ha)

Millet
Two scenarios were simulated for pearl millet. These are as follows:

- Millet with low fertility (nitrogen level of 10kg/ha)
- Millet level with medium fertility (nitrogen level of 37kg/ha)

Groundnuts
Two scenarios were simulated for groundnuts. The varieties and characteristics are as follows:

- Traditional Variety
  - 120 day maturity
  - lower nut to biomass ratio

- Improved Variety
  - 90 day maturity
  - higher nut to biomass ratio

Cowpeas and cotton
Cowpeas and cotton, the two remaining crops, had only one scenario each. These were simulated to provide yield estimates for use in extrapolation procedures in areas where historical data was unavailable.

Each of the 13 crop scenarios in all 191 simulation environments was run through 20 sequential years to produce a mean yield for each of the 2483, 20-year simulations. This kind of highly specific biophysical modeling exploits tools that can be exercised across regions, evaluating the biophysical adaptation of technology developed in a specific place. The crop simulation models use data from the specific place to 'verify' the simulations (in this case Mali). Extrapolation of verified, simulated results in one place provide some confidence for estimates in another.

4.4.1 Relating Biophysical Results in Simulations Environment to Results in Administrative Districts

Because economic data is often gathered in political reporting districts, rather than by agro-environmental areas, it was necessary to adapt the outputs of the EPIC model to political districts to use them as input to economic models. The mean yield for each of the 191 simulation zones was converted to mean area yields for the political reporting districts. These area yields were compared to the historical reported yields when available from Food and Agricultural Organization (FAO) and Famine Early Warning System (FEWS). These data were used to evaluate the accuracy of the models by comparing yield estimates to historical reported yields. Results were reported in the fraction of cases where model outputs and reported data were within +15% of each other.

Yield estimates for sorghum, maize, and millet were within ±15% of the long-term historical reported yields in 80% of the districts in all three countries (Figure 4.4.1-1; Tables 4.4.1.1 and 4.4.1.2). However, simulated yields for groundnuts, cowpea, and cotton were not as consistent; fewer political districts had historical yields close to simulated (Figure 4.4.1-1; Tables 4.4.1.3 and 4.4.1.4). The reason for this may be that the historical data were much weaker in both quantity and quality for these crops.

Groundnut yield estimates for approximately 80% of the reporting districts in Mali were within the ±15%, but for Burkina Faso, only 40% of the reporting districts fell within this target range (Figure 4.4.1-1) Data for comparison were not available for Senegal. Cotton simulations were within the ±15% target for approximately 70% of the Burkina Faso regions, but a very low percentage of regions in Mali met the ±15% target. However, these simulations were for dryland cotton because there was a lack of sufficient information to identify specific simulation environment where irrigation was used for cotton crops. Cowpeas simulations were quite stable, but the reported historical yields were very erratic. This may reflect that cowpeas are frequently planted to replace other crops in severely dry years.

An overview of the several regional simulations using outputs from the EPIC model are presented in Figures 4.4.1-2, 4.4.1-3, and 4.4.1-4. Figure 4.4.1-2 depicts a simulated total precipitation across the region, while

Figure 4.4.1-3 shows the simulated mean yield for the low fertility sorghum simulations by simulation zone. Figure 4.4.1-4 shows the mean low fertility sorghum yields by political unit after creating the area weighted mean yields.

Given the uncertainty about consistency and quality of reported data, the agreement between this and modeled outputs for the yield estimates is considered very good. While further analysis may improve the relationships, especially for cotton, it was concluded that these results were quite adequate to allow this method to be used in the subsequent analyses.

4.5 The Agricultural Sector Analysis of Mali

An agricultural sector model (ASM) for Mali was constructed and used to estimate the economic impacts of sorghum and pearl millet technology improvements under current and full adoption conditions. Adoption rates for sorghum and pearl millet production systems for the various variety, tillage and fertility improvements were obtained from published farmer survey data; unpublished data from research trials and Mali Extension Service (PNVA) and ICRISAT/IER; and expert opinion of researchers and extension personnel located at the Sobuta and Cinzana research stations. Current adoption rates are defined as the percentage of the sorghum and pearl millet planted area in each region using existing technology (Table 4.5.1). Full adoption rates are based on the expert opinions of the research and extension personnel in Mali, and defined as the maximum percentage of the area planted to sorghum and pearl millet that would use the

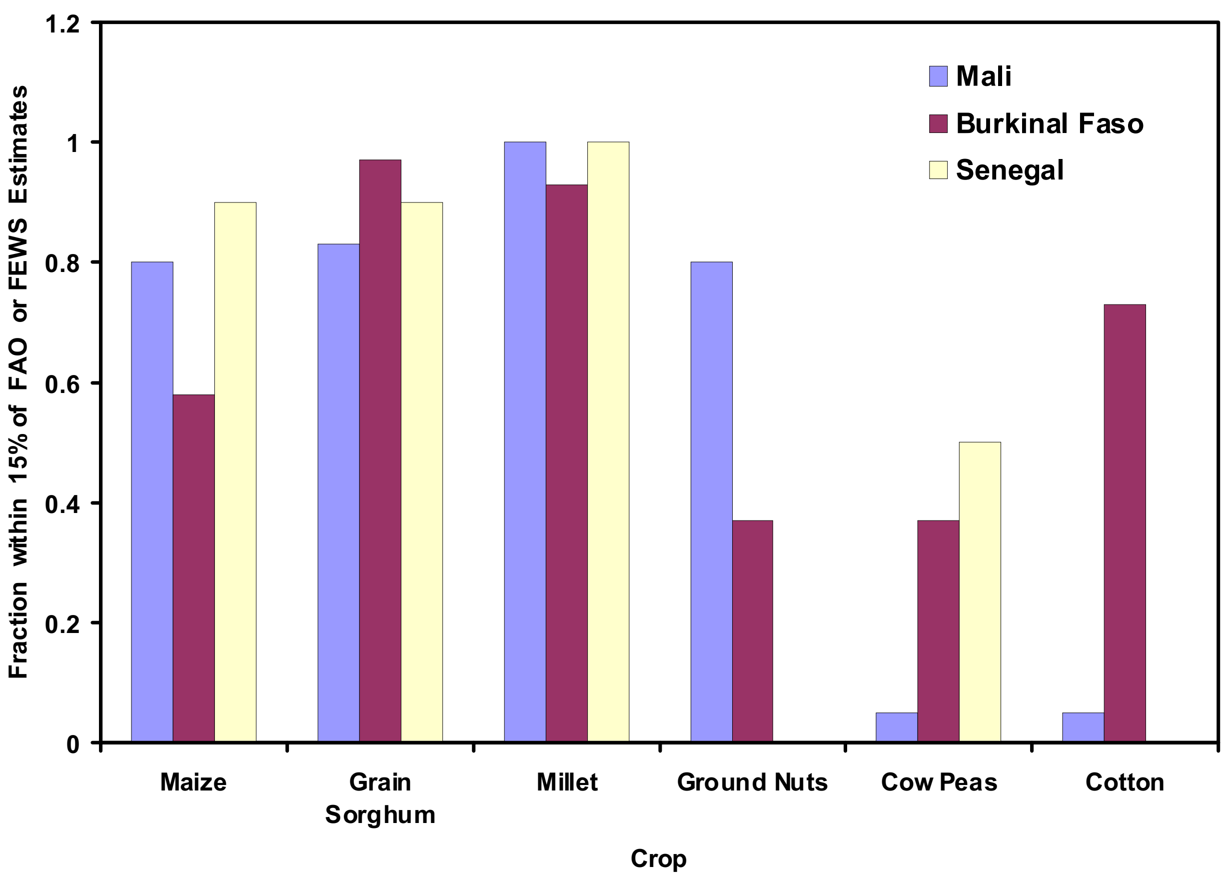


Figure 4.4.1-1. The fraction of country regional simulations by the EPIC model that were within 15% of FAO or FEWS estimates for that region.

Table 4.4.1.1. West Africa - Simulated (EPIC) and Reported Yield Estimates of Maize by Political Districts in Metric Tons/HA

		Maize Yield (Mt/ha)		
County/Region	**Area (ha)**	**EPIC F10**	**FAO Estimate**	**FEWS Estimate**
Mali				
Bamako	90442.1670	0.9567	0.7700	1.0000
Gao	811192.7470	0.0510	0.0000	
Kayes	117759.2210	0.8551	0.8300	0.9600
Mopti	89980.1780	0.8761	0.3600	0.2300
Segou	55142.6560	1.0703	0.9200	0.8900
Sikasso	76944.0890	1.1242	0.9800	1.0800
Burkina Faso				
Bam	4111.9010	0.9071	0.727	
Bazega	4471.2590	1.0327	0.551	
Bougouriba	6635.0900	0.9185	1.084	
Boulgou	9566.7690	1.1170	0.608	
Boulkiemde	4591.3730	1.1046	0.698	
Comoe	17152.0030	0.9769	1.182	
Ganzourgou	4153.3450	1.1036	0.805	
Gnagna	8641.1130	0.8987	1.037	
Gourma	26043.6770	0.9625	1.071	
Houet	15972.3510	1.0086	1.575	
Kadiogo	1858.7210	1.1488	0.662	
Kenedougou	8228.9150	1.1391	1.293	
Kossi	12894.8930	1.0012	1.338	
Kouritenga	1658.7110	1.0813	0.69	
Mouhoun	10627.7820	1.0272	1.566	
Nahouri	3535.3240	0.9350	0.694	
Namentenga	7251.4560	0.9465	0.589	
Oubritenga	4479.2140	0.9983	1.139	
Oudalan	9939.4610	0.8185	0	
Passore	3932.8100	0.8971	0.389	
Poni	9181.5440	0.9512	1.03	
Sanguie	4993.2670	0.9068	0.681	
Sanmatenga	8976.1760	0.9107	0.664	
Seno	13270.4130	0.9094	0.956	
Sissili	13045.2040	1.0141	0.906	
Soum	12648.5240	0.9162	0.623	
Sourou	9696.6390	0.8852	1.709	
Tapoa	14519.9730	0.9617	1.508	
Yatenga	12339.3270	0.8057	0.496	
Zoundweogo	2918.9680	1.0481	0.848	
Senegal				
Dakar	304.9970	0.9000	0.78	
Diourbel	4198.8880	0.8763	0.601	
Fatick	7591.0720	1.1363	1.374	
Kaolack	15129.6030	1.0823	1.423	
Kolda	20792.7280	1.0692	1.139	
Louga	29590.9350	0.8588	0.418	
Saint-Louis	44336.3890	0.8396	0.81	
Tambacounda	57573.6370	0.9499	1.033	
Thies	6482.7230	0.9552	0.947	
Ziguinchor	6873.9650	1.0980	1.024	

Table 4.4.1.2. West Africa - Simulated (EPIC) and Reported Yield Estimates of Sorghum by Political Districts in Metric Tons/HA

County/Region	Area (ha)	Sorghum Yield (Mt/ha)							
		EPIC F37	EPIC STF10	EPIC F10	EPIC STF37	EPIC F37	EPIC F50	FAO Estimate	FEWS Estimate
Mali									
Bamako	90442.1670	1.6866	0.5376	0.8084	0.8755	1.4554	1.5983	0.9500	0.8300
Gao	811192.7470	0.0917	0.0289	0.0460	0.0533	0.0857	0.0857	1.3300	
Kayes	117759.2210	1.4558	0.4846	0.7275	0.7742	1.3520	1.5015	0.9500	0.8400
Mopti	89980.1780	1.6573	0.5015	0.7617	0.9172	1.5564	1.6637	0.5600	0.5100
Segou	55142.6560	1.8024	0.5835	0.9175	0.9493	1.6530	1.7862	0.7300	0.8000
Sikasso	76944.0890	1.8701	0.6232	0.9325	0.9625	1.5959	1.7726	0.8000	0.7400
Burkina Faso									
Bam	4111.9010	1.6795	0.4892	0.7071	0.8388	1.5516	1.7524	0.471	
Bazega	4471.2590	1.8213	0.5213	0.9161	0.8185	1.6891	1.8891	0.652	
Bougouriba	6635.0900	1.6762	0.5881	0.7280	0.9558	1.4339	1.6279	0.626	
Boulgou	9566.7690	2.0883	0.7190	0.9244	1.2392	1.8816	2.1607	0.735	
Boulkiemde	4591.3730	1.9030	0.4809	0.9561	0.7595	1.7414	1.9503	0.599	
Comoe	17152.0030	1.6442	0.5778	0.7898	0.9431	1.4983	1.6925	0.855	
Ganzourgou	4153.3450	1.9591	0.5209	0.9695	0.8313	1.8118	2.0624	0.743	
Gnagna	8641.1130	1.6179	0.4240	0.7482	0.6887	1.4909	1.7329	0.748	
Gourma	26043.6770	1.7893	0.5497	0.7826	0.8935	1.5841	1.8365	0.842	
Houet	15972.3510	1.7843	0.6382	0.8358	1.0131	1.5846	1.7564	1.036	
Kadiogo	1858.7210	1.9488	0.4997	0.9994	0.7994	1.7992	1.9994	0.476	
Kenedougou	8228.9150	1.8993	0.7033	0.9993	1.0911	1.7499	1.8757	0.992	
Kossi	12894.8930	1.8343	0.5393	0.8374	0.8488	1.6282	1.8102	0.8	
Kouritenga	1658.7110	1.8978	0.5288	0.9669	0.8475	1.7669	1.9647	0.701	
Mouhoun	10627.7820	1.8368	0.5782	0.8747	0.9152	1.6408	1.8211	0.805	
Nahouri	3535.3240	1.7790	0.6144	0.7350	1.0133	1.4802	1.6813	0.651	
Namentenga	7251.4560	1.6907	0.4391	0.7671	0.7438	1.5539	1.7849	0.531	
Oubritenga	4479.2140	1.7853	0.4109	0.8204	0.6219	1.5754	1.8180	0.572	
Oudalan	9939.4610	1.4954	0.4576	0.7115	0.8307	1.4971	1.5675	0.422	
Passore	3932.8100	1.6967	0.3489	0.6971	0.4982	1.4217	1.6974	0.556	
Poni	9181.5440	1.6417	0.5708	0.7731	0.9394	1.4880	1.6880	0.685	
Sanguie	4993.2670	1.6975	0.4214	0.7213	0.6181	1.4158	1.6520	0.599	
Sanmatenga	8976.1760	1.6547	0.4226	0.7127	0.7292	1.5145	1.7524	0.515	
Seno	13270.4130	1.6795	0.4633	0.7365	0.8310	1.5876	1.7396	0.557	
Sissili	13045.2040	1.9165	0.6950	0.8183	1.1007	1.6315	1.8382	0.741	
Soum	12648.5240	1.6648	0.4867	0.7877	0.8535	1.5986	1.7377	0.39	
Sourou	9696.6390	1.6591	0.4528	0.7055	0.7223	1.5133	1.7748	0.67	
Tapoa	14519.9730	1.7258	0.5052	0.7828	0.7765	1.5201	1.7332	0.772	
Yatenga	12339.3270	1.5366	0.3914	0.6087	0.6703	1.3383	1.6292	0.447	
Zoundweogo	2918.9680	1.9733	0.6835	0.8523	1.1461	1.7223	1.9630	0.895	
Senegal									
Dakar	304.9970	1.7001	0.5001	0.7001	0.8001	1.5001	1.8000	0.64	
Diourbel	4198.8880	1.7168	0.5534	0.7671	0.9755	1.6056	1.6518	0.739	
Fatick	7591.0720	1.8687	0.7011	0.9593	1.1452	1.7725	1.8587	0.766	
Kaolack	15129.6030	1.7953	0.6548	0.9355	1.0661	1.7154	1.7990	1.114	
Kolda	20792.7280	1.7201	0.6811	0.9822	1.0286	1.6579	1.7703	0.94	
Louga	29590.9350	1.5475	0.5448	0.7601	0.9963	1.4653	1.4674	0.418	
Saint-Louis	44336.3890	1.4493	0.5338	0.7512	0.9882	1.3987	1.4579	0.698	
Tambacounda	57573.6370	1.6336	0.5802	0.8523	0.9436	1.5690	1.7172	0.776	
Thies	6482.7230	1.8601	0.5965	0.8215	1.0440	1.7135	1.8468	0.86	
Ziguinchor	6873.9650	1.8034	0.6811	0.9909	1.0368	1.6733	1.8033	0.806	

Table 4.4.1.3 West Africa - Simulated (EPIC) and Reported Yield Estimates of Groundnuts by Political Districts in Metric Tons/HA

		Groundnut Yield (Mt/ha)			
County/Region	**Area (ha)**	**EPIC 90**	**EPIC 120**	**FAO Estimate**	**FEWS Estimate**
Mali					
Bamako	90442.1670	0.9006	0.8366	0.7900	0.8800
Gao	811192.7470	0.0322	0.0356	0.0000	
Kayes	117759.2210	0.8803	0.8334	2.0200	0.8800
Mopti	89980.1780	0.7371	0.7201	0.8600	0.4600
Segou	55142.6560	0.8595	0.7851	0.8200	0.5800
Sikasso	76944.0890	1.0455	0.9583	0.7600	0.7900
Burkina Faso					
Bam	4111.9010	0.9334	0.8387	0.683	
Bazega	4471.2590	1.0000	0.9075	1.386	
Bougouriba	6635.0900	1.0060	0.9415	0.718	
Boulgou	9566.7690	1.0791	0.9816	0.503	
Boulkiemde	4591.3730	1.0000	0.8537	0.359	
Comoe	17152.0030	1.0840	0.9926	0.891	
Ganzourgou	4153.3450	1.0388	0.9037	0.832	
Gnagna	8641.1130	0.9464	0.8423	0.552	
Gourma	26043.6770	1.0281	0.9262	0.722	
Houet	15972.3510	0.9832	0.9025	0.918	
Kadiogo	1858.7210	1.0000	0.8505	0.879	
Kenedougou	8228.9150	0.9197	0.8569	0.89	
Kossi	12894.8930	0.9675	0.8560	0.41	
Kouritenga	1658.7110	0.9978	0.8978	1.34	
Mouhoun	10627.7820	0.9831	0.8846	0.507	
Nahouri	3535.3240	1.0205	0.9525	0.854	
Namentenga	7251.4560	0.9418	0.8349	1.165	
Oubritenga	4479.2140	0.9984	0.8164	0.59	
Oudalan	9939.4610	0.6850	0.6426	0	
Passore	3932.8100	1.0000	0.8004	0.358	
Poni	9181.5440	1.0439	0.9662	0.729	
Sanguie	4993.2670	1.0000	0.8530	0.436	
Sanmatenga	8976.1760	0.9284	0.8190	0.698	
Seno	13270.4130	0.8406	0.7719	0.967	
Sissili	13045.2040	1.0066	0.9066	0.487	
Soum	12648.5240	0.8235	0.7539	0.665	
Sourou	9696.6390	0.9770	0.8551	0.319	
Tapoa	14519.9730	0.9840	0.8683	0.637	
Yatenga	12339.3270	0.9151	0.8727	0.59	
Zoundweogo	2918.9680	1.0522	0.9636	0.782	
Senegal					
Dakar	304.9970	0.8999	0.7999		
Diourbel	4198.8880	0.7444	0.7156		
Fatick	7591.0720	0.8678	0.7849		
Kaolack	15129.6030	0.8328	0.7789		
Kolda	20792.7280	0.9325	0.8332		
Louga	29590.9350	0.6409	0.6651		
Saint-Louis	44336.3890	0.5600	0.5917		
Tambacounda	57573.6370	0.8714	0.8118		
Thies	6482.7230	0.8217	0.7496		
Ziguinchor	6873.9650	0.8909	0.8010		

Table 4.4.1.4 West Africa - Simulated (EPIC) and Reported Yield Estimates of Cotton by Political Districts in Metric Tons/HA

		Cotton Yield (t/ha)		
County/Region	**Area (ha)**	**EPIC F67**	**FAO Estimate**	**FEWS Estimate**
Mali				
Bamako	90442.1670	0.6779	1.34	1.34
Gao	811192.7470	0.0494	0	
Kayes	117759.2210	0.5863	0	
Mopti	89980.1780	0.9076	0	0
Segou	55142.6560	0.8489	1.35	1.16
Sikasso	76944.0890	0.7180	1.39	1.31
Burkina Faso				
Bam	4111.9010	0.7714	0.903	
Bazega	4471.2590	0.6681	0	
Bougouriba	6635.0900	0.7383	0.946	
Boulgou	9566.7690	0.9959	0	
Boulkiemde	4591.3730	0.5841	0	
Comoe	17152.0030	0.7381	1.546	
Ganzourgou	4153.3450	0.6870	0.759	
Gnagna	8641.1130	0.4953	0	
Gourma	26043.6770	0.6867	0.495	
Houet	15972.3510	0.9056	1.242	
Kadiogo	1858.7210	0.6007	0	
Kenedougou	8228.9150	1.0766	1.017	
Kossi	12894.8930	0.8354	1.005	
Kouritenga	1658.7110	0.7187	0	
Mouhoun	10627.7820	0.7489	0.881	
Nahouri	3535.3240	0.7235	0	
Namentenga	7251.4560	0.5760	0	
Oubritenga	4479.2140	0.4281	1.98	
Oudalan	9939.4610	0.8086	0	
Passore	3932.8100	0.3489	0	
Poni	9181.5440	0.8330	0	
Sanguie	4993.2670	0.4627	0.516	
Sanmatenga	8976.1760	0.6039	0	
Seno	13270.4130	0.8029	0	
Sissili	13045.2040	0.8124	1.022	
Soum	12648.5240	0.7922	0	
Sourou	9696.6390	0.6342	1.199	
Tapoa	14519.9730	0.6254	0.87	
Yatenga	12339.3270	0.4294	0	
Zoundweogo	2918.9680	0.8805	0.758	
Senegal				
Dakar	304.9970	0.5002		
Diourbel	4198.8880	1.0897		
Fatick	7591.0720	1.1352		
Kaolack	15129.6030	0.9907		
Kolda	20792.7280	0.7803		
Louga	29590.9350	1.1341		
Saint-Louis	44336.3890	0.9700		
Tambacounda	57573.6370	0.7440		
Thies	6482.7230	1.0125		
Ziguinchor	6873.9650	0.8874		

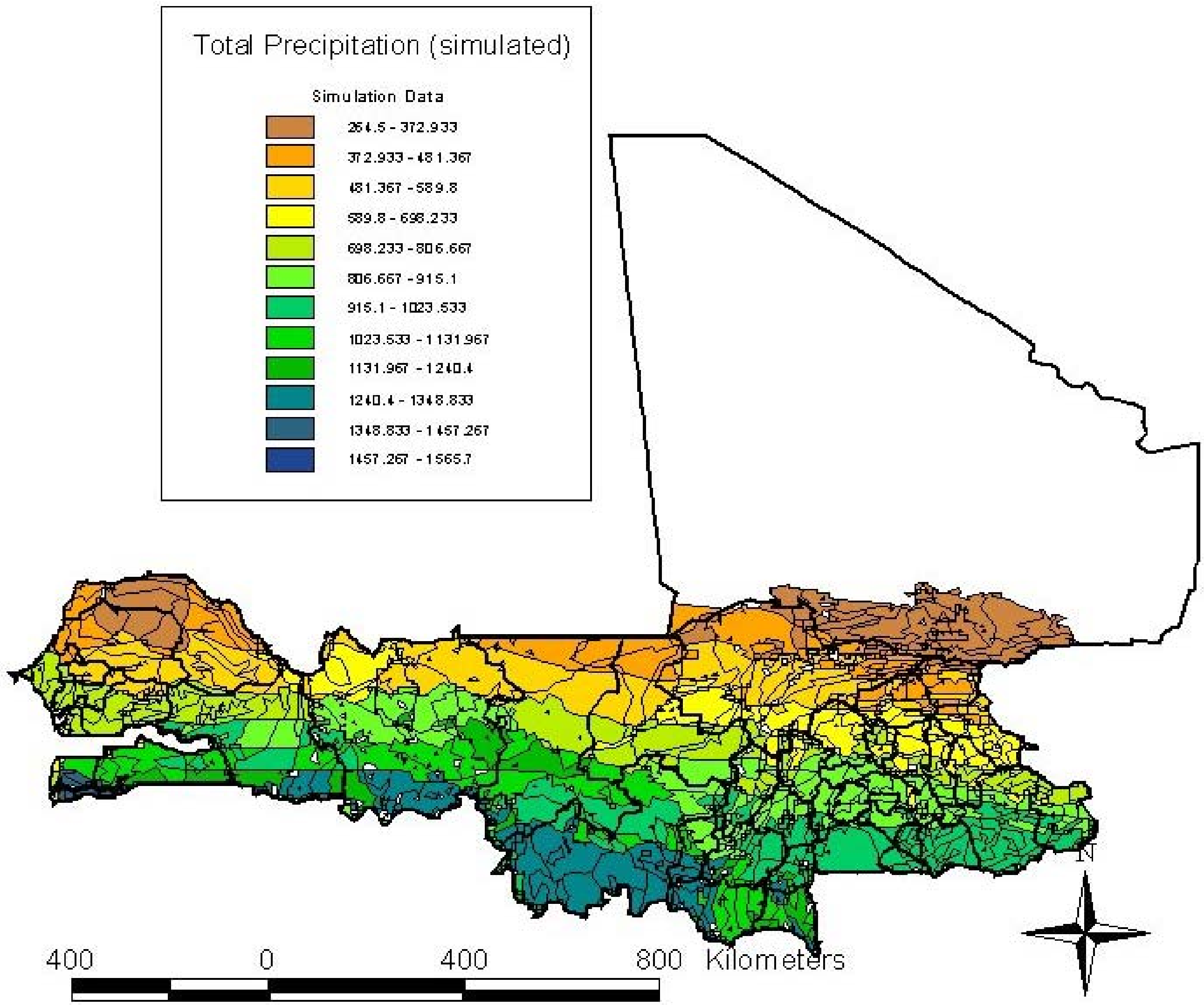


Figure 4.4.1-2. Simulated precipitation output from the WxGen weather generator model scaled across regions in Senegal, Mali, and Burkina Faso.

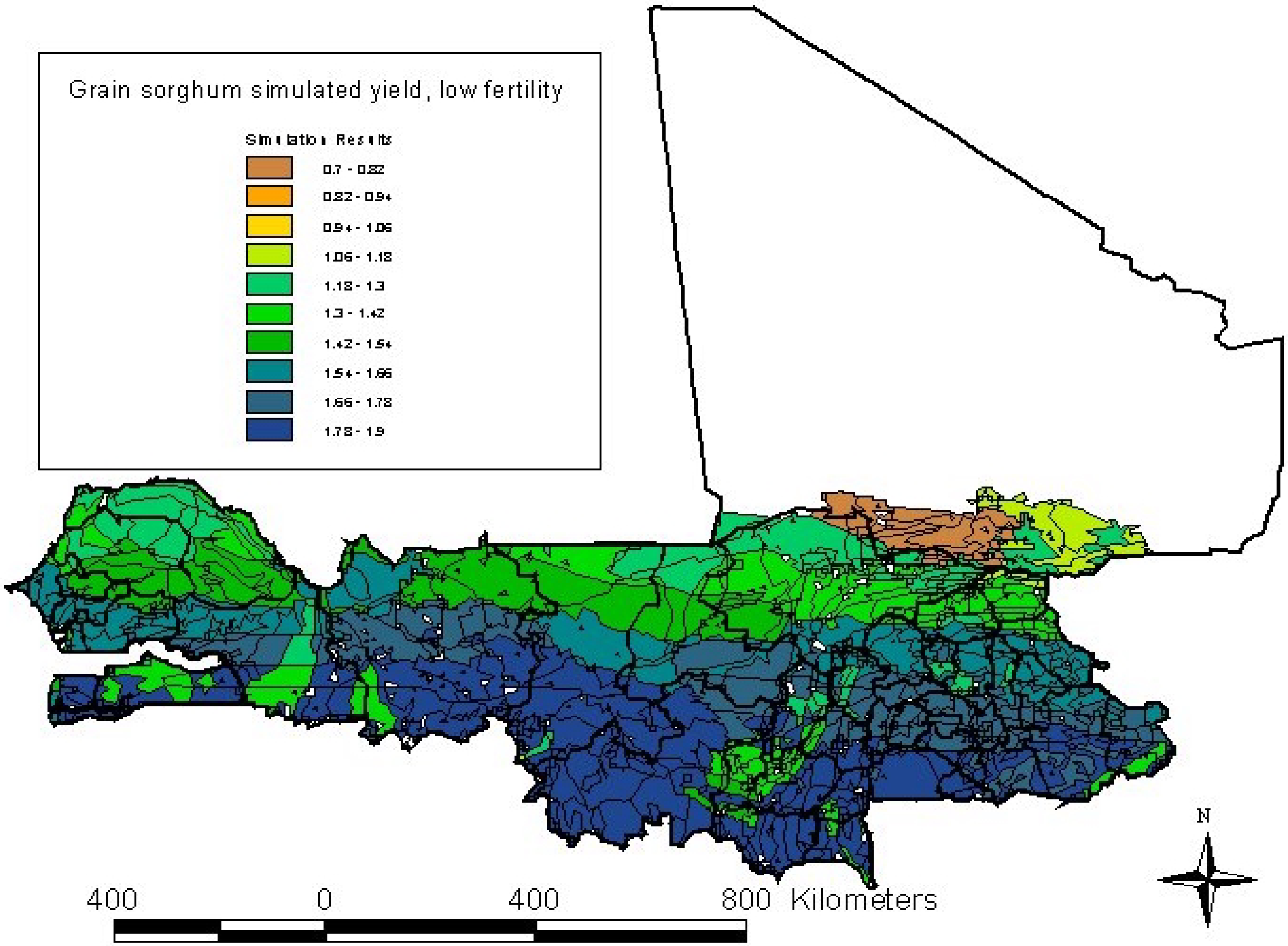


Figure 4.4.1-3. Results of EPIC model simulations for sorghum yield, by simulation zone, for gra
sorghum in low fertility soils.

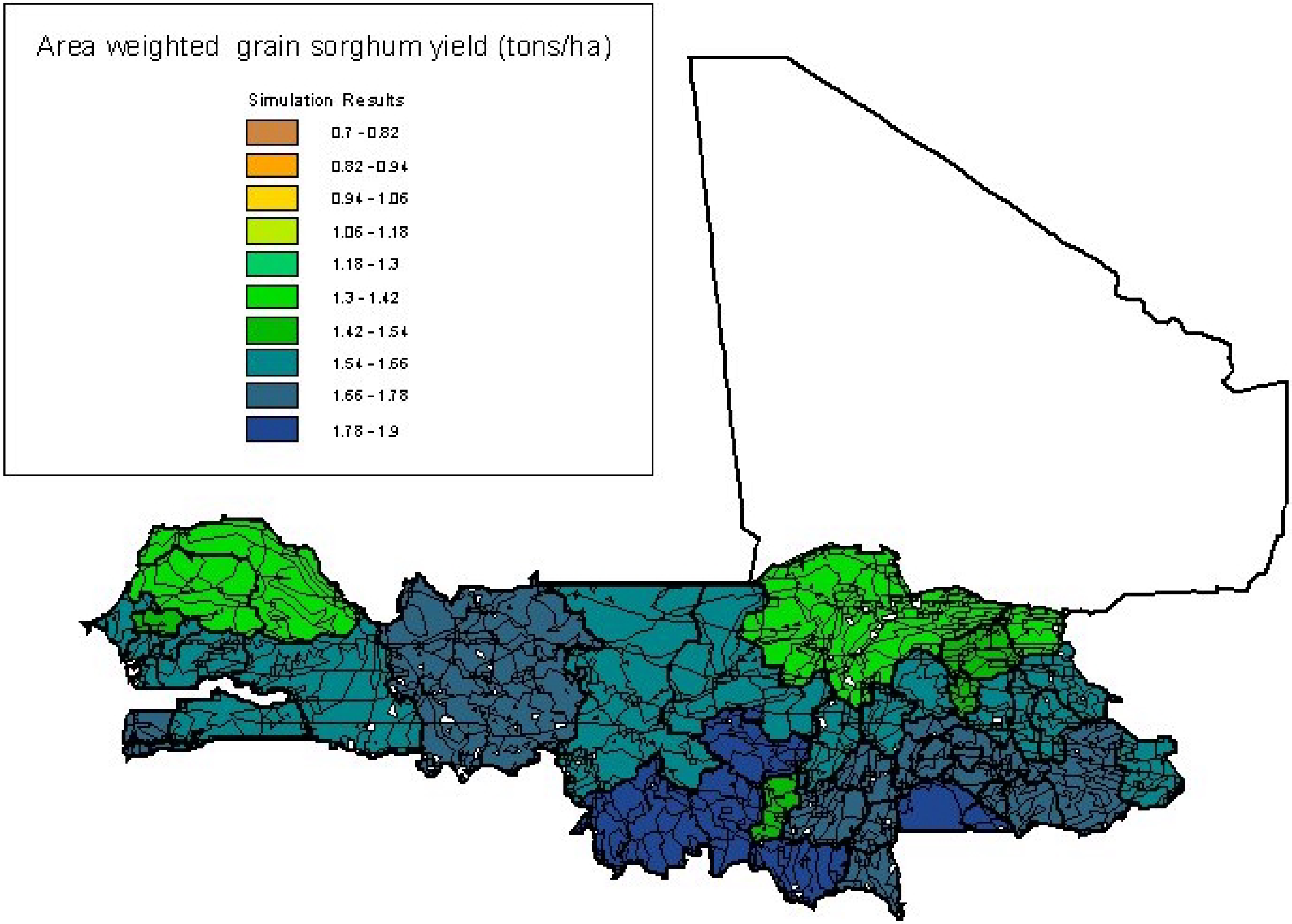


Figure 4.4.1-4. Area weighted results of EPIC model simulations for the low fertility sorghum by administrative region.

technologies. Full adoption was estimated to be attainable within 10 to 15 years after introduction of the technology.

Both deterministic and stochastic versions of the Mali ASM were developed. The deterministic Mali ASM treats all technological improvements at their mean production effect and computes resultant economic implications at regional, national, and global scales. The stochastic version of the Mali ASM includes a crop yield distribution and examines the outcome of variability in production income and farmers' risk aversion on aggregate economic welfare as well as the way consumers, producers, farm family home consumption, and foreign surpluses are affected. The uncertainty in the model arises due to crop yield variations stemming from variable rainfall conditions (i.e., states of nature).

Sorghum and pearl millet yields for local and improved varieties for the Sudanian Zone and the Sudano-Guinean Zone are from Coulibaly (1995). These yield data were collected from different sources in Mali within the sorghum and pearl millet breeding program. The available data covered 5 to 8 states of nature regarding the distribution of rainfall within season and the annual quantity of rainfall and 9 years of yield data. On-station, researcher managed trials and researcher managed on-farm trials and farming systems data were collected. On-station yields were reduced 25% and researcher managed on-farm yields were reduced 15% to account for better conditions on station for conducting experiments and better management (plowing, weeding, and harvesting on a timely basis) of researcher managed on-farm trials than farmers fields.

Technology improvements were appraised in the Mali ASM by setting up different crop yields and cost of production versions of the model to provide simulation with and without the sorghum and pearl millet improvement technologies in Mali agriculture. The Mali ASM upon solution generated estimates of regional and national agricultural commodity prices and quantities, input use, land use and crop mixes, and consumer and producer economic surpluses.

The stochastic version of the Mali ASM provides insight into the relationship between individual farmer behavior and aggregate welfare. It represents an important methodological contribution to the analysis of impacts from technology advance under risk and uncertainty. In Mali, actions that may appear profitable to an individual farm firm may not be profitable to the aggregate sector after market adjustments have occurred. Because of farm sector and foreign surplus losses in welfare due to increasing risk aversion behavior, total social welfare may be decreased, even though the variability in producers, consumers, foreign, and total economic surpluses decreases. Consequently, with uncertainty, there is a trade-off between the mean level of total social welfare and its variability in Mali as producers become more risk averse in their behavior. A mathematical description of the stochastic Mali ASM is provided in the Appendix.

4.5.1 Model Characteristics

In ASM, the market is assumed competitive and equilibrium price and quantity are determined by the intersection of supply and demand for each commodity. Two types of consumers are modeled. Subsistence level farmers are presumed to retain sufficient food for family consumption to meet specified minimum caloric needs and tastes and preferences before products are marketed. Market-based consumers in the cities are assumed to maximize their utility subject to budget constraints. Similarly, producers maximize their profit given a production technology and prices; therefore, the supply function depends on prices and technology. Aggregation of each consumer demand function and each producer supply function results in market demand and supply functions. In this competitive market, social welfare is maximized when the

Table 4.5.1 Adoption Rates for Variety/Cropping System Alternatives

Scenario and Production System Technology	Adoption Rate by Region (%) Mopti	Segou	Koulikoro/Kayes
Current Adoption Scenario - sorghum			
LORDG (1)	33	27	26
LOMANRDG (2)	40	40	40
LOFERRDG (3)	4	4	4
IMMANRDG (4)	18	24	25
IMFERRDG (5)	5	5	5
Current Adoption Scenario - millet			
LORDG (1)	36	24	33
LOMANRDG (2)	45	45	45
LOFERRDG (3)	2	2	2
IMMANRDG (4)	14	26	17
IMFERRDG (5)	3	3	3
Full Adoption Scenario - sorghum			
LORDG (1)	5	5	5
LOMANRDG (2)	10	10	10
LOFERRDG (3)	15	15	15
IMMANRDG (4)	50	50	50
IMFERRDG (5)	20	20	20
Full Adoption Scenario - millet			
LORDG (1)	10	10	10
LOMANRDG (2)	10	10	10
LOFERRDG (3)	15	15	15
IMMANRDG (4)	45	45	45
IMFERRDG (5)	20	20	20
N'Tenimissa Scenario - sorghum			
TEMRDG (6)	5	5	5
TEMMANRDG (7)	10	10	10
TEMFERRDG (8)	15	15	15
Seguetana Cinzana Scenario - sorghum			
SEGMANRDG (9)	10	10	10
SEGFERRDG (10)	15	15	15

market is in equilibrium. That is, maximum welfare will occur at the intersection of the market demand and supply functions. ASM assumes maximization of social welfare as the objective function, and also includes market balance constraints and resource constraints.

The Mali ASM has five sorghum production systems. The current sorghum production technology has a mix of traditional and improved production practices. Traditional practices include the use of local varieties, ridge tillage, and some manure to increase soil fertility. Improved practices not only include manure applications and ridge tillage to improve water retention of the soil but also use of improved varieties and inorganic fertilizers (Table 4.5.1.1). The more intensive production scenario includes a more complete adoption of the improved production practices and varieties, and the adoption of two new varieties – N'Tenimissa and Seguetana Cinzana.

In conducting the impact assessment, the Mali ASM was run under 1997 demand and supply conditions

Table 4.5.1.1 The Definition of Sorghum Production Technology for the Variety/Cropping System Alternatives.

Scenarios	Allowed Sorghum/Millet Production System Technology
Current adoption - no yield change and current adoption rates	Local varieties with ridge tillage (1) Local varieties with manure and ridge tillage (2) Local varieties with inorganic fertilizer and ridge tillage (3) Improved varieties with manure and ridge tillage (4) Improved varieties with inorganic fertilizer and ridge tillage (5)
Full Adoption - no yield change and full adoption rates	Local varieties with ridge tillage (1) Local varieties with manure and ridge tillage (2) Local varieties with inorganic fertilizer and ridge tillage (3) Improved varieties with manure and ridge tillage (4) Improved varieties with inorganic fertilizer and ridge tillage (5)
N'Tenimissa - with increased yield and full adoption rates	Local varieties with ridge tillage and 37% yield increase (6) Local varieties with manure and ridge tillage, and 25% yield increase (7) Local varieties with inorganic fertilizer and ridge tillage, and 25% yield increase (8)
Seguetana Cinzana - with increased yield and full adoption rates	Local varieties with manure and ridge tillage, and 33% yield increase (9) Local varieties with inorganic fertilizer and ridge tillage, and 33% yield increase (10)

that reflected current levels of technology in crop and livestock production in each region. This was defined as the base model simulation. The five alternative production systems as defined for the current adoption scenario are presented in Table 4.5.1.1. The current adoption rates for each region as given in Table 4.5.1.2 were used to allow the systems to enter the base model simulation.

Then a full adoption scenario was run using 1997 demand conditions but with supply conditions reflecting full adoption rates for the traditional and improved sorghum and pearl millet technologies in each region (Table 4.3.5.2). The two new variety scenarios considered full adoption rates for sorghum and pearl millet technologies, but the budgets were changed to reflect yields and production costs consistent with the N'Tenimissa and Seguetana Cinzana sorghum cultivar advantages over local varieties included in the full adoption scenario. In this manner, the economic impacts from fully adopting existing technologies can be separated from the expected potential benefits from the two new variety improvements.

The third simulation is called the N'Tenimissa scenario and allows the new sorghum cultivar to be competitive with the local and improved varieties being produced with the ridge tillage only, manure and ridge tillage, and inorganic fertilizer and ridge tillage systems under the full adoption rate conditions. The fourth simulation, known as the Seguetana Cinzana scenario, allows the Striga-tolerant variety to compete with the local and improved varieties being produced with the manure and ridge tillage and the inorganic fertilizer and ridge tillage systems under full adoption rates.

A final scenario considered full adoption of the suite of improved technologies but under future growth in demand during adoption that reflected projected population growth in both rural and urban areas. Results from the five scenarios are contrasted. Price, production, and welfare components are compared in the following economic impact assessment.

4.5.2 Base Model Solution Comparison with Reported Data

The ASM model solution was compared to observed 1997 data to determine how well it corresponded to actual conditions in the Mali agricultural sector. Market prices and total production for the base model solution are close to the observed data for 1997, as shown in Table 4.5.2.1. For example, the prices of pearl millet and sorghum under the current adoption base model solution are within 2% of the observed prices in 1997. Production quantities for these two commodities were within 4% of observed levels. Prices and production quantities for the other commodities, in the base model solution are generally within 1% to 10% of observed values. Thus the base ASM solution corresponds fairly closely to current production quantities and prices for most major agricultural commodities in Mali.

4.5.3 Economic Impact of Sorghum Technology Alternatives: Results of the Static ASM

4.5.3.1 Price and Production

Current vs. Full Adoption at 1997 Demand Levels

First, the base model solution is contrasted with the full adoption scenario. Full adoption of existing sorghum and pearl millet varieties and cultural practices would result in price decreases of 46.12 and 24.12 fcfa/kg, respectively, or 58.45% and 31.35%, as compared with current adoption (Table 4.5.3.1). The quantity of pearl millet and sorghum produced would increase 137.0 and 118.2 thousand tons, respectively, or 17.88% and 21.35%. Prices of maize and peanut would decline as production of these commodities would be increased. In contrast, rice production would be reduced 14.0 thousand tons, resulting in a price rise of 8.97 fcfa/kg. Rice production in Mali appears to be the buffer crop that is reduced in area and production as new and improved varieties of sorghum and pearl millet are introduced along with improved tillage and fertility practices. Consequently, the production of rice is reduced as the sorghum and pearl millet production is increased, resulting in a lower production quantity and a higher price for rice.

Table 4.5.2.1 Comparison of the Current Adoption Solution in the ASM with Observed 1997 Data

Unit: fcfa/kg and tons

Item by Commodity	Current Adoption (Value)	Observed Data (Value)	Ratio of Current Adoption to Observed
Price (fcfa/kg)			
Millet	78.91	77.00	1.02
Sorghum	76.92	77.00	1.00
Rice	108.73	105.00	1.03
Maize	68.96	69.00	1.00
Peanut	254.73	250.00	1.02
Cotton	139.92	155.00	0.90
Production (ton)			
Millet	766139	738856	1.04
Sorghum	555569	540273	1.03
Rice	532667	613965	0.87
Maize	274169	289761	0.95
Peanut	151013	157112	0.96
Cotton	408529	452046	0.90

With home consumption demands at fixed levels shown in Table 4.5.3.1, the additional production for maize, peanut, sorghum, and pearl millet would be absorbed by regional demand from consumers in the towns and urban areas.

Second, a scenario was run in which the improved N'Tenimissa and Seguetana Cinzana cultivars were allowed to compete with the local and improved varieties under full adoption conditions. The results show that the impacts on price and production quantity are not as profound as the differences between the current and full adoption rates for the general suite of technologies. The price of pearl millet, sorghum, and peanut in Table 4.5.3.2 show a decrease by an additional 0.12, 2.64 and 10.23 fcfa/kg, respectively, and the quantity produced increases by 5.3, 10.9, and 1.9 thousand tons, respectively, when the N'Tenimissa variety is allowed in the simulation. The price and production impacts for these three crops when the Seguetana Cinzana cultivar is considered are similar to the N'Tenimissa scenario. However, the sorghum price declines and production increases are about double the values for the N'Tenimissa scenarios. Maize production is decreased some 4.2 thousand tons for both the N'Tenimissa and Seguetana Cinzana scenarios, resulting in about an 11.0% rise in maize price.

Current vs. Full at 2015 Projected Demand Levels

The current adoption base model solution is compared with the simulation reflecting full adoption of the existing sorghum and pearl millet varieties and cultural practices under projected 2015 demand conditions. Yields of other commodities also are trended to account for productivity increases over the 15 years. Population projections to year 2015 in urban and rural areas within each region of Mali were used to project food demands by commodity. Projected food demands for farmer and family home consumption and domestic regional consumers in towns and cities by region were based on current per capita consumption rates for each commodity by region and place of residence, i.e. rural or urban.

Table 4.5.3.3 shows the results from full adoption of existing sorghum and pearl millet varieties and cultural practices under 2015 demand projections and yield increase for all commodities sufficient to maintain near 1997 price levels. Pearl millet and sorghum prices decrease 2.86 and 0.87 fcfa/kg, respectively, or 3.74%

Table 4.5.3.1 Prices, Production, Uses, and Trade for Major Commodities and Comparison Between the Current and Full Adoption Scenarios

Unit: fcfa/kg, ton, %

		Full Adoption	
Item by Commodity	**Current Adoption (Value)**	**Difference (Value)**	**Percentage (%)**
Price (fcfa/kg)			
Millet	78.91	-46.12	-58.45
Sorghum	76.92	-24.12	-31.35
Rice	108.73	8.97	8.25
Maize	68.96	-6.59	-9.56
Peanut	254.73	-21.28	-8.35
Cotton	139.92	-0.42	-0.30
Production (ton)			
Millet	766139	137008	17.88
Sorghum	555569`	118206	21.35
Rice	532667	-14024	-2.63
Maize	274169	3126	1.14
Peanut	151013	3293	2.18
Cotton	408529	2179	0.53
Home Consumption (ton)			
Millet	538680	0	0
Sorghum	197650	0	0
Rice	201000	0	0
Maize	187208	0	0
Peanut	107200	0	0
Domestic Demand (ton)			
Millet	227459	137008	60.23
Sorghum	355919	118206	33.21
Rice	331667	-14024	-4.23
Maize	86960	3126	3.60
Peanut	43814	3293	7.52
Export (ton)			
Cotton	408529	1876	0.46

[a]Note: The numbers in the full adoption columns are the difference between the current adoption value and the full adoption value expressed as a numerical or percentage change.

and 1.11%. A corresponding increase in production quantity of 456.4 and 623.0 thousand tons, or about 59.6% for pearl millet and 112.0% for sorghum, respectively, would be required to meet projected demand levels.

Home consumption for each of the cereal grains and legume crops would increase about 31.0%. Domestic consumption of these commodities would more than double for the cereal grains and peanut and near double for cowpea. Yield increases to meet projected 2015 demands at near 1997 price levels would need

Table 4.5.3.2 Prices, Production, Uses, and Trade for Major Commodities and Comparison Between the Full Adoption and the N'Tenimissa and Seguetana Cinzana Cultivar Scenarios

Unit: fcfa/kg, ton, %

Item by Commodity	Full Adoption (Value)	N'Tenimissa Difference[a]	Seguetana Cinzana Difference[a]
Price (fcfa/kg)			
Millet	32.79	-0.12	-0.12
		(-0.37)	(-0.37)
Sorghum	52.81	-2.46	-5.40
		(-5.00)	(-10.22)
Rice	117.69	-3.77	-3.77
		(-3.20)	(-3.20)
Maize	62.37	6.97	6.64
		(11.17)	(10.65)
Peanut	233.46	-10.23	-13.62
		(-4.38)	(-5.84)
Cotton	139.50	-6.93	-8.28
		(-4.97)	(-5.94)
Production (ton)			
Millet	903148	5337	5163
		(0.59)	(0.57)
Sorghum	671776	10937	24794
		(1.63)	(3.69)
Rice	518643	5755	5656
		(1.11)	(1.09)
Maize	277296	-4185	-4159
		(-1.51)	(-1.50)
Peanut	154308	1919	1921
		(1.24)	(1.25)
Cotton	410709	11055	11052
		(2.69)	(2.69)
Home Consumption (ton)			
Millet	538680	0	0
Sorghum	197650	0	0
Rice	201000	0	0
Maize	187208	0	0
Peanut	107200	0	0
Regional Demand (ton)			
Millet	364468	5337	5163
		(1.46)	(1.42)
Sorghum	474126	10937	24794
		(2.31)	(5.23)
Rice	317643	5755	5656
		(1.81)	(1.78)
Maize	60087	-4185	-4159
		(-4.65)	(-4.62)
Peanut	47108	1919	1921
		(4.07)	(4.08)
Export (ton)			
Cotton	410405	9825	9822
		(2.39)	(2.39)

[a]Note: The numbers in the full adoption columns are the difference between the current adoption value and the full adoption value expressed as a numerical or percentage change.

Table 4.5.3.3 Prices, Production, Uses, and Trade for Major Commodities and Comparison Between the Current and Full Adoption Scenarios Under 2015 Demands and Yield Increase

Unit: fcfa/kg, ton, %

		Full Adoption	
Item by Commodity	**Current Adoption (Value)**	**Difference (Value)**	**Percentage (%)**
Price (fcfa/kg)			
Millet	76.57	-2.86	-3.74
Sorghum	78.56	-0.87	-1.11
Rice	107.44	4.74	4.42
Maize	68.93	-1.33	-1.93
Peanut	229.32	-14.63	-6.38
Cotton	144.24	-10.76	7.46
Cowpea	99.39	-10.03	-10.10
Production (ton)			
Millet	765299	456436	59.64
Sorghum	555129	622954	112.22
Rice	534980	578674	108.17
Maize	274205	160526	58.54
Peanut	202281	120794	59.72
Cotton	408297	-27225	-6.67
Cowpea	30724	17321	56.38
Home Consumption (ton)			
Millet	538680	165863	30.79
Sorghum	197650	60857	30.79
Rice	201000	61889	30.79
Maize	187208	60330	32.23
Peanut	140700	43322	30.79
Cowpea	17187	5191	30.21
Domestic Demand (ton)			
Millet	226619	290573	128.22
Sorghum	357479	562097	157.24
Rice	333980	516785	154.74
Maize	86997	100196	115.17
Peanut	61581	77472	125.80
Cowpea	13537	12130	89.61
Export (ton)			
Cotton	408297	-27226	-6.67

[a]Note: The numbers in the full adoption columns are the difference between the current adoption value and the full adoption value expressed as a numerical or percentage change.

to average about 3.0% annually for maize, pearl millet, cowpea, and sorghum. Yields for rice would need to increase 5.0% annually, while peanut yield would need to grow at a 1.4% annual rate. Cotton yield and production would be maintained at the current 1997 levels.

4.5.3.2 Welfare Effects

Current vs. Full Adoption At 1997 Demand Levels

The national welfare components for the four scenarios are listed in Tables 4.5.3.2.1 and 4.5.3.2.2. Consumers' surplus represents the Mali domestic consumers' surplus while foreign surplus refers to the trade surplus in Mali. Producers' surplus is the returns to land and labor resources of farmers. Home consumption expenditure is the value of the food produced and consumed on the farm by rural people. Farmers and their families benefit from both increases in returns to land and labor resources and reductions in home consumption expenditures. Total social welfare is the summation of consumers' surplus, foreign surplus, producers' surplus, and home consumption expenditure.

The analysis indicates that when current sorghum and pearl millet technologies are fully adopted under current 1997 demand conditions, consumers are the primary beneficiaries. Tables 4.5.3.2.3 and 4.5.3.2.4 display the changes in regional benefits to producers and their families and regional consumers resulting from the sorghum and pearl millet technology improvements. Regional consumers gain 19.6 billion fcfa annually from the full adoption of the technologies. These gains are distributed among the regions according to consuming population. The regions having the largest concentrations of people in towns and cities receive

Table 4.5.3.2.1 Welfare Comparison between the Current and Full Adoption Scenarios

Unit: Million fcfa, %

Welfare Measure	Current Adoption (Value)	Full Adoption (Change in Value)
Consumers' Surplus	764475	19687 (2.58)
Producers' Surplus	151331	-45704 (-30.20)
Home Consumption Expenditure	-126381	31864 (-25.21)
Foreign Surplus	6818	188 (2.76)
Total Social Welfare	796243	6035 (0.76)

Note: Consumers' surplus is the Mali domestic consumers' surplus;
Producers' surplus is the Mali domestic producer's surplus;
Home consumption expenditure is the Mali farmer and family home consumption expenditure;
Foreign surplus is the trade surplus;
Total social welfare is the summation of consumers' surplus, foreign surplus, producers' surplus and home consumption expenditure. The numbers in parentheses are the percentage change between full adoption and current adoption values.

Table 4.5.3.2.2 Welfare Comparison between the Full Adoption and the N'Tenimissa and Seguetana Cinzana Cultivar Scenarios.

Unit: Million fcfa, %

Welfare Measure	Full Adoption (Value)	N'Tenimissa (Change in Value)	Seguetana Cinzana (Change in Value)
Consumers' Surplus	784162	2279 (0.29)	3672 (0.47)
Producers' Surplus	105627	-461 (-0.44)	-4181 (-3.96)
Home Consumption Expenditure	-94517	1210 (-1.28)	2200 (-2.33)
Foreign Surplus	7007	3132 (44.70)	3744 (53.44)
Total Social Welfare	802278	6160 (0.77)	5436 (0.68)

Note: The numbers in parentheses are the percentage change between the full adoption and N'Tenimissa and Seguetana Cinzana scenarios.

the largest amount of benefit (Table 4.5.3.2.3). In contrast, regional producers experience a 45.7 billion fcfa annual reduction in the returns to their labor and land resources. This loss is partially offset by the 31.86 billion fcfa annual reduction in the home consumption expenditure for food by farmers and their families. The annual net loss to producers and rural families is 13.84 billion fcfa.

The introduction of N'Tenimissa and Seguetana Cinzana produces additional annual benefits totaling 3.49 billion fcfa and 5.87 billion fcfa, respectively to all consumers, both regional consumers and home consumption by farmers and their families. Producers and their families gain an additional 0.75 billion fcfa annually in the aggregate from the introduction of N'Tenimissa. Producers surplus is decreased 0.46 billion fcfa and home consumption expenditures are reduced 1.21 billion fcfa annually (Table 4.5.3.2.2). Regional consumers received additional benefits of 2.28 billion fcfa annually. With Seguetana Cinzana, producers experience a 4.18 billion fcfa loss annually in income while home consumption expenditures are reduced 2.20 billion fcfa annually. Thus the net loss to producers and their families is about 2.0 billion fcfa annually. Regional consumers gain about 3.67 billion fcfa annually, or 0.47%, in welfare.

Total social welfare in Mali increased 6.03 billion fcfa annually with full adoption of current sorghum and pearl millet technologies under current 1997 demand conditions. With the introduction of the new sorghum and pearl millet cultivars, total social welfare increases 6.16 and 5.43 billion fcfa annually for N'Tenimissa and Seguetana Cinzana, respectively. These results indicate that current technologies when fully adopted and new cultivars being introduced may be expected to increase consumers' and national economic welfare but reduce the economic welfare of farmers and their families in the aggregate.

Current vs. Full Adoption at 2015 Projected Demand Levels

Changes in national welfare components for the demand growth and full adoption scenario are shown in Table 4.5.3.2.5. Also provided in the table are the separate welfare effects from the full adoption of the sorghum and millet technologies. The analysis indicates that when current sorghum and pearl millet technolo-

Table 4.5.3.2.3 Regional Producers' and Consumers' Surplus, and Home Consumption Expenditures, and Land, Labor Usage and Comparison between the Current and Full Adoption Scenarios

Unit: 1000 man-day, 1000 hectare, million fcfa,%

Item by Commodity	Current Adoption (Value)	Full Adoption Difference (Value)	Full Adoption Percentage (%)
Labor (1000 md)	789742	15039	1.9
Land (1000 ha)	2803.23	0.00	0.00
Producers' Surplus (mil fcfa)			
Kayes	15337	-2669	-1740
Koulikoro	28569	-12649	-44.28
Sikasso	22600	-7856	-34.76
Segou	39190	-11916	-30.40
Mopti	34120	-10023	-29.37
Tombouctou	7539	-982	-13.02
Gao	3975	391	9.83
Total	151331	-45704	-30.20
Home Consumption Expenditure (mil fcfa)			
Kayes	-22474	5294	-23.56
Koulikoro	-22705	6094	-26.84
Sikasso	-22342	5760	-25.78
Segou	-23938	6101	-25.49
Mopti	-22078	5716	-25.89
Tombouctou	-6808	1576	-23.15
Gao	-6035	1322	-21.91
Total	-126381	31864	-25.21
Consumers' Surplus (mil fcfa)			
Kayes	122345	2052	1.68
Koulikoro	120983	2800	2.31
Sikasso	105377	2557	2.43
Segou	117257	2763	2.36
Mopti	80355	1623	2.02
Tombouctou	57235	1171	2.05
Gao	57564	978	1.70
Bamako	103359	5742	5.56
Total	764475	19687	2.58

gies are fully adopted under demand growth rates associated only with rising population of the next 15 years, as contrasted to current adoption rates, both domestic consumers and producers are beneficiaries. Urban consumers nationally gain 33.02 billion fcfa (4.25%) annually while home consumption expenditures by farmers and their families is increased by 55.76 billion fcfa (43.04%) annually. Producers returns to land and labor are increased 112.37 billion fcfa (82.68%) resulting in a net welfare gain of 61.61 billion fcfa annually when combined with home consumption expenditures. In contrast foreign surpluses are eliminated as cotton exports are reduced by some 27.2 thousand tons. Total social welfare in Mali is increased 94.63 billion fcfa (12.04%) annually under the demand growth scenario. These results emphasize the importance of assumptions about demand growth when economic impacts of new technologies are assessed in developing economies where agriculture is a dominant source of gross domestic product and employment.

Table 4.5.3.2.4 Regional Producers' and Consumers' Surplus, and Home Consumption Expenditures, and Land, Labor Usage, and Comparisons Between the N'Tenimissa and Seguetana Cinzana Cultivar and Full Adoption Scenarios.

Unit: 1000 man-day, 1000 hectare, million fcfa,%

Item by Region	Full Adoption (Value)	N'Tenimissa Difference (Value)	N'Tenimissa Percent (%)	Seguetana Cinzana Difference (Value)	Seguetana Cinzana Percent (%)
Labor (1000 md)	804782	493	0.06	-1547	-0.19
Land (1000 ha)	2803.23	0.00	0.00	0.00	0.00
Producers' Surplus (mil fcfa)					
Kayes	12668	592	4.68	48	0.38
Koulikoro	15820	62	0.39	-633	-3.98
Sikasso	14744	-522	-3.54	-1995	-13.53
Segou	27275	601	2.20	-194	-0.71
Mopti	24098	-926	-3.84	-1073	-4.45
Tombouctou	6557	-152	-2.32	-224	-3.42
Gao	4365	-117	-2.67	-109	-2.51
Total	105627	-461	-0.44	-4180	-3.96
Home Consumption Expenditure (mil fcfa)					
Kayes	-17180	135	-0.79	267	-1.56
Koulikoro	-16611	143	-0.86	295	-1.78
Sikasso	-16582	280	-1.69	492	-2.96
Segou	-17837	230	-1.29	451	-2.53
Mopti	-16362	215	-1.32	423	-2.58
Tombouctou	-5232	112	-2.14	145	-2.77
Gao	-4713	95	-2.01	126	-2.68
Total	-94517	1210	-1.28	2200	-2.33
Consumers' Surplus (mil fcfa)					
Kayes	124396	240	0.19	368	0.30
Koulikoro	123784	249	0.20	416	0.34
Sikasso	107934	489	0.45	791	0.73
Segou	120020	473	0.39	794	0.66
Mopti	81978	315	0.38	514	0.63
Tombouctou	58406	102	0.17	143	0.24
Gao	58542	87	0.15	134	0.23
Bamako	109102	323	0.30	513	0.47
Total	784162	2279	0.29	3672	0.47

Table 4.5.3.2.5 Welfare Comparison between the Current and Full Adoption Scenarios Under 2015 Demands and Yield Increase

Unit: Million fcfa, %

Welfare Measure	Current Adoption (Value)	Full Adoption (Change in Value)
Consumers' Surplus		
- all commodities	776840	538245 (69.29)
- sorghum technology only		33022 (4.25)
Producers' Surplus		
- all commodities	133860	137407 (102.65)
- sorghum technology only		117374 (87.68)
Home Consumption Expenditure	129573	
- all commodities		-35844 (27.66)
- sorghum technology only		-55765 (43.04)
Foreign Surplus		
- all commodities	4863	-4863 (-100.00)
- sorghum technology only		0 (0)
Total Social Welfare		
- all commodities	785989	634945 (80.78)
- sorghum technology only		9631 (12.04)

Note: Consumers' surplus is the Mali domestic consumers' surplus;
Producers' surplus is the Mali domestic producer's surplus;
Home consumption expenditure is the Mali farmer and family home consumption expenditure;
Foreign surplus is the trade surplus;
Total social welfare is the summation of consumers' surplus, foreign surplus, producers' surplus, and home consumption expenditure.
The numbers in parentheses are the percentage change between full adoption and current adoption values.

4.6 Results of the Stochastic ASM

Risk effects in agriculture have been studied following Sandmo's (1971) early study. Chavas and Holt (1990) focused on farmer acreage and output quantity decisions under risk. They found that cross-commodity risk reduction is potentially important since there is some range over which increasing the support price for corn would actually result in more acres planted to soybeans. Ramaswami (1992) examined the impact of production risk on a producer's optimal input decision. Coyle (1992) developed a duality model of production under risk aversion and price uncertainty. Pope and Chavas (1983) focused their efforts on the definition of welfare under uncertainty. Uncertainty effects on individual and aggregate measures, such as farmer acreage, production quantity, and social welfare could be estimated with their approach. However, the link between individual behavior and aggregate welfare was absent. Effects on aggregate welfare as individual decision makers change their risk attitude have not been developed. Therefore, one of the purposes of this study was to measure aggregate welfare effects as individual producers change their aversion to risk in coping with uncertainty.

In the previous section, the construction of an agricultural sector model (ASM) for Mali was reported and used to estimate the economic impacts of the sorghum and pearl millet technology improvements under current adoption rates and full adoption conditions. The static Mali ASM computes the economic impacts of the technological improvements for agriculture at the subnational, national, and global scales. A stochastic Mali ASM was also developed to examine the aggregate welfare effects of changes in decision makers risk aversion parameter (RAP) associated with yield variations stemming from variable rainfall conditions.

4.6.1 Welfare Effects Resulting from Risk Aversion by Farmers

When farmers change their risk aversion parameter (RAP) to avoid more uncertainty, variations in production, demand, and welfare result. The level and variation of welfare effects from altering farmers' RAP is discussed in this section along with the relationship between individual farmer behavior and aggregate welfare.

Four alternative RAP values, 0.0005, 1.0, 1.5, and 4.0, were simulated in the stochastic Mali ASM. The level and variation of the welfare measures are listed in Table 4.6.7.1 for the current adoption and current demand conditions scenario. As the RAP increases from risk neutral (RAP=0.0005) to becoming more risk averse (RAP = 1.5), the mean level of regional consumers' surplus increases, the mean level of home consumption expenditures decreases, and thus total consumers' surplus increases. The standard deviations of regional consumers surplus and home consumption expenditures both decrease. However, producers' surplus decreases as the RAP is increased. The reduction in producers' surplus and foreign surplus is greater than the increase in total domestic consumers' surplus. Thus, total social welfare decreases. An increasing RAP results in a reduction in total welfare and welfare variation, indicating that more risk-averse behavior by farmers reduces total welfare variability, but it also results in a lower total social welfare.

At higher levels of risk aversion (RAP = 4.0), regional consumers' surplus decreases. Home consumption expenditures continue to decrease but are not sufficient to offset the loss in regional consumer surplus. Thus, total consumer surplus decreases. Both producers' surplus and foreign surplus continue to decrease. Total welfare also continues to decrease. In a macro setting, farmers aversion to risk that results in a relatively high RAP to avoid uncertainty, may not benefit themselves or society. Even though such behavior may increase aggregate welfare of consumers, their gains may be less than aggregate welfare loss to producers and foreign economic surplus. Consequently, a total social welfare loss is experienced. This phenomenon illustrates the economic fallacy of using risk behavior of the firm in appraising impacts on aggregate social welfare. Actions that may appear profitable to an individual firm may not be profitable to the aggregate sector after market adjustments have occurred. The empirical results for Mali indicate that welfare losses to producers and foreign surplus exceed welfare gains to consumers as the RAP increases, resulting in decreased total social welfare. Only at exceptionally high RAP values did regional consumers lose welfare. The increasing risk-aversion behavior reduced variability in producers' surplus, foreign surplus, regional consumers' surplus, home consumption expenditures, and total social welfare. Thus, with uncertainty there is a tradeoff between the mean level of total social welfare and its variability as producers become more risk averse in their behavior.

4.6.2 Significant Findings and Stochastic Elements of Mali ASM

Three major findings of the ASM product resulted from the IER/INTSORMIL case study. First, the development, transfer, and adoption of new output increasing and cost reducing technology in primary production of commodities with highly inelastic demands (i.e. percent change in price is substantially greater than percent change in quantity) and/or slowly growing demands such as for sorghum and pearl millet are likely to benefit domestic consumers in towns and cities and disadvantage rural producers and their families in the aggregate. Second, commodities with more elastic demand and/or rapidly growing demand offer potential for increased benefits to both rural people (producers and their families) and urban consumers from output increasing and cost reducing technology. Knowledge of demand changes that may be expected during periods of technology adoption by producers is necessary to assess total economic impacts of the technology and the distribution of the economic benefits among groups in the society. Third, risk aversion behavior on the part of individual producers may not be profitable to the aggregate sector after market adjustments have been made. Reductions in mean levels of aggregate producer income and foreign exchange balances may exceed gains in mean levels of urban consumer surplus and home-consumption expenditure reductions, such that total national welfare is reduced. Even though increasing risk-aversion behavior of producers reduces variability in total economic welfare and for the various groups in society, the loss in mean levels of economic welfare to producers and society as a whole poses the necessity to examine the tradeoff between mean values of the various economic welfare measures and their variances as producers become more risk averse in their behavior.

Future research will need to examine more fully the relationships among the elasticities of demand and supply and the nature of shifts in demand and supply emanating from the technology and/or policy changes for commodities under risk-aversion behavior impacting on the economic welfare of various groups in society. The IER/INTSORMIL case study in Mali demonstrates that aggregate economic welfare impacts from risk-aversion behavior by producers can be quite different than predicted impacts at the farm level unless appropriate aggregate sector market adjustments are taken into account in the use of FLIPSIM or other firm/household level models.

4.7 Analysis of Farm (Household) Impact of INTSORMIL Technology

4.7.1 FLIPSIM Methodology

The ASM provided a description of expected impact on production, trade, and economic welfare at regional, national, and global scales. It also provided information on changes in resource allocations, prices, and quantities consumed. The ASM approach does not, however, examine impacts of technology at the farm level. By incorporating equilibrium price and quantity changes from the ASM solutions into a farm-level economic model such as the Farm Level Income and Policy Simulation (FLIPSIM) model, an assessment of the impact of technology at the farm level may be achieved.

The impacts of introducing the technologies were estimated for different adoption conditions (early adoption, non adoption, and full adoption) on the representative farms. Price changes for different scenarios were derived from the Mali ASM.

In the early adoption scenario, improved sorghum technology is adopted on the representative farms but is not widely adopted in the region or nation. The additional production of sorghum at regional and national levels is not significant enough to cause price shifts in the early adoption scenario. It was expected that the representative farms would reap the rewards of higher sorghum yields without the effect of price changes.

In the non-adoption scenario, improved sorghum technology is widely adopted at regional and national levels but not on the representative farm, i.e., the representative farm is a non-adopter. Commodity prices in the non-adoption scenario will likely change due to an outward shift in the supply of sorghum caused by increased yield of improved sorghum varieties. The representative farm will be subject to new price regimes with lower yield than regional averages.

In the full adoption scenario, improved sorghum technology has been adopted at regional and national levels as well as on the representative farm. Both yield and price effects from improved sorghum varieties will impact the farm under the full adoption scenario.

4.7.2 Site Selection and Description of the Three Representative Farms

Three representative farms were selected. These selections were made prior to the development and use of sampling frames based on spatially explicit analysis of biophysical variables affecting economic outcomes. The selection process used in this case incorporated the expertise of Malian and U.S. regional experts and local extension agents who helped identify farms in representative agro-ecological environments of Mali. The determining factor in the selection process was annual rainfall that each area received. The farms in these regions had also been targeted for the introduction of the improved varieties of sorghum.

After regional experts identified representative farms, the economic and technical data required as inputs for the farm-level model were collected in a farm interview process. In this process, a Malian agricultural economist familiar with the farm-level model, local extension agents, and U.S. scientists interviewed each farm operator. The interview was aided by an extensive survey that was developed specifically to gather farm-level data. Through the interview process, data required to model the farms were collected with interactive feedback from the farm operator and extension specialist.

Representative farms were located in the Segou and Sikasso regions of Mali (Table 4.7.4.1). Each region contains a major town or city that acts as the primary marketplace. However, perishable goods are sold in villages where the representative farms are located. Because the farms are engaged in subsistence agriculture, less than half of the farms' production is sold in villages, towns or cities.

The representative farm in the Segou region located at the Cinzana Yare Village has 10 hectares of cropland planted to millet, cowpea, sorghum, peanut, and sesame. Peanut has historically been the main revenue crop grown on the farm. Average annual rainfall in the area is 400 to 600 mm with a 90 to 120 day rainy season. The household contains 29 people, with 14 actively working on the farm. The farm is located at the northern limit of the region's cotton producing zone. The farm operator works part-time off the farm as a self-employed tailor.

The representative farm in the Segou region located near the town of Koutiala has 18.0 hectares of cropland. Crops produced are cotton, sorghum, millet, peanut, and maize with half the hectares planted to cotton as a cash crop. The rainy season is 120 to 150 days with rainfall averaging 600 to 800 mm. Twelve of the 29 farm household members are of working age and employed on the farm.

The representative farm in the Sikesso region near Kadiolo receives 800 to 1200 mm of rainfall annually during a 180-day rainy season. This contributes to a wider variety of crops grown on this farm's 20 hectares of cropland. Maize, sorghum, cotton, millet, peanut, rice, and fonio are grown with cotton being the major cash crop. The household consists of 20 family members with 10 working-age family members employed on the farm. Other family members work off-farm and are not dependents of the farm household.

4.7.3 Results of Representative Farm Impact Assessments

Tables 4.7.3.1, 4.7.3.2, and 4.7.3.3 contain summaries of the results of the farm level analysis for three technology adoption scenarios. The Cinzana farm had the lowest probability of economic success under the base level current adoption conditions for the variety improvement, fertility and tillage/water retention technologies. Probability of economic success was defined as the chance of obtaining a return on equity of 12.6% or more. This farm had a 64% chance of being economically successful. Both the N'Tenimissa and Sequetana varieties if adopted on this farm would substantially increase the chances for economic success (Table 4.7.3.1) under the low adoption scenario where only this farm adopted the new varieties. The farm-level impact from adopting N'Tenimissa Seguetana sorghum varieties was most pronounced for the Cinzana farm, allowing for a 50% to near 100% increase in real net worth.

The probability of economic success declined from 64% to 24% for the Cinzana representative farm under the non adoption scenario (Figure 4.7.3-1), but it increased 86% to 94% under the full adoption scenarios (Figure 4.7.3-2). The low adoption scenario was similar to full adoption for the Cinzana producer.

Table 4.7.3.1 Implications of Introducing Improved Varieties of Sorghum Under the Low Adoption Scenario

Region	Base	N'Tenimissa	Seguetana
		Probability of Economic Success[1]	
Cinzana	0.64	0.96	0.97
Koutiala	1.00	1.00	1.00
Kadiolo	1.00	1.00	1.00
		Present Value Ending Net Worth 1000 fcfa[2]	
Cinzana	201.19	334.36	390.10
	(106.87)	(152.50)	(158.61)
Koutiala	22358.38	23777.15	24233.86
	(1949.15)	(1964.57)	(1970.30)
Kadiolo	10650.01	11098.41	11281.60
	(479.56)	(487.68)	(557.49)

[1] Probability of Economic Success is the chance that the farm will earn a return on equity greater than .1260.
[2] Present Value Ending Net Worth is the discounted value of farm's net worth in the last year simulated

The Koutiala and Kadiolo representative farms had probability of successfully obtaining a positive net return of 100% under base and both new variety scenarios. These farms have higher rainfall and longer crop growing seasons. Both produce cotton as a cash crop with a price that is supported by CMDT and little affected by changes in sorghum yield.

Table 4.7.3.2. Implications of Introducing Improved Varieties of Sorghum Under the Non-Adoption Scenario

Region	Base	N'Tenimissa	Seguetana
		Probability of Economic Success[1]	
Cinzana	0.64	0.24	0.24
Koutiala	1.00	1.00	1.00
Kadiolo	1.00	1.00	1.00
		Present Value Ending Net Worth 1000 fcfa[2]	
Cinzana	201.19	147.08	146.92
	(106.87)	(72.70)	(72.63)
Koutiala	22358.38	21369.36	21365.15
	(1949.15)	(1930.2)	(1930.9)
Kadiolo	10650.01	10728.13	10729.60
	(479.56)	(550.09)	(550.42)

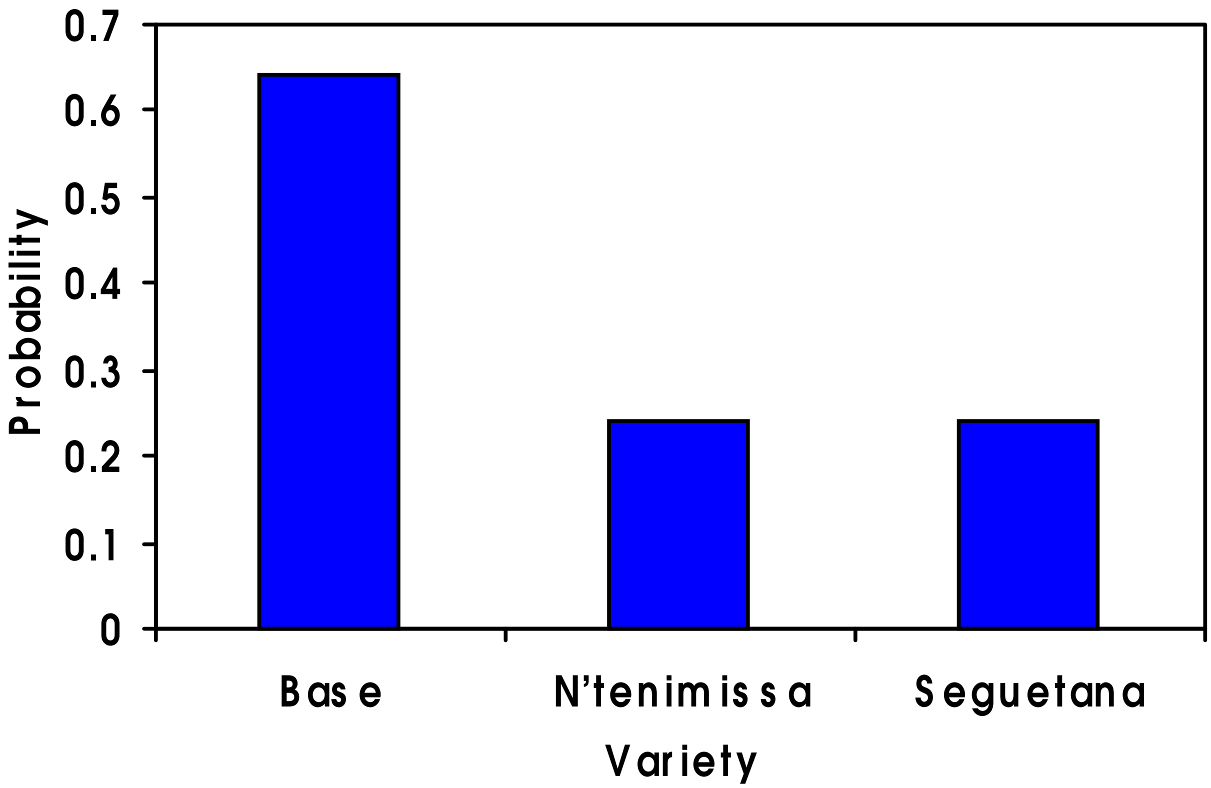
[1] Probability of Economic Success is the chance that the farm will earn a return on equity greater than .1260.
[2] Present Value Ending Net Worth is the discounted value of farm's net worth in the last year simulated

Table 4.7.3.3. Implications of Introducing Improved Varieties of Sorghum Under the Full Adoption Scenario

Region	Base	N'Tenimissa	Seguetana
		Probability of Economic Success[1]	
Cinzana	0.64	0.86	0.94
Koutiala	1.00	1.00	1.00
Kadiolo	1.00	1.00	1.00
		Present Value Ending Net Worth 1000 fcfa[2]	
Cinzana	201.19	300.16	355.27
	(106.87)	(109.61)	(110.16)
Koutiala	22358.38	22696.76	23111.34
	(1949.15)	(1943.9)	(1948.55)
Kadiolo	10650.01	11148.32	11281.60
	(479.56)	(555.16)	(557.49)

[1] Probability of Economic Success is the chance that the farm will earn a return on equity greater than .1260.

[2] Present Value Ending Net Worth is the discounted value of farm's net worth in the last year simulated.



Figures 4.7.3-1. Expected economic success under non-adoption scenario, Cinzana farm.

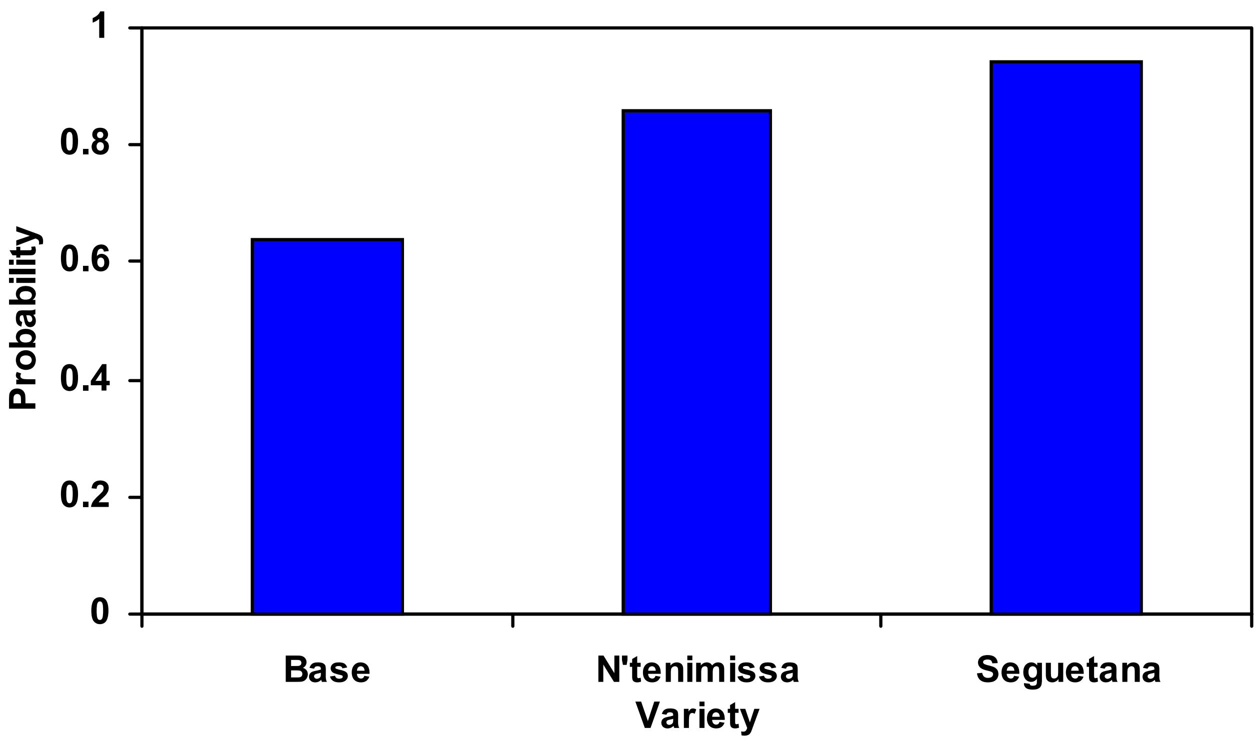


Figure 4.7.3-2. Expected economic success under full adoption, Cinzana farm.

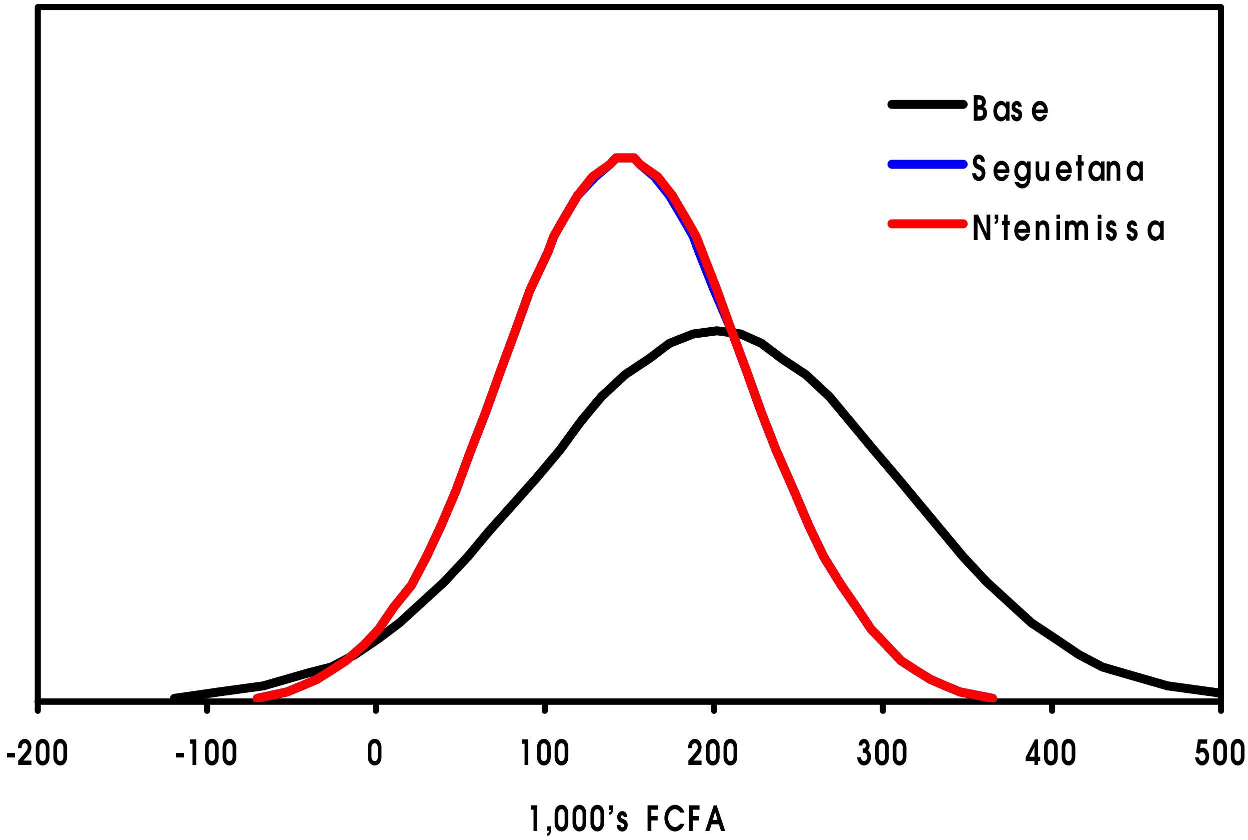


Figure 4.7.3-3. Net present value for the non-adoption scenario, Cinzana farm.

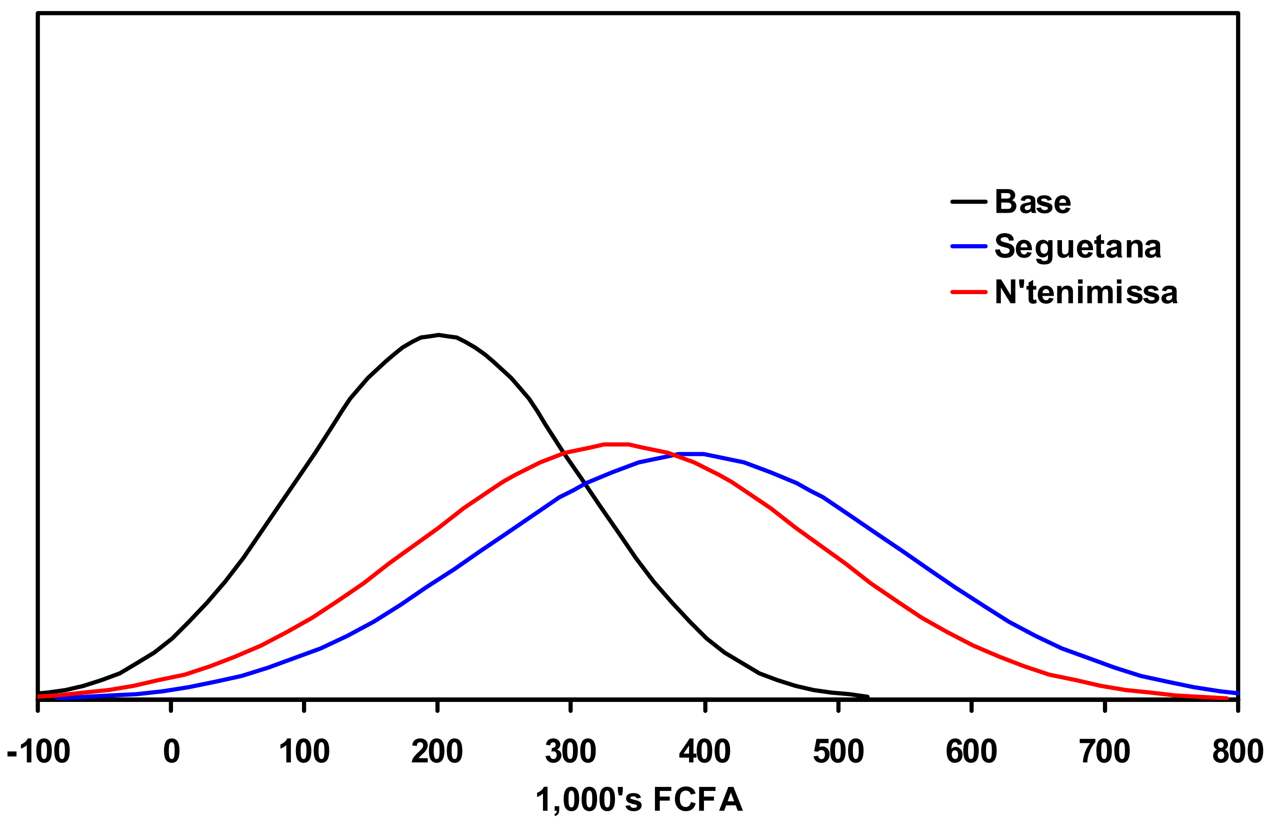


Figure 4.7.3-4. Net present value for the low adoption scenario, Cinzana farm.

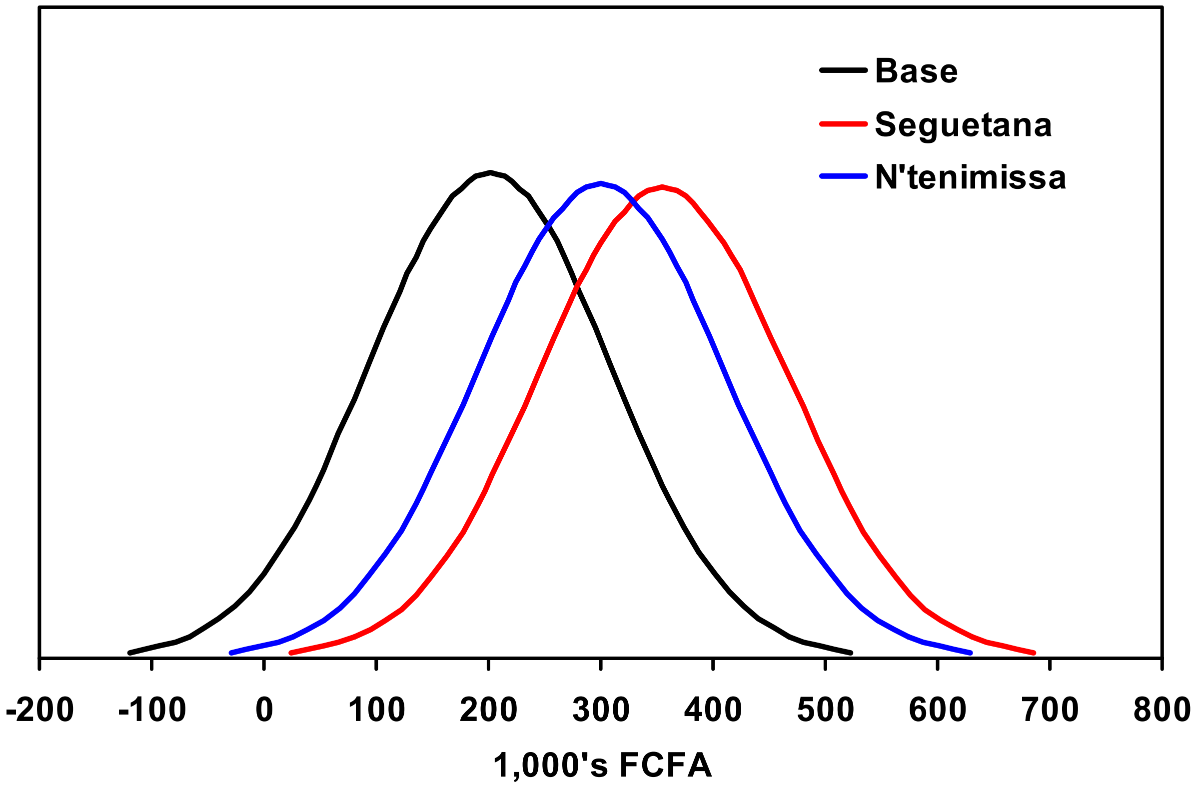


Figure 4.7.3-5. Net present value for the full adoption scenario, Cinzana farm.

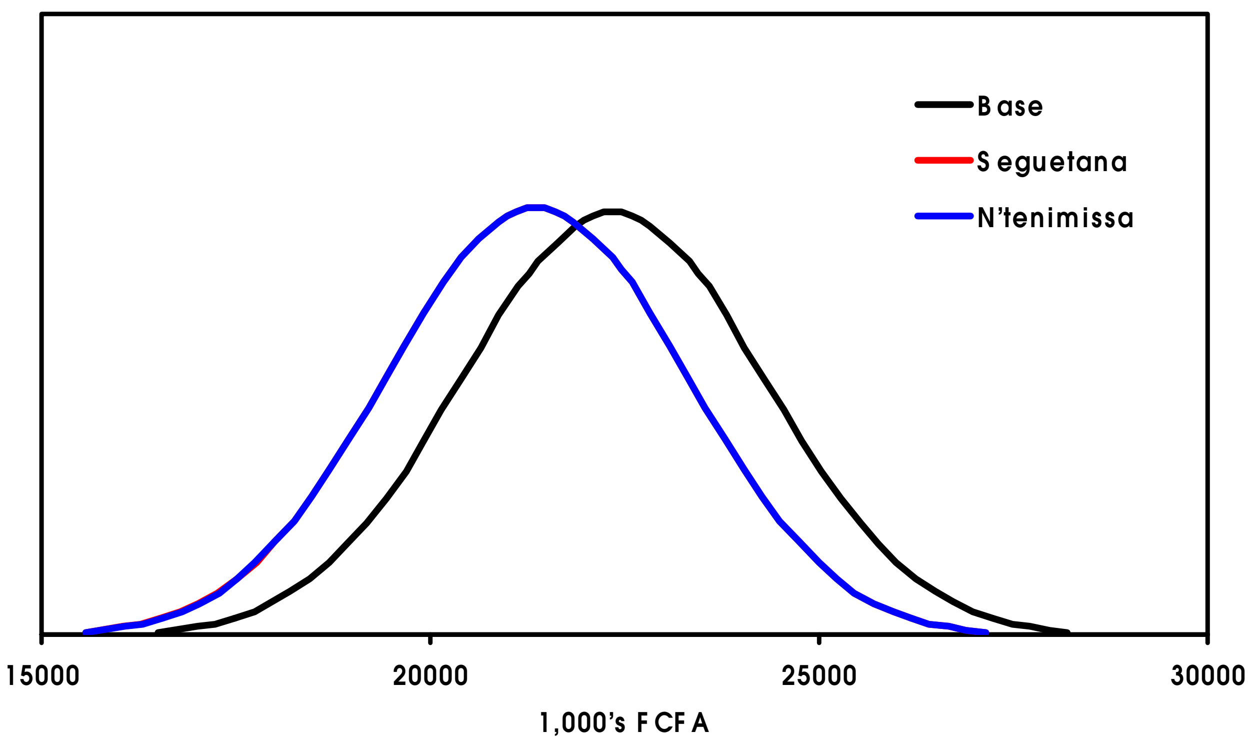


Figure 4.7.3-6. Net present value for the non-adoption scenario, Koutiala farm.

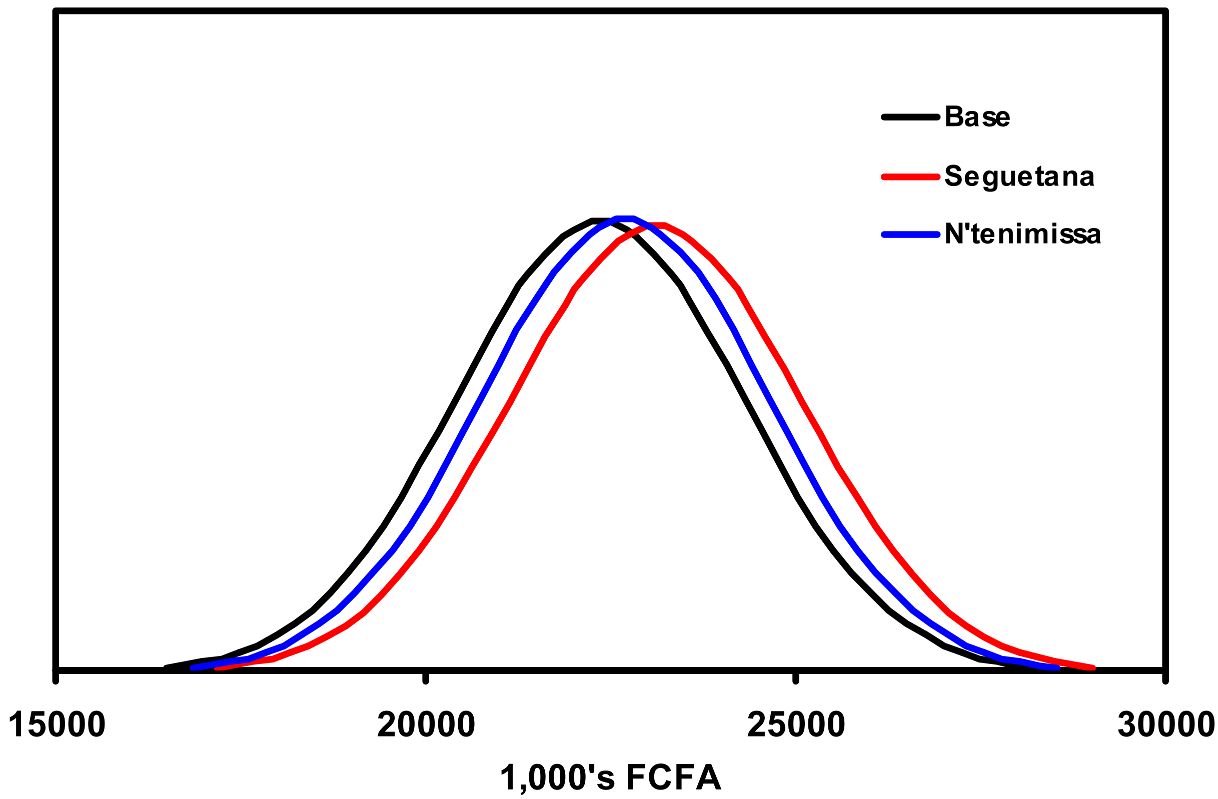


Figure 4.7.3-7. Net present value for the low adoption scenario, Koutiala farm.

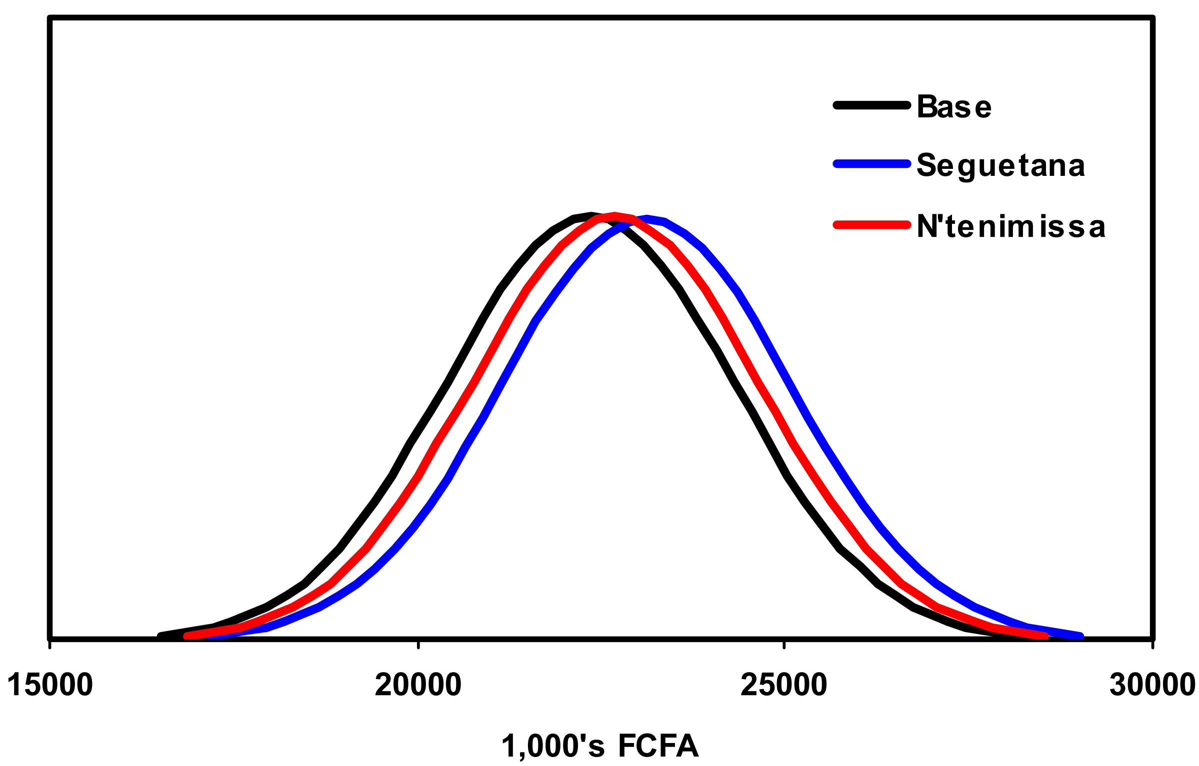


Figure 4.7.3-8. Net present value for the full adoption scenario, Koutiala farm.

The net present value (NPV) for the representative farms increased under the early and full adoption scenarios. Net present value summarizes the economic performance over the planning horizon. Net present value is defined as NPV=PVNCFI + (PVENW-BNW), where PVNCFI is the present value of net cash farm income, PVENW is the present value of the net worth in the last year of the planning horizon, and BNW is the beginning net worth (Richardson).

The present value of ending net worth (PVENW) declined under the non-adoption scenario for the Cinzana and Koutiala farms in the Segou region. The Kadiolo farm experienced a slight increase (0.7%) in PVENW. The variance of real net worth increased for the Cinzana and Kadiolo representative farms under the early and full adoption scenarios for the new varieties. Figures 4.7.3-3 to 4.7.3-8 illustrate the results for the Cinzana and Koutiala farms under the three scenarios.

4.7.4 Conclusions

The representative farms had high probability of economic success by early adoption of the N'Tenimissa or Seguetana varieties. Adoption of the N'Tenimissa variety increased the real net worth of the Cinzana farm by 66%. For the Koutiala and Kadiolo farms, the increase in real net worth was 4% to 6%. Adoption of the Seguetana variety increased the real net worth of the representative farms slightly more than adoption of N'Tenimissa. Results from the full adoption scenario were very similar to the early adoption results.

Non adoption of the improved varieties would be particularly disadvantageous for the Cinzana farm. The probability that the farm would achieve an economic success declined from 0.64 in the base scenario to 0.24 under the N'Tenimissa and Seguetana adoption scenarios.

Adoption of the high yielding varieties substantially reduced the Cinzana farm's financial risk. The impact for the Koutiala and Kadiolo farms was much less pronounced. The probability of success was 1.0 on each of these farms with or without adoption of the new sorghum varieties. However, failure to adopt the new varieties on the Koutiala farm had a negative impact on the farm's real net worth of about 1.0 million fcfa.

The differential impacts across the agro-ecological zone were apparent and reflected by the crop mixes produced by the different farms. The Cinzana farm produces mainly subsistence crops due to the low precipitation and high yield variability. Producers represented by the Koutiala and Kadiolo farms allocate more of their resources to cash crops of cotton and peanut because of higher rainfall and lower yield variability. The earnings for the three representative farms were forecast to increase from the adoption of the new sorghum varieties. The variance of the expected earnings was also projected to increase.

4.8 Environmental Impact of INTSORMIL Technology in Mali

Following the analysis of economic impact, we conducted an analysis to determine the effects of technology adoption on the local environment. Two of the important environmental indicators monitored and reported as part of the simulations process were water runoff and erosion. In the simulations for West Africa, these indicators were extracted for each of the simulations and are reported here for the political districts in Mali.

4.8.1 Methodology

The runoff and erosions simulations were extracted from each of the 20-year simulations by crop, technology level, and ecological zone. The ecological zones were aggregated to each Mali political district and an average runoff and erosion rate was calculated from each crop and technology level. The number of hectares for each crop in each political district was obtained from the equilibrium values for the four scenario runs of the ASM Model. No attempt was made in this analysis to reallocate acreages assigned to each of the ecological zones within a political district among scenarios. Only the acreage total adjustments among political districts were considered. (With additional information within-district adjustments can be examined.) The pre-technology coefficients for runoff and erosion were used with the weighted estimates of the base run scenario. The post-technology estimates for runoff and erosion were used for the other three technology scenarios. These scenarios included adjustments for variety changes in sorghum and groundnuts and for increased fertilizer use in sorghum.

Table 4.8.2.1. Simulated Runoff by Scenario for Mali Districts in mm

Region	Base	N'Tinmissa	Segutana	Full Adoption
Kayes	154	154	154	152
Koulikoro	153	153	153	153
Sikasso	186	188	188	186
Segou	112	112	112	112
Mopti	54	58	58	58
Tombouctou	19	19	19	19
Gao	15	18	16	16

In order to maintain a common land base, a land use category of idle land was added to make district totals of cropland equal in all scenarios. Since no simulations were made to estimate erosion on unused (idle) cropland, the erosion and runoff rates from moderately fertilized millet were used as proxies for these coefficients. Previous experience with other simulations leads us to believe this is a reasonable substitution.

Table 4.8.2.2 Simulated Erosion by Scenario for Mali Districts in metric tons per hectare

Region	Base	N'Tinmissa	Segutana	Full Adoption
Kayes	9.1	6.4	6.4	5.2
Koulikoro	10.2	9.0	9.0	8.9
Sikasso	9.9	8.6	8.6	8.8
Segou	6.9	6.7	6.7	6.9
Mopti	3.2	1.9	1.7	1.9
Tombouctou	0.6	0.6	0.6	0.6
Gao	0.6	0.5	0.5	0.6

4.8.2 Runoff and Soil Erosion Loss

The simulations exhibited no significant changes in runoff among any of the four scenarios, even though there were substantial changes in cropland mixes and areas among the scenarios. The simulated weighted runoff values for each district are reported in Table 4.8.2.1.

Table 4.8.2.3 Percentage Decline in Erosion from Baseline Scenario Resulting From Adoption of New Technologies for Mali Political Districts			
	N'Tinmissa	Segutana	Full Adoption
Kayes	30	30	43
Koulikoro	12	12	13
Sikasso	13	13	11
Segou	3	3	0.5
Mopti	41	49	40
Tombouctou	1	3	3
Gao	19	19	6

The estimated erosion levels are a different story. In all cases across all districts and all scenarios, the technology adoption scenarios reported reductions in erosion when compared to the baseline scenario. These reduction ranged from very small in Segou district (1-3%) to substantial reductions in Kayes district (30-43%). The weighted average erosion rates per hectare are reported in Table 4.8.2.2 and the percentage reductions are reported in Table 4.8.2.3. The reduction in the Kayes district is almost totally attributable to the changing technology not the adjustment in area or mixes.
Both groundnuts and sorghum had substantial reduction in erosion rates when moving from the baseline scenario to each of the improved technology options. For example, erosion on groundnut areas dropped from an estimated 10.5 MT/Ha to 9.0 MT/Ha while sorghum dropped from 8.9 MT/Ha to 4.0 MT/Ha. For the most part, this reduction in erosion in both crops is attributed to the faster development of canopy cover and the increased development of biomass exhibited by the improved varieties and higher fertility levels (in the case of sorghum). This improved canopy and biomass provides added ground cover during the rainy season when the erosion accrues. Moving erosion in the opposite direction was a 30% increase in the groundnut area with the improved technology scenarios. However, this by itself would increase weighted area erosion estimates as groundnuts have the highest erosion estimated of all the crops simulated in the area (e.g. 10.% MT/Ha for groundnuts vs. 8.9 MT/Ha for sorghum in the base run). The net results of the various interactions were a reduction in the area erosion rates.

Other districts like Koulikoro and Sikasso report erosion reductions in the 10% to 15% range. In Koulikoro, there was no significant change in cropland area among crops for the three technology scenarios. This implies that all of the reduction of erosion is attributed to the variety and cultural practices used with the new technologies.

In Sikasso, the ASM reported a 50% reduction in cotton area for the full adoption scenario. Cotton has the highest erosion rate of all crops in the region; therefore, the movement out of cotton would be reflected in a decrease in total erosion for the region. However, cotton accounts for less than 2% of the cropland base in the Sikasso region. Movement in equilibrium acreage in other crops like maize, sorghum, and millet accounts for the small movement from 13% to 11% reduction that occurs in erosion in the full adoption scenario.

In summary, the simulations report no significant changes in the water runoff but significant reduction in erosion when the technologies under consideration are adopted. In some areas there are significant changes in cropland areas and crop mixes. Even though this shift in areas will affect the economies of the district, the environmental impact of the cropping area changse and mixes are negligible. However, the adoption of the new technologies does affect the total area erosion and, therefore, provide a measurable environmental benefit in all areas. This benefit is attributable to the crop-growing characteristic associated with the new technologies.

Section 5: Assessment of Impact of Technologies in West Africa: Estimation of Welfare Effects of Technologies Developed in One Location and Used in Another Location

One of the methodological objectives of this study was to develop and evaluate methods for extrapolating the impact of new technology from the areas in which experimental or field trial data exist to other locations. In Section 1, we describe the use of the concept of geographic equivalence to provide first order approximations of zones of adaptation or areas where the geographic similarities would allow one to predict the results of using the new technology. In Section 4, we describe the use of the ACT and EPIC to compute predicted yields based on biophysical considerations with results summarized in politically defined areas. In this section, we describe two case studies in West Africa which were used to estimate regional impacts of new sorghum and peanut technology. We modeled the extrapolation of the sorghum production system described in Section 4 for Mali for other areas in Mali (past where experimental data were available) and in Senegal and Burkina Faso.

To provide an indicative result of another USAID sponsored program, we conducted a limited economic assessment of new germplasm developed in Senegal under the Peanut CRSP. We modeled the impact of introduction of the new germplasm in Mali, Senegal, and Burkina Faso. To provide input to the economic models, it was necessary to estimate yields of relevant crops using methods described in Section 4. To assess the credibility of the methods, comparisons were made of observed yields and biophysically simulated yields in Mali, Senegal and Burkina Faso.

A previously developed ASM for Senegal by Martin (1988) was updated and evaluated as part of this study. The full development of national and subnational agricultural sector models (ASM) for Kenya and Mali proved to be time consuming and relatively expensive. While we believe that ASMs provide the more accurate method of assessing the impact of technology or policy options at these levels, we elected to explore the utility of an alternative method that was less demanding. A spatial extrapolative economic surplus model (SPEC) was developed for Senegal and Burkina Faso (an ASM did not exist for Burkina Faso) and used to evaluate the economic impact of the INTSORMIL CRSP and Peanut CRSP variety improvements. In combination, the ASM's for Mali and Senegal assisted in calibrating the SPEC model.

The SPEC model is a variation of the closed economic surplus model described by Alston and Purdey. The model was used to assess the PEANUT CRSP technology in Mali and Burkina Faso. An INTSORMIL CRSP sorghum variety assessment was performed in Senegal and Burkina Faso. Figure 5-1 describes the general methodology used to estimate the potential economic impact of a new agricultural technology using the SPEC approach.

Summary of Methods and Outputs	
Activity	**Purpose**
Develop Spatial Extrapolative Economic Surplus Model (SPEC)	Evaluate simpler option for sector models at national level
Evaluate impact of germplasm from USAID Peanut CRSP in West Africa	Additional case study to develop and evaluate methods of extrapolation and impact of CRSP activity
Evaluate impact of INTSORMIL germplasm from Mali in Senegal and Burkina Faso	Develop and evaluate methods for extrapolation and impact of CRSP activity
Spatial characterization of crops and yield estimation	Provide inputs on hectarage and yields for economic models (ASM and SPEC)
Estimation of price changes with new technology introduction	Provide input to economic models
Use of SPEC to estimate welfare benefits	Estimate consumer and producer benefits of new technology in Senegal, Burkina Faso, and Mali
Summary of Results on extrapolation methods and case study impacts	Conclusion on methods for extrapolation, comparison of results with previous experiences, and evaluation of the SPEC model

5.1 Problem Definition

In the Kenya and Mali studies, we examined the national and regional economic benefits of introducing a technology into a country by developing and using a multi-commodity ASM and farm level models. In this section, we describe methods to extrapolate these results to other countries with similar geographic and social circumstances that might also benefit from adoption of the technology. Quantifying the value of such benefits requires extrapolating productivity changes from a base country to other country environments and estimating resulting price, quantity, and economic welfare changes in recipient countries.

The two sorghum varieties considered, N'tenimissa and Seguetana, on average respectively yielded 25% and 33% more than traditional sorghum varieties in Mali. In Senegal, EPIC simulations modified by expert opinions of expected yields were used as no observed yields were available for the N'tenimissa and Seguetana varieties. Yields for improved varieties in Senegal that are similar to these two variety types were used to simulate expected yields. Traditional and expected improved variety yields for each country are provided in Table 5.1.1. These yields are weighted national yields, weighted by the hectares and simulated yields for each geographic area comprising the country, as presented in equation 5.4.2-2 of section 5.4.2 of this report.

Four regionally specific peanut varieties developed in Senegal were considered. Data on peanut yields were obtained from Dr. Ousmane Ndoye of the Institut Senegelais de Recherche Agriculture (ISRA). The Fleur

11 variety has a 25% greater yield than its traditional equivalent for the Sahelo-Sudanian and Sudanian zones. Its vegetative cycle is 90 days and produces large pods. It has good resistance to drought and is well suited to cropping conditions in dry zones (Ndoye; Oléagineux). This variety has no dormancy and will sprout if grown in regions with longer rainy periods than its vegetative cycle. Thus Fleur 11 is not well adapted to the southern one-third of Senegal.

GC8-35 variety yields 10% more than traditional varieties in the Sahelian zone. It produces a yield of approximately 550 kg/ha, and is best suited for regions of northern Senegal that normally experience 350 mm or less of annual precipitation. The H75-0 and GHN119-20 varieties yield 5% more than traditionally recommended varieties for the Sudano-Guinean zone. Two varieties are best suited for the southern portion of the country. H75-0 has a larger seed than the traditional varieties. The PC79-79 variety is more resistant to leaf spore than traditional varieties. Both new varieties produce about 5% better yield than traditional varieties adapted to the southern zone (Ndoye). Traditional and improved variety yields for each country are given in Table 5.1.2. The expected improved peanut variety yields are weighted national yields as explained above for the improved sorghum varieties.

Table 5.1.1: National Crop EPIC-BASED Yields (tonnes/hectare)

Country	Sorghum Traditional	Sorghum" N'tenimissa	Sorghum Seguetana	Millet/Sorghum 10%	Millet/Sorghum 40%
Burkina Faso	0.749	0.751	0.764	—	
Mali	0 .780	0.801	0.986	—	
Senegal	0.587	—	—	.590	0.648

*Data available for Senegal groups millet and hectares together. For 1997 sorghum varieties comprised 15% of the total millet sorghum hectares.
** Improved Senegal millet sorghum was considered for two different levels of maximum hectare adoption for the improved varieties. In Burkina Faso and Mali only one maximum hectare adoption was considered because of the different nature of the ASM model

Table 5.1.2: National Crop EPIC-BASED Yields (tonnes/hectare)

Country	Groundnuts Traditional	Groundnuts" Improved	Groundnuts Maximum Hectares
Burkina Faso	0.670	0.743	--
Mali	0.926	0.940	--
Senegal	0.587	0.745	0.776

*Data available for Senegal groups millet and hectares together. For 1997 sorghum varieties comprised 15% of the total millet sorghum hectares.
** Improved Senegal millet sorghum and groundnuts were considered for two different levels of maximum hectare adoption for the improved varieties. In Burkina Faso and Mali only one maximum hectare adoption was considered because of the different nature of the ASM model

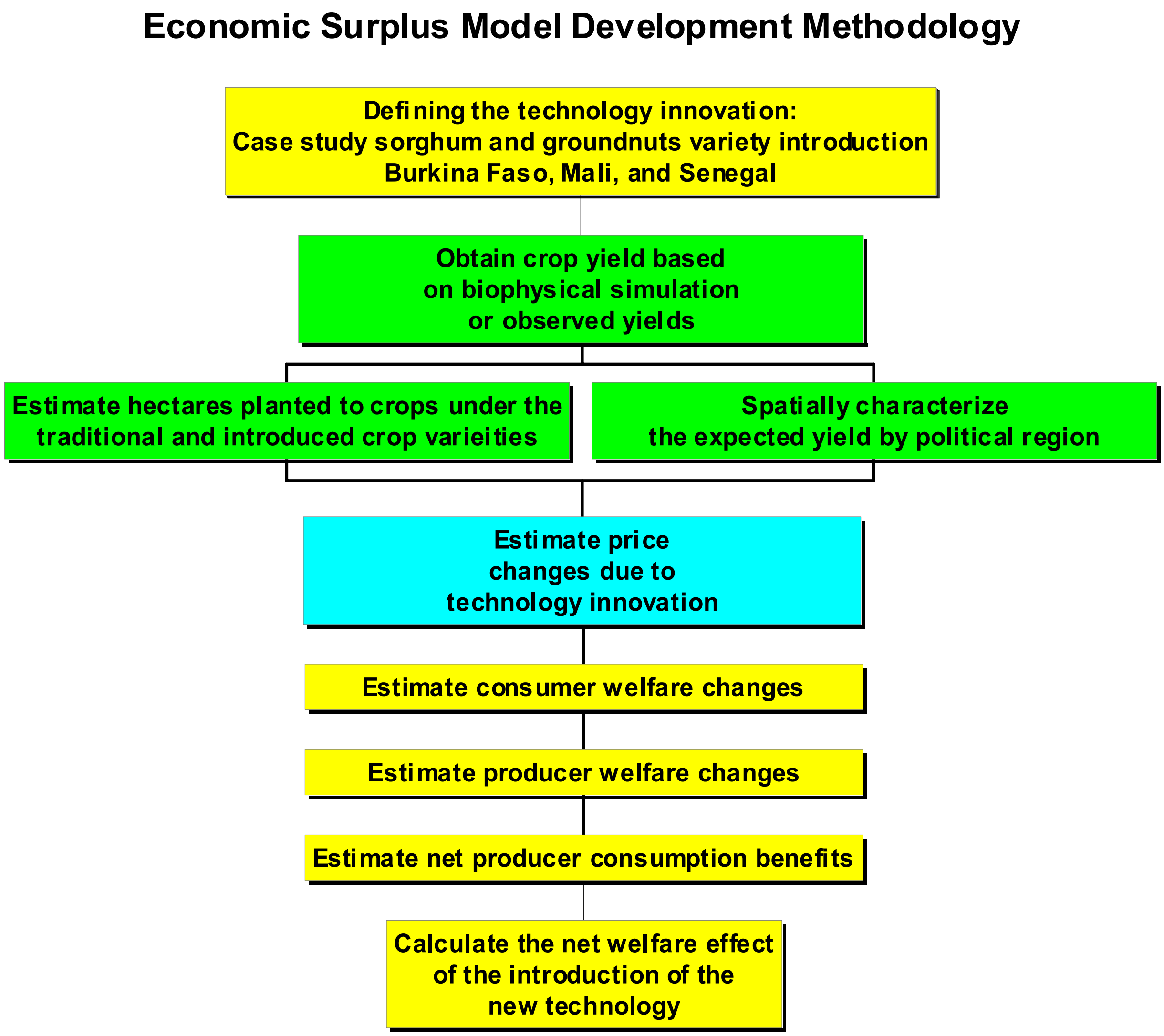


Figure 5-1. SPEC Methodology

5.2 Regional Assessment Methodology

The SPEC method involved a six step procedure. Step 1 involved stratifying regions using ACT to identify compatible areas in other countries for the introduction of the technology. Step 2 required development of yield estimates for the base technologies and the introduced technology improvements through biophysical simulation for representative soils and climatic zones in each country. Step 3 involved estimating adjustments in hectares planted for the target crop and competing crops due to changes in the yield of the target crop. Step 4 was estimating national production as a weighted sum of the expected yields for each soil type and climatic zone times adjusted hectares from step 3 to obtain a national yield. In step 5 commodity price is calculated using the percentage change in national production and the demand elasticity for the commodity. Step 6 adjusts for impacts of changes in production of other crops on commodity price using economic results produced by the ASM in Mali, and computing changes in national consumer and producer surplus. The SPEC methodology is repeated in other countries of the WA Region using the procedures described in steps 1 to 6. Figure 5-1 provided a description of the flow up to step 5.

5.3 Models Used to Estimate Impact of Introducing Technologies in Countries Other than Origin of Experimental Data

5.3.1 INTSORMIL Technology

Potential West Africa (WA) regional impact of improved INTSORMIL varieties in Senegal, Mali and Burkina Faso was estimated with the ASM and SPEC models for Mali. The SPEC models estimated the economic impact of the sorghum variety introduction at the national level only. The process was repeated in Senegal and Burkina Faso with a SPEC model developed for each of those countries for evaluating the national economic impact of introducing the improved INTSORMIL varieties.

5.3.2 Peanut CRSP Technology

Similar to the INTSORMIL case study, potential economic impact of adopting improved Peanut CRSP varieties in Mali and in Burkina Faso was carried out with a SPEC model. First, the model estimated the economic impact of introduction of the peanut varieties developed in Senegal. Estimates were made only at the national level. This process was repeated for Mali and Burkina Faso using extrapolated crop yields and adjusted hectares of crop plantings from introducing the improved Peanut CRSP technology into Mali and Burkina Faso.

5.4 Spatial Characterization of Crops and Yield Estimation

5.4.1 Historic Sorghum and Peanut Yields

Sorghum yields in Burkina Faso and Senegal and peanut yields in Burkina Faso and Mali were simulated using the EPIC biophysical crop simulation model. Sorghum and peanut plant growth was modeled under a wide range of soil, climatic, and geographic categories. A description of the crop modeling process is given in the crop modeling Section 4 of this report. Historic traditional and simulated improved sorghum yields are provided in Table 5.1.1. Historic traditional and simulated improved peanut yields are provided in Table 5.1.2.

5.4.2 Spatial Yield Variation

Yield information obtained from the EPIC biophysical simulations should approximate reported yields from politically defined areas that span agroecological zones. To obtain EPIC simulated yields that correspond to yields reported in the official statistics requires weighting yields by hectarage, soils, and climates observed in each political district.

The Almanac Characterization Tool (ACT) was used to achieve the required synthesis. ACT defines polygons that represent each of the modeled soil types within each political entity studied. It then defines the polygons more precisely by accounting for the climatic, physical and human geographic conditions observed. The yield assigned to each polygon is then weighted by the hectares each polygon represents. The weighted yields are then summed to produce the expected yield for the political area under analysis. Equation 5.4.2-1 describes the weighting process for a political district. This process is discussed in detail in Section 4 of this report.

Equation 5.4.2-1

$$Y_{oij} = \sum_{n=1}^{l} Y_{olij} * H_{ol}$$

Y_{oij} = **The Epic yield for subregion o, agronomic practice i, and crop j**

Y_{olij} = **Epic yield for subregion o, polygon l, agronomic practice i, and crop j**

H_{ol} = **Hectares in sub – region o, represented by polygon l**

The numeric yields produced by the EPIC model and aggregated with the ACT program are not used directly in the SPEC analysis. Rather the percentage change from the traditional yield under the relevant agronomic practice is calculated and used to adjust the base yields in the ASM or the historic traditional yields in the SPEC model. The ASM thus uses the subnational regional yields from equation 5.4.2-1 in its analysis. The SPEC model uses a national yield that is the hectare weighted average of the subnational regional yields (equation 5.4.2-2). ASM contains accounting equations that aggregates across regions and commodities to derive national estimates of consumers surplus, producers surplus, home consumption costs, foreign surplus and total economic surplus. In the SPEC analysis these measures of economic welfare changes are computed directly for the national level.

To provide a comparison between modeled and reported data, the EPIC model had to reflect yield changes of millet and sorghum combined in Senegal since millet and sorghum yields are reported jointly in official Senegal agricultural statistics. Two scenarios were considered for Senegal. In one scenario, hectarage allocated to the improved sorghum was 10 percent of the total area planted to sorghum. In the other scenario it was assumed that 40 percent of the sorghum hectarage was planted to improved varieties.

Equation 5.4.2-2

$$IY_{oij} = (((EY_{oij} - Y_{ob}) / Y_{ob}) + 1) * B_{oij}$$

o = ***subnational ~ region***

i = ***the agronomic practice***

j = ***the crop variety***

IY_{oij} = ***Improved yield for agronomic practice j for crop i***

EY_{oij} = ***Epic Yield for agronomic practice j for crop i***

Y_{ob} = ***The low fertility traditional yield for crop i***

B_{oij} = ***The traditional yield for agronomic practice j for crop i***

5.4.3 Estimation of Crop Hectarage

Changes in crop yield can potentially lead to changes in hectares planted to that crop and alternative crops. The SPEC approach reflects changes in land allocation due to improvements in crop yield by capturing historic relationships between planted hectares of a crop, expected yield, and other independent variables. For the SPEC model to reflect changes in land allocation due to improvements in crop yield it was necessary to estimate historic relationships between planted hectares of a crop, expected yield and other independent variables.

The estimation of peanut, millet, and sorghum hectarage with various technology innovations was based on evaluation of a set of independent variables estimated for each crop using the "Seemingly Unrelated Regression Method" (Zellner). Independent variables included historic data on crop price, crop yields, precipitation, fertilizer use, agriculture labor, fertilizer price and time. Prices were indexed for inflation. Logarithmic transformations were made to the original data set and crop hectares were expressed as a function of the previous year's values for the independent variables.

Tables 5.4.3.1 to 5.4.3.3 provide the estimated regression coefficients of the equations for planted hectares for each commodity respectively in Burkina Faso, Senegal and Mali. Millet and sorghum were treated as one commodity in Senegal due to that country's method of gathering and reporting combined data for these commodities. In 1997 sorghum hectares represented 15% of the total millet-sorghum hectares planted in Senegal. The estimated regression coefficients along with the adjusted R^2 values and t-value statistics (shown in the parenthesis) are reported in each table. The regression coefficients indicate the change in planted hectarage for a crop associated with a one-unit change in the independent variables included in the regression.

Table 5.4.3.4 describes the percent difference in estimated hectares and observed national hectares by commodity for each country. Five regressions provided hectarage estimates within 4 to 7% of those reported in the base year. The remaining three regressions provided estimates greater than 20% of the reported base hectarage for peanuts in Senegal and millet in Burkina Faso and Mali.

Allocation of hectarage to sorghum, peanut, and millet production was performed using yields of improved varieties. Adjustments in the sorghum, millet, or peanut hectarage were proportionately added to or deleted from hectares of other major crops to maintain national cropland resource balance. Base production of sorghum, millet, and peanut is base hectarage multiplied by the national base yield for each crop. Production from introducing new varieties is improved variety yields multiplied by estimated hectarage allocations for each crop. Other major crops are assumed to maintain base yield levels in the estimation of production as new varieties of sorghum, millet, or peanut are introduced.

Table 5.4.3.1 Estimated parameters for Burkina Faso sorghum, millet, and groundnut hectare equations, 1966 to 1991

Crop* **(R^2)**	**0** **(T-stat)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Sorgh (0.724)	13.821 (164.0)[3]	0.077 (3.621)[3]	-	0.201 (1.557)	-0.1408 (-1.332)	-0.0394 (-2.510)[2]	-	-	-
Mill. (0.503)	13.570 (136.4)[3]	0.067 (2.819)[3]	0.3290 (3.143)[3]	-	-	-0.036 (-2.163)[2]	-	-	-
Gr. (.201)	14.562 (7.982)[3]	-	-	-	-	-	-0.081 (-0.709)	-0.457 (-1.548)	0.101 (1.799)[1]

* Sorgh = sorghum, Mill. = millet, and Gr. = Peanuts,
[1] Significant at the 10% confidence interval, [2] significant at the 5% confidence interval, [3] Significant at the 1% confidence interval

$_0$ = Constant term
$_1$ = Lagged logged millet price
$_2$ = Lagged logged millet yield
$_3$ = Lagged logged sorghum yield
$_4$ = Lagged logged peanut yield
$_5$ = Lagged logged fertilizer value
$_6$ = Lagged logged peanut to sorghum yield
$_7$ = Lagged logged precipitation
$_8$ = logged time period t

Sources: Crop and Price information
Minstere De L'agriculture et des Ressources Animales, Project "Amelioration Des Instruments Du Diagnostic Permanent Pour la Securite Alimentaire Regionale Phase III, CILSS-CE, Performances De L'Agriculture 1984- 1996.
Ministere De L'Agriculture, General Secretariat, Direction Des Etudes et de la Planification, Cellule Technique Du Comite De Coordination De L'Information, Resultats Definitifs De La Campagne Agricole 1996-1998
Institut National De la Statistique et De la Demographie, Annuaire Series Longue Du Burkina Faso, Ministere De l'Economie et Des Finances, Burkina Faso, December, 1996.
International Monetary Fund Annual Report, 1998,
FAOSTAT data base
USDA international database, Mann Library, Cornell University

Table 5.4.3.2 Estimated parameters for Senegal sorghum-millet, and groundnut hectare equations, 1966 to 1996

Crop Ha. [*] **(R^2)**	$_0$ **(T-stat)**	$_1$	$_2$	$_3$	$_4$	$_5$	$_6$
Mill-Sorgh (0.42)	13.146[3] (27.2)	0.534 (1.09)	-0.236[3] (-2.56)	0.21[3] (4.24)	-	0.009 (1.14)	-
Gr. (0.74)	11.599[3] (44.53)	0.545[3] (-2.96)	0.186[1] (-1.42)	-0.30[3] (-5.39)	-0.038[1] (-1.76)	-	0.545[3] (5.21)

[*] Mill. = millet, Sorgh = sorghum, and Gr. = s,
[1] Significant at the 10% confidence interval, [2] significant at the 5% confidence interval, [3] Significant at the 1% confidence interval

$_0$ = Constant Term
$_1$ = Lagged logged ratio of millet to groundnut price
$_2$ = Lagged logged millet yield
$_3$ =Lagged logged peanut yields
$_4$ = Lagged logged fertilizer price
$_5$ =Lagged logged fertilizer use (kg/ha)
$_6$ =Lagged logged peanut price

Sources:
Dr. M. Gaye, Dissertation, Les Politiques D'Ajustement Dans le Secteur Agricole Senegalais: Analyse Critique Des Implications Sur La Filiere Arachidiere
FAOSTAT data base
USDA international database, Mann Library, Cornell University
International Monetary Fund Annual Report, 1998
Institut Sénégalais De Recherches Agricoles Unité De Recherche Politique Agricole et Socio-Economie (ISRA)
Ministere de L'economie, Des Finances et du Plan, Direction de la Prévision et de la Statistique

Table 5.4.3.3 Estimated parameters for Mali sorghum, millet, and peanut hectare equations, 1966 to 1991									
Crop Ha.[*] (R^2)	0 **(T-stat)**	1	2	3	4	5	6	7	8
Sorgh (0.39)	12.866 (58.60)[3]	0.643 (3.59)[3]	-	-0.044 (3.50)[3]	-0.020 (-1.15)	-	-	-	-0.679 (-1.45)
Mill. (0.73)	13.290 (90.17)[3]	0.768 (5.915)[3]	0.647 (-5.865)[3]	-	-	-0.018 (-1.984)[1]	-	-	-0.277 (-0.85)
Gr. (0.50)	11.702 (44.53)[3]	-0.763 (-2.96)[3]	-0.536 (-1.42)	-	-	-	1.401[3] (3.042)	0.060[3] (2.54)	-1.262[2] (-1.95)

[*] Sorgh = sorghum, Mill. = millet, and Gr. = Peanuts,
[1] Significant at the 10% confidence interval, [2] significant at the 5% confidence interval, [3] Significant at the 1% confidence interval

0 = Constant term
1 = Lagged logged millet price
2 = Lagged logged cotton price
3 = Lagged logged cotton price squared
4 = Lagged logged ratio of sorghum to groundnut yield
5 = Lagged logged ratio of millet to groundnut yield
6 = Lagged logged groundnut price
7 = Lagged logged ratio of groundnut to millet yield
8 = Lagged logged fertilizer to agriculture labor ratio

Sources:
Institut D'économie Rurale (IER)
International Monetary Fund Annual Report, 1998,
FAOSTAT data base
USDA international database, Mann Library, Cornell University

Table 5.4.3.4: Percent difference in estimated and observed national hectares in production by commodity

Country	**Commodity**			
	Peanuts	**Millet**	**Sorghum**	**Millet/Sorghum**
Burkina Faso	-7.0	21.0	7.0	--
Mali	5.9	34.7	-3.6	--
Senegal	20.9	--	--	5.5

5.4.4 Price Change Estimation

In the SPEC model price changes are estimated by determining the market clearing price for a given change in production of each commodity. This is determined by dividing the percentage change in production by the demand elasticity coefficient. This ratio is then multiplied by the base price and added to the base price as shown in equation 5.4.4-1.

Equation 5.4.4-1

$$IP_j = ((((Q_{1j} - Q_{oj}) / Q_{oj}) / h_j)) + 1) * BP_j$$

IP_j = ***Price of commodity j with the introduction of the improved variety***

Q_{1j} = ***Quantity produced under the new hectares and yields associated with improved variety j.***

Q_{oj} = ***Quantity produced under the base hectares and yields associated with traditional variety j.***

h_j = ***Demand elasticity for commodity j***

BP_j = ***Base price for commodity j***

5.5 Welfare Estimation and Results

The shift in production is assumed to be a parallel shift and the demand elasticity coefficient is assumed to be constant for each commodity. Consumer surplus is estimated for sorghum, millet, and peanut in Burkina Faso and Mali. In Senegal consumer surplus is estimated for millet/sorghum and peanut.

Estimation of consumer surplus is calculated using the closed economic surplus model of Alston and Purdey, where the change in the area under the demand curve above the price line before and after the innovation is calculated. Producer surplus is calculated by taking the difference between total revenues and total costs in the SPEC model.

5.5.1 Sorghum

5.5.1.1 Burkina Faso

Sorghum production increased by an estimated 32 thousand tons (0.29%) for N'tenimissa and 25 thousand tons (2.28%) for Seguetana when these varieties are introduced into Brukina Faso. Price declined by 0.36% for the N'tenimissa and 2.85% for the Seguetana scenarios. Annual consumer surplus was increased by 42 million fcfa with the introduction of N'tenimissa and 299 million with Seguetana. Producer surplus also increased due to the reallocation of land to sorghum, peanuts, and millet. Home consumption costs increased for both varieties. The increase in price of other crops as land reallocation caused a decline in production resulted in a subsequent increase in cost of food stuffs for home consumption. Total national welfare increased 3.198 billion fcfa for the N'tenimissa scenario and 1.991 billion fcfa for the Seguetana scenario (Table 5.5.1.1).

Table 5.5.1.1: Estimation of the welfare implications of introducing sorghum varieties to Burkina Faso based on EPIC yields

	Sorghum Variety	
Variable	**N'tenimissa**	**Seguitana**
Sorghum Production Change (thousands tonnes)	32.01	25.14
Sorghum Price Change	-0.36	-2.85
Change in Consumer Surplus (Billions of fcfa)	0.042	0.299
Change in Producer Surplus (Billions of fcfa)	3.173	1.869
Home Consumption Benefit (Billions of fcfa)	-0.017	-0.175
Total Welfare Change (Billions of fcfa)	3.198	1.991

5.5.1.2 Senegal

Two scenarios were considered for Senegal. The first was an adoption rate of 10% for total sorghum area planted to improved varieties. Millet/sorghum production increased by 2,352 tons (0.39%), and peanut production increased by 76 tons (0.09%). With an assumed adoption rate of 40% of total sorghum area planted to improved varieties, production of millet/sorghum increased 47 thousand tons (7.83%) while peanut production increased 14 thousand tons (1.8%). The different production levels under the two adoption rates reflected substantial differences in commodity price changes. Sorghum price declined 1.04% and peanut price declined 0.19% under the 10% adoption rate, whereas sorghum price declined 16.45% and peanut price decreased 3.77% under the 40% adoption rate. Consumer surplus increased while producer surplus declined under both scenarios. In each adoption scenario producer losses in welfare were about equal consumer gains in welfare. Rural families, however, benefitted through home consumption costs decreasing for both adoption rates. The increase in total national welfare under the 10% adoption rate was only 650 million fcfa. It was 9.57 billion fcfa for the 40% adoption rate (Table 5.5.1.2).

5.5.2 Peanuts

5.5.2.1 Burkina Faso

Peanut production increased by 19 thousand tons (15.6%) with the adoption of the improved peanut varieties in Burkina Faso. Peanut price declined by 25.2%. Due to increased hectares allocated to peanut production, prices of other crops except sorghum and millet increased by 2 to 6%. These price increases

Table 5.5.1.2:Estimation of the welfare implications of the introduction of improved sorghum varieties to Senegal based on EPIC yields assuming different adoption rates

Variable	10% Adoption Rate	40% Adoption Rate
Millet/Sorghum Production Change* (thousands tonnes)	2.352	47.317
Peanut Production Change (thousands tonnes)	.076	13.833
Sorghum Percentage Price Change*	-1.04	- 16.45
Peanut Percentage Price Change	-0.19	-3.77
Change in Consumer Surplus (Billions of fcfa)	1.050	16.866
Change in Producer Surplus (Billions of fcfa)	-1.042	-17.641
Home Consumption Benefit (Billions of fcfa)	0.643	10.342
Total Welfare Change (Billions of fcfa)	0.650	9.57

* Data for millet and sorghum is reported jointly in the Senegal Government statistics

resulted in a net decrease in consumer surplus of 834 million fcfa. Producer surplus increases by 2.577 billion fcfa and home consumer benefit declines 927 million fcfa. Total national welfare increases 814 million fcfa (Table 5.5.2.1).

5.5.2.2 Mali

Sorghum production increased by 126 thousand tons (20.2%) as land was shifted from peanut production to sorghum in Mali. Millet production also increased by 285 thousand tons (29.4%). New varieties increased peanut production by 12 thousand tons (7.2%). A sorghum price decline of 1.75 % resulted in an increased consumer surplus of 46.82 billion fcfa. The sorghum price decline resulted in a loss of producer surplus of 62.69 billion fcfa, but home consumption benefits increased by 43.49 billion fcfa. The total national welfare change was 27.6 billion fcfa (Table 5.5.2.2).

5.6 Conclusions on Extrapolations

Results from the SPEC analyses for sorghum indicate relatively small gains in economic welfare to domestic consumers in towns and cities from adoption of the improved varieties in Burkina Faso and Senegal under the 10% adoption rate. Similarly, home consumption benefits were relatively small ranging from a 17 million fcfa to a 643 million fcfa increase in food costs (USD 1.0 million) gain in home consumption benefit. Producer benefits were relatively modest for Burkina Faso, between 1.9 billion fcfa and 3.2 billion fcfa (USD 3.0 to 5.0 million). Only with the 40% adoption rate in Senegal for the improved sorghum varieties were substantial benefits to consumers indicated. Consumers in towns and cities and rural families would experi-

Table 5.5.2.1. Estimation of the welfare implications of introducing improved peanut varieties to Burkina Faso based on EPIC yields

Variable	Improved Groundnuts
Sorghum Production Change (thousands tonnes)	0.00
Millet Production Change (thousands tonnes)	0.00
Groundnut Production Change (thousands tonnes)	19.485
Sorghum Percentage Price Change	0.0
Millet Percentage Price Change	0.0
Groundnut Percentage Price Change	-25.17
Rice Percentage Price Change	4.77
Fonio Percentage Price Change	5.08
Cotton Percentage Price Change	6.22
Maize Percentage Price Change	1.97
Change in Consumer Surplus (Billions of fcfa)	-0. 834
Change in Producer Surplus (Billions of fcfa)	2.577
Home Consumption Benefit (Billions of fcfa)	-0. 927
Total Welfare Change (Billions of fcfa)	0.814

ence increased economic welfare of some 27 billion fcfa (USD 42 million). However, producers would have welfare losses of over 17 billion fcfa (USD 27 million) so that total national welfare gain was only 9.5 billion fcfa (USD 15 million).

Introducing improved peanut varieties into Burkina Faso from Senegal was estimated to have little impact on domestic consumers welfare and rural families' home consumption costs. Producers gain some 2.6 billion fcfa (USD 4 million), but with the welfare losses to consumer, the total national welfare gain was only 814 million fcfa (USD 1.25 million).

The most profound impact of adopting the improved peanut varieties was indicated for Mali, whereby domestic consumers would gain 47 billion fcfa (USD 72 million) in welfare. Rural families would benefit by an estimated 43.5 billion fcfa (USD 67 million). However, producers would lose an estimated 63 billion fcfa (USD 96 million) so that national welfare gains would be some 27.6 billion fcfa (USD 42 million).

Introduction of improved sorghum varieties from Mali into Senegal under a 40% adoption rate, and improved peanut varieties from Senegal into Mali provided much larger expected economic welfare gains than introduction of the improved varieties into Burkina Faso. These results arise primarily from the relatively small increases in simulated yields form the improved sorghum varieties in Burkina Faso (between 0.3 to 2.0% as was shown in Table 5.1.1) and the large peanut production change and resulting price decline relative to sorghum and millet, in particular, but also to other crops (as was shown in Table 5.5.2.1).

The results of the analysis to extrapolate the impact of sorghum and peanut technology to outside areas where experimental data are lacking produced these estimated economic impacts of the technologies in the three countries. The relationship of model outputs to reported yields gave some credibility to these results, but showed that further work is needed to extend and verify the utility of the approach. Even with current limitations, the use of these models to extrapolate results to other areas could be justified for planning purposes in ex ante assessment of alternative investments in research or in helping to focus the areas where extension activities might explore the utility of the technology.

As expected, data limitations were shown to be a constraining factor in the utility of this kind of methodology. Further consideration must be given to non-modeled factors that affect adoption of this type of technology, even though there is considerable comparability of both geography and socio-cultural factors affecting adoption.

Table 5.5.2.2: Estimation of the welfare implications of introducing improved groundnut varieties to Mali based on EPIC yields

Variable	Improved Groundnuts
Sorghum Production Change (thousands tonnes)	126.063
Millet Production Change (Thousands tonnes)	285.168
Groundnut Production Change (thousands tonnes)	12.410
Sorghum Percentage Price Change	-1.75
Change in Consumer Surplus (Billions of fcfa)	46.82
Change in Producer Surplus (Billions of fcfa)	-62.69
Home Consumption Benefit (Billions of fcfa)	43.49
Total Welfare Change (Billions of fcfa)	27.62

The SPEC approach has a number of limitations. It is only capable of assessing the welfare implications of a technological innovation at the national level. It could not capture substitution among different management practices nor could it capture substitution of hectares among crops that were not included in the regressions. SPEC provided some indication of the potential national welfare impact of the introduction of improved varieties. It cannot provide as detailed information as the agricultural sector model. SPEC calculations used a spreadsheet approach that was cumbersome and increased the potential for errors. An alternative approach would have been to use a GAMS based format to increase the efficiency of data entry and reduce data handling errors. However, based on time requirements, data acquisition costs, and total resources required to carry out SPEC analysis, development and use of country specific national level ASMs (without subnational regional specificity of resource constraints and production activities) appears to be a more cost effective and accurate approach to estimating economic welfare impacts from extrapolating technologies developed in one country to other countries within a multinational region such as West Africa.

Section 6: Perspectives and Insights about Impact Assessment Methodologies

In 1996, the Impact Assessment Group at Texas A&M University began to work together as an interdisciplinary group of scientists and analysts from relatively diverse disciplines to develop the integrated suite of models that we refer to in this report as IMPACT. Over the intervening three years, we have learned how to bring these disciplines into a more coherent and usable framework for impact assessment and gained substantial experience in developing and demonstrating the concepts for use in international settings. We stated in Section 1 that we regard the status of IMPACT as being "imperfect but usable." The development of this suite of models is being continued under USAID sponsorship as part of the Global Project of the SANREM CRSP.

This section of the report includes a summary of the "lessons learned" as our team has gone about making the diverse set of models interactive and useful in a developing country scenario. We also use this section of the report to convey some of the overarching principles and innovations that result from this research.

We had our share of false starts and inefficiencies. Since this project was funded as a methodological development, we felt it would be appropriate to share our general reflections about the way the project unfolded. As we move ahead, we believe that the next steps will be more efficient than our initial efforts.

This was obviously not the first interdisciplinary project ever done. In fact, most of this team had previous experience in such research. Nonetheless, we relearned a number of lessons that we hopefully will not have to learn again. First, the effort required to understand and appreciate each other's science is time-consuming but critically important to this kind of research. Second, communication between collaborators is never as complete as it needs to be for efficient engagement. Repeated communication to review and ensure understanding about each other's work in this kind of modeling are even more important than in other kinds of collaboration. Even seasoned investigators often failed to recognize the impact that decisions taken about one part of a complex project can have on other parts. The importance of a relatively tight experimental design was demonstrated again in our experiences on this project. We revalidated the importance of maintaining commitments of individuals to team schedules and deadlines.

Our group found itself pulled in two directions as we set about developing and extending methods for IMPACT in the context of the case studies that were used as platforms for this research. The primary purpose of the project was to develop methods. However, we often found ourselves being swept up in the individual components of the case study, with less than needed attention to making the models fit together into a coherent package. We had to keep reminding ourselves about both objectives as we moved through the project.

Because the level of development of models used in these studies was not uniform, we found that some parts moved ahead faster than others did. Scheduling of intersections and interactions between models proved challenging in the developmental stage of our work. We expect this will continue to be difficult as others use the models in practice.

Summary of Perspectives and Insights	
Methods	***Perspectives and Insights***
Interdisciplinary Teamwork	Importance of planning and ongoing communication
Intensification vs. Extensification	Methods to achieve increased productivity and their potential impacts
Geographical equivalence and use of spatially explicit analysis	Methods of defining geographically similar zones for modeling biophysical inputs to economic models. Comparison of methods used in East and West Africa.
Environmental simulation zones and extrapolation of impact outcomes	Assessment of methods for extrapolation of impact of new technology in areas where experimental data were not present
Watershed level impact assessment	Evaluation of Sondu river basin analysis in Kenya and importance of this level of assessment
Providing interactions between commodities	Economic models that allow interaction between commodities to reflect economically driven shifts in hectarage and resulting changes in welfare from introduction of technology for one commodity
Linking multiple models to address multi-dimensional assessments	First generation integrated models provide a usable, if imperfect, methodology to relate economic, environmental, and biophysical factors affecting impact of new technology
Contrasting East and West Africa studies	Methods were similar in concept but tailored to meet needs of the case studies and geography of the countries. Illustrated the flexibility of methods.
Criticality of non-modeled variables in defining adoption and economic-environmental outcomes	Non-modeled variables can have substantial impact on impact of new technology. Estimates of these impacts using local, regional, and national experts provides an approximation of their contribution

Summary of Perspectives and Insights (continued)

Methods	*Perspectives and Insights*
Use of modeled variables as proxies for indicators that are difficult or expensive to measure directly	Specific model outputs serve as proxies for broad politically defined indicators of food security, poverty, and environmental degradation. Inputs to economic models not otherwise available were successfully estimated using biophysical models.
Improved methods for risk assessment at farm and national levels	Adding stochastic components to models provided a means of modeling risk aversion methods used by farmers and for including risk in impact assessment
Verification of models relative to measured or reported outcomes and data	Comparison of model outputs with reported or measured outcomes and data provides one way of verifying that models are behaving in ways consistent with the real world and adds credibilityto estimates reaching beyond the data
Status of models for environmental and natural resources impact of new technology or policy options	Environmental models in IMPACT are less well developed than economic models. Development and use is paced by overall state of knowledge and useful indicators of the impact of change on overall ecosystem health and paucity of needed long-term data.
Conclusions about case studies	The general form and direction of the results of technology evaluations in these studies are consistent with other studies. Consumers and early innovators benefit most. Projected increases in population and related increase in demand provide benefits for producers and consumers with final future adoption rates.

6.1 Intensification vs. Extensification

When use of a practice, technology, or policy option was modeled, we defined two generic ways in which it could occur. Intensification involves exercising the option on land areas currently used in production of the relevant commodity(s) — creating more product with the same land area in the same location. For purposes of our analysis, we defined intensification to include the displacement of one commodity by another within existing land areas suitable for production of both commodities. Displacement in these models occurs when the technology or policy option causes a more favorable economic outcome relative to current land use. Extensification is the process of introducing production into land areas that were previously unused or used for less intensive purposes. In practice, to meet the demands for food imposed by an increasing population, extensification has often involved exploiting marginal lands with resultant degradation and/or desertification. These terms define the limits of a continuum of land use change resulting from outcomes driven by technology or policy options.

6.2 Geographical Equivalence and Use of Spatially Explicit Analysis

The term "geographical equivalence" in its simplest manifestation describes the ability to create an empirical model of a select location and identify all areas similar to that location. Geographical equivalence specifically relates to the observation-environment relationship and its spatial analogue. In many ways, the crudest forms of adaptation zones are those areas that are geographically equivalent to a location where a given technology appears well suited. However, geographical equivalence relates also to other characteristics that may not be fully part of a technology or policy-level adaptation zone.

Closely related to the idea of geographical equivalence is the term "adaptation zone." In the case of new technology, this means geographically equivalent areas in which, as a first approximation, the technology might be adaptable. For example, a specific maize germplasm may have characteristics that loosely describe its adaptation zone (temperature, rainfall, and soil requirements). Geographical equivalence is the term used to describe a series of spatial tests relating other important characteristics to the initial adaptation zone. Perhaps the germplasm is not tolerant of a certain disease — a disease that has its own set of characteristics for which geographic equivalence might be identified. In these studies, we distinguished between the terms adaptation and adoption. Adaptation was a first-order approximation of areas of geographic equivalence to which new technology may be adapted. The precision of this estimate is dependent on the extensiveness of the analysis of geographic equivalence. We used the term adoption to mean the actual use of new technology, both in terms of the location and the extent of utilization. We recognized that the analysis of adaptation in ex ante analysis would be different from actual adoption as a result of factors that were not completely represented in our models.

Geographic equivalence was used in these studies as a fundamental part of establishing an objective method for determining spatial sampling frames that required spatially explicit analysis to assess the impact of new technology or policy. Objectively defined sampling frames provide a very important tool to improve the efficiency of research on impact assessment. Knowing how often and where to sample to acquire representative data avoids either over or under investing in detailed research. A spatial sampling frame not only sets up the rigorous examination of predictive data but also sets in place an understanding of how far (and how representative) results can be applied. We exercised two different spatial sampling mechanisms in our case studies.

For Kenya, the complexity of the local environments, extensive use of an established agro-ecological zonation scheme, and the steep local environmental gradients encouraged the following steps in establishing our sampling frame. First, we used the Jaetzold and Schmidt zones from the "Farm Management Handbook of Kenya" to better communicate with our local collaborators and to ensure sampling across all ecotypes. We then took GPS (latitude and longitude) readings of actual smallholder dairies in each ecotype. We linked these locations to our spatial databanks, and built a quantitative characterization of each dairy. A principle component analysis on these climatic characteristics produced groups of similar smallholder dairies. We took the mean characteristics of these groups and found areas of geographical equivalence for each. This technique differs markedly from the published agro-ecological zonation scheme because that scheme attempts to amalgamate a wide range of agricultural activities into one coherent scheme. Our system rapidly assembled even more data than the Jaetzold and Schmidt study but then built a smallholder dairy-specific spatial sampling frame of the target environments. We named them in a similar fashion to the Jaetzold and Schmidt scheme to better communicate the ecotype, but the spatial manifestation of the ecotype was specific to smallholder dairies. The underlying purpose of this quantitative method was to allow development of quantitative environment characteristics and seek similar areas throughout East Africa (Uganda and Tanzania). This step would have been impossible following the more traditional Jaetzold and Schmidt approach as their method was specific to Kenya.

In Mali, the approach we used reflected the relatively simpler environmental gradients found in West Africa — a steep north-south rainfall gradient and a single rainy season. We used the climate surfaces in our foundation database, extracting the monthly data for the 5 consecutive months that maximized the moisture availability (defined by the precipitation to potential evapotranspiration ratio). Then we ran a cluster analysis on these variables. The resulting clusters set the sampling frame for both the representative farms in Mali and for the next step, the linkage between these climate clusters and the soils database. Once linked to the soils database, we created simulation zones for which yields were simulated for six crops and a variety of management conditions. This sampling frame allowed us to verify the simulated yields using data from Mali but then cross political boundaries and produce simulated results in Burkina Faso and Senegal. Extrapolation of the simulations into other related but non-verified areas helps define the adaptation zone for agricultural technology. The economic refinement of these zones leads to identification and characterization of adoption zones.

Problems with spatially explicit analyses often stem from limitations in the resolution of the data available. High-resolution soil maps could add tremendous value in further targeting of agricultural technologies as would high-resolution land-cover databases probably based upon remotely sensed imagery. These data would help, for example, understand soil fertility constraints, identify areas of intense striga infestations, and even allow for real-time monitoring. Most economic and crop simulation models can be improved by further linking them to the relevant spatially explicit data in an iterative manner. Earlier methods often involved rather tedious steps necessary to push data from spatial sources through these models and then back to a spatial frame. Technologies are rapidly evolving to reduce these constraints, and it is likely that future impact assessments of agricultural endeavors will link seamlessly to spatial models and spatial database and decision support mechanisms.

A spatial information system like the ACT enables characterization of target environments to be far more specific than was possible using analogue (paper maps) methods. We are able to mix spatial data of both qualitative and quantitative origin, of various scales, and from multiple sources and disciplines. Our results have sufficient spatial resolution to greatly facilitate implementation steps for the transfer of technology and for the evaluation of technology developed in one place carried to other, similar locations.

6.3 Environmental Simulation Zones and Extrapolation of Impact Outcomes

In situations where farm-level assessments are done, defining simulation zones with geographic equivalence provides a quantitative and statistically valid method of establishing adequate and sufficient sampling frames for further site specific experimentation, i.e. the location of individual farms that are average or modal farms representative of the area under study.

Methods to predict the use of new technology at locations other than where experimental data exist also involved the use of spatially explicit analysis and the concept of geographic equivalence. First, the geographic characteristics of areas were identified in which experimental data existed on the performance of crops using new technology. Then, areas of geographic equivalence were identified – areas which had similar rainfall and soil patterns. For each of these simulation zones, the EPIC model was used to predict the performance of the major crops grown in the area. The model was used to determine both baseline conditions and estimates assuming adoption of the new technology. These results were based on biophysically defined zones, which did not correspond to politically defined boundaries under which economic data on agriculture is collected. The results from biophysically defined simulation zones were aggregated using weighted mean averages to define the performance of crops and livestock by politically defined areas. This allowed us to make biophysical inputs to economic models and vice versa in a holistic approach to assessing the utility of the new technology.

6.4 Watershed Level Impact Assessment

Assessing the impact of technology or policy options at the watershed level is both ecologically and politically relevant. The consequences of changes in farming practices at the field level are integrated at the watershed level and the downstream consequences of upstream practices can be estimated. In the Kenya case study, we used a combination of field, area, and watershed models to estimate the consequences of land practices on erosion and streamflow levels in a watershed that represented a diversity of the agriculture we had studied at farm and province levels. The same methods for determining baseline conditions and estimating effects of introducing new technology at field and province level were employed to develop inputs for watershed models. Results were correlated with measured streamflow data. The development and demonstration of the utility of watershed models in this suite requires substantial additional effort. In the single watershed studied, we found that data availability and quality were even more limiting than was the case in national and regional studies. However, we believe the general principles and the form of the models and their interrelationships are sufficiently encouraging to continue their development in the next phase of our research.

6.5 Providing Interactions between Commodities

Since the Agricultural Sector Model (ASM) is a mathematical optimizing algorithm constrained by total production resources, among commodities produced in each region compete for the available resources in contributing to the objective function, i.e. consumers and producer economic surplus. Interactions between commodities result from economic efficiency in the use of regional resources, i.e., land, labor and other regional resource constraints. The interpretation of these results is limited because estimates of cross-price elasticities of demand and/or supply are not currently available for use in the ASM analyses. However, even with these limitations, the interaction between commodities provides a very useful insight into the overall economic-biophysical-environmental performance of agricultural systems in developing countries.

6.6 Linking Multiple Models to Address Multi-Dimensional Assessments

We are encouraged that the linkage and interaction between biophysical, environmental, and economic models has been achieved under research conditions. The resulting linkages produced results that would not have been achieved with the use of individual models. The remaining concern about this methodology is its relative complexity and difficulty for full use in many developing countries. We are engaged in an active collaboration with FAO to further develop packaging techniques that allow the interface between these kind of models to be as seamless as possible and to work with our developing country partners to ensure their utility. It is important to think of the IMPACT product as a tool-kit of methods, from which individual studies may be crafted using the most relevant models for the needs of the analysis.

The integrated suite of analyses conducted within this document represent a first generation attempt to identify the proper sequencing of information flow between models that insures that output of one model meets input needs of another. This is needed in the quest for an integrated analysis capable of capturing the spatial extent of resources, production systems and markets, and then project yield variations of crops and livestock reflected in economic models with resulting environmental responses.

The resulting analytical flow has allowed a clearer definition of how best to optimize the flow of information between models. This analysis has resulted in development of a first generation “middleware” program called the Common Modeling Environment (CME) that allows placement of models in a computing environment where developers do not have to modify their models but can place their tools online and allow users to interact with their models via the Internet or local host. A suite of models can be either be run as individual modules with a common interface or be directed to share common data where output from one module can be input into another model.

The challenging aspect of impact assessment of complex systems at multiple scales is to design analytical systems that capture the complexity in a manner that users can comprehend the necessary data requirements, follow the information flow protocol, learn to use the tools in a timely manner, and interpret output. Design of a common interface with smart linkages between models to meet the multiple dimensions of impact assessment couple with a sound foundation of supporting data is the key to a long-term investment in impact assessment methodologies.

6.7 Contrasting the Complexity of the East and West Africa Studies

The impact assessments conducted in East and West Africa involved two quite different environments for testing our methods. West Africa provided a mechanism to work with crop and farming technologies in a region with well-defined climatic conditions that repeat themselves across several countries. East Africa was a more complex landscape in terms of crops, vegetation, and geographical distribution of the technology and weather conditions. The emphasis on livestock in East Africa provided an added dimension of complexity that was not studied in West Africa.

Livestock data is much weaker in terms of spatial specificity due to mobility of animals over time, the use of common grazing lands, and the multi-year production cycles of saleable products. Derivation of suitable biophysical data to support the economic models challenged our group to devise improved methods to characterize land area and forage/livestock yields. The geographical extrapolation of effective environments was much more complex in East Africa due to the topographic effects of highland/lowland interactions. The technology suite selected with smallholder dairy was found in the cool highland areas and hot, humid peri-urban coastal zones, requiring representation of a large variety of environmental conditions in the model along with a large number of crops.

6.8 Criticality of Non-Modeled Variables in Defining Adoption and Economic-Environmental Outcomes - Sociologic Variables Affecting Adoption and Use of Technology

Assessing the economic impact of a specific technology package requires realistic estimation of the traditional, current, and maximum future adoption rates that can be expected for the technology. This is also important when trying to quantify the environmental impact of a technology. The selection of realistic adoption levels requires careful and methodical consideration of a variety of factors. Socio-economic variables, in particular, often add complex and site-specific considerations to decisions regarding the adoption of a technology. One method to ensure reasonable adoption rates is to seek opinions from a panel of experts that will contribute to the development of heuristic models and rules for behavior of people as part of the adoption process.

The individual providing this kind of expert opinion must have an extensive knowledge of producers' ability to integrate the technology over a range of social and geographic settings. It is important that the experts have a "mental geography" that allows them to define and stratify geographically where the technology can be applied appropriately. When considering the environmental impacts of a technology, the "where" question of adoption is particularly critical.

There are a number of steps required to effectively solicit the information from an expert panel. The solicitation process needs to be carefully guided to ensure the participants are focused on the correct target group and technology suite or package. The process then requires that experts incorporate into their assessment non-modeled socio-economic and environmental variables that affect producers' adoption of the technology. A short, but by no means complete, list of these factors includes: type of production orientation of the producer (subsistence versus commercial production), access of the producer to credit and markets, land tenure rights of the producer, accessibility to animal draft power, natural resource endowment and climatic variability in the region. These and other factors influence the adoption of a new technology.

Greater efforts will be needed in the future to better use indigenous and local expert knowledge to help translate the impact of the adoption of a suite of technologies on ecosystem health. Regardless of the type of analysis, the challenge is to ensure realistic assumptions are made regarding the technology adoption rates that take into account the socio-economic and environmental factors facing the target decision-makers.

6.9 Use of Modeled Variables as Proxies for Indicators that are Difficult or Expensive to Measure Directly

In Section 1, we describe the use of measured variables such as quantities and prices of food as proxies for more global, politically defined variables such as poverty and hunger. The suite of models developed under IMPACT was designed with the intention of providing first order estimates of the more general outcomes of food security and environmental indicators. The extent to which these "measurable" outcomes can serve as reasonable proxies for the more general indicators remains to be determined. But, in many cases, accurate estimates of the more general indicators is unlikely to be achieved so that reasonable approximations may serve a useful albeit interim purpose at this point in the evolution of methodologies.

Acquiring geographically robust and attribute-rich data in developing countries is a major challenge for conducting impact assessments when using biophysical, economic, and environmental models. This is frequently complicated by discontinuity of data. For instance, in many countries, weather stations are located in cropping zones but are poorly distributed in pastoral livestock regions. Weather data is also incomplete, often with months and years missing, and in many cases, data accumulated for several days are reported on one day, e.g. Saturday and Sunday rainfall reported with Monday data. To overcome these limitations, a suite of tools has been developed and methods devised to help approximate the necessary biophysical attributes that are needed to run data-hungry models.

Soils data are available in most countries but are organized in paper form and only look at a limited number of physical attributes with emphasis on nitrogen, phosphorus, and cation exchange. The biophysical models require more physical data such as saturated hydrologic conductivity or wet/dry bulk density by layer. A program called MUUF (Mapping Unit Utility Function) has been developed within our group that uses a wide array of common attributes and soil classification information and estimates hard-to-find biophysical and chemical attributes. We also use a program developed by Washington State University to estimate physical attributes when the texture of the soil is known. We still subject the parameterization to scrutiny by regional experts to confirm our choice of values for a given simulation environment.

Weather data present some unique problems because there are few reliable online reporting stations and the data are discontinuous. We required filled data files with reliable information to run our long-term models. Given the stability of the World Meteorological Organizations (WMO) reporting stations, we have established weather generator coefficients for 7,000 stations around the world. Using the ACT tool and its climate surfaces, we can pinpoint a location on the map, e.g. representative farm, and feed the monthly mean maximum/minimum temperatures and precipitation into the WxGEN module using the coefficients from the nearest WMO station. This is used to generate a predetermined number of years of weather to determine the level of variability in crop, forage, or livestock response. Where historical data is available, we use the same method to fill missing data with the generator. Finally, we have used the historical METEOSAT satellite-based precipitation estimates based on NOAA's and AGRHYMET's methods of estimating rainfall from temperatures of tops of colds relative to physiographic conditions. Historical 10-d precipitation estimates are available since 1982 for Africa, and daily estimates are available from January 1, 1998 to present. A web site has been established by our group at http://cnrit.tamu.edu/rsg/rainfall/rainfall.cgi where daily weather data from NOAA RFE estimates can be downloaded by clicking on a map or putting the longitude and latitude of a site and specifying the date range you desire.

Animal production models are generally limited by the lack of adequate nutrition data for the array of vegetation types in question. We have developed a rapid assessment technique that allows an in-country specialist to pick up fecal samples of livestock (cattle, sheep, and goats) in remote regions and predict dietary crude protein and digestible organic matter of animals in question. By spatially sampling feces using a GPS unit, a profile of nutrition of the animals can be built over a growing season or year and those values fed into the animal production models. The system is based on drying the sample, grinding through a 1-mm sieve and then scanning with a near-infrared reflectance spectrophotometer. Our laboratory or regional labs established throughout the world can turn around samples in 10 days from almost any part of the world.

By far the most critical cultural operations for crops are the planting and maturity dates. These can vary with soil conditions and elevation even in relatively small areas. Harvest dates, when available, are used as proxies for crop maturity. Some of the models like the EPIC model have been modified to accept "heat unit scheduling" to refine the planting dates and schedule tillage and fertilizer applications. Using these algorithms, inputs like minimum soil temperature, soil moisture, and percentage of the growing season are used to determine planting dates and operations.

Critical crop parameters like maturity classes of local or unknown varieties are frequently estimated by using historical information of planting and harvest dates. The maturity parameters are then adjusted to reproduce the historical timing patterns. These coefficients in the form of accumulated heat units are then returned to the parameter file for use in future runs when addressing changes in weather, elevations, and location that are assumed to be using the same genetic varieties.

In general, the models themselves are frequently used to verify, reject, and refine estimates of "soft input data". Iterations of model runs will reveal many refinements needed in the inputs shown as inappropriate outputs and estimates. A person familiar with the model can generally trace these bad estimates to the sources in the inputs.

6.10 Improved methods for risk assessment at farm and national levels

Most risk in agriculture stems from the uncertainty in the biological and environmental variability associated with agricultural production, as well as economic uncertainty due to price fluctuations in inputs and demand. Providing point or average estimates of the economic impact of the introduction of a technology cannot provide the decision-maker with any information regarding the risk or uncertainty associated with the adoption of a new technology.

At the farm level, uncertainty was incorporated into the analysis by the use of the simulation tool Farm Level Income and Policy Simulation Model (FLIPSIM) linked with cropping and grazingland biophysical models. Simulation is a means of estimating the economic impact of a new technology under uncertainty by reproducing random events that are statistically equivalent to the probabilistic outcomes that occur in the system being modeled. The descriptive nature of a simulation model allows experiments to be performed on complex systems under conditions of uncertainty. Calculating the statistical variability provides an estimate of risk or uncertainty. The simulation approach is used to compare different technologies to determine which provides the highest probability of achieving different targets. It also allows a decision maker to compare two technologies to determine which provides the least amount of risk. Use of this modeling method provides insights into the impact on producers of introducing new technologies at the farm level that were not captured by simply comparing the average change in the yields, cash costs, farm income, real net worth, and net present value.

At the national level, uncertainty was incorporated into the agricultural sector model by calculating the optimal allocation of resources under different expected climatic states of nature and risk aversion preferences. The expected long-run welfare implications of a new technology is reflected in the weighted average of the probabilities of each state of nature. Use of this approach again provided insights that were not captured by the static model. One insight in particular was the gain in producer surplus observed under the stochastic scenario that was not captured under the deterministic analysis.

6.11 Verification of Models Relative to Measured Data and Conditions

Verification of the output of economic models required comparison of the base runs of the models with the observed yields and land allocation at subregion and national levels noted in statistical data for the starting year. If the percentage difference in the base model output was within a range considered acceptable, generally less than 10% of the observed data, the model was considered to be correctly calibrated.

Verification of biophysical models can be accomplished by locating actual field data with accompanying information on such things as soils, weather, animal attributes, etc., and running the models to determine if yield response (crops, forage, livestock) are tracking observed data. Another method to confirm yields of widely reported crop species is to develop a spatial stratification of soils and weather, generate yields within each resulting simulation environment (polygon), and produce an area-weighted yield corresponding to administrative reporting districts.

We felt that the models were performing well if predicted yields were within 15% of reported yields across 80% of the reporting districts for each crop. If deviations occurred, we had to explain the cause in terms of markets and home consumption, or we had to reparameterize the biophysical models. Other forms of verification involved knowledgeable experts reviewing output to determine if the input data and the yield responses are within the domain of acceptable response for a given biophysical and managerial environment. In the case of hydrologic response, it is critical to have access to streamflow gauge data and sediment loading data to both calibrate and verify projections at the watershed scale. Normally the up-stream gauges are used to calibrate the model and the outflow basin gauge used to verify model accuracy.

6.12 Status of Modeling Environmental and Natural Resources Impact of New Technology

The overall state of the art in modeling environmental and NRM consequences of technology innovations is paced by the state of knowledge about plant-animal-natural resources interactions and behavior at the fundamental level. Researchers and NRM managers at all levels are looking for better indicators of the status of natural resources and the time course of changes in NRM characteristics as a function of their use in farming over time. The EPIC model and several hydrologic models have been used in IMPACT as tools that are available and that seem to be representative of the state of the art. Our group does not aspire to engage in the badly needed fundamental research to define the needed indicators and underlying biology to improve such models. However, we do aspire in our future work to develop linkages with those who do this kind of research and to apply the results to improved environmental models that describe the overall state of the ecosystem as a function of agricultural operations to provide improved food security.

6.13 General Conclusions from Case Studies

The three commodities evaluated in these studies were milk from smallholder dairy operations in East Africa and sorghum and peanuts in West Africa. The more detailed studies were done in Kenya and Mali and approximations were made for the use of technology developed in these countries for adjacent countries.

Generally, the results obtained were consistent with both the predicted and measured historical results of the introduction and use of agricultural technology in both developed and developing countries. Consumers were the major and continuing beneficiaries of the introduction of new technology. Producers who were the early users of new innovations benefited both in terms of what was sold in the market and what was consumed in the household. In steady state, after adoption peaked, the models estimated that increased quantities of the commodity in question would result in lowered prices which would reduce producer welfare – assuming that demand remained relatively constant. However, when population predictions for the year 2015 were included in the analysis, the increase in demand accommodated the increase in production, prices were less depressed and both consumers and producers found substantial benefits from the introduction of new technology. When risk avoidance was incorporated in the models, the behavior of risk-avoiding individual producers tended to reduce consumer benefits because less quantities of commodity would be produced. Assessment of the behavior of individual "firm-level" operations was not necessarily the same as assessment of behavior of the commodity in the aggregate at the national level with regard to risk aversion. The particular technology packages used as test platforms for development of these methods were not associated with substantial negative environmental consequences, as measured by IMPACT. In fact, positive benefits were predicted for the sorghum production system introduced into Mali because of the use of ridge tilling as a means of conserving water and preventing erosion.

These studies were neither ex ante nor ex poste in the formal sense of the definition. In all cases, there was experimental data and producer experience to provide quantitative information on how the technology package performed under experimental conditions. The ultimate utility of the technology and its result will not be known until there is substantially more experience over time. Thus, these studies, as is often the case in technology assessment, predict future impact of new technology based on experimental results obtained at specific sites. The ability to objectively assess the geographic extent to which these technologies may be used provides an emerging new capacity for estimating the broader utility of technology and the broader impact of policy options involving agriculture and natural resources.

APPENDIX A
MATHEMATICAL DESCRIPTION OF ASM MODEL

Description of Kenya ASM:

Technology improvements are appraised by setting up different forage, animal breed/feed/management systems, cost of production, and associated technology adoption versions of the model to provide simulations with and without the smallholder dairy intensification technologies in Kenya agriculture. As a reminder, technologies currently in practice and considered in this assessment included traditional and improved dairy production systems. Simulation results for each technology and adoption scenario are compared to evaluate the economic impact of the technology advance on subnational regional, national, and foreign consumers and producers. Current and full adoption rates for the dairy production systems are included in simulations of the technology alternatives in order to estimate past and potential economic impacts.

The technology assessment focuses on four dairy production systems. The current dairy production technology has a mix of traditional through intensive production possibilities. The available budget data indicated that milk production primarily occurs in the Central, Coast, Eastern, Nyanza, Western, and Rift Valley regions. The Central and Rift Valley regions are major milk production areas. Native grasses, napiergrass, and maize residue are controlled in the analysis to meet the animal diet requirements in terms of dry matter (DRYM), crude protein (CP), and net energy maintenance (NEM).

Three alternative dairy production technology scenarios using the four dairy production systems in the Kenya ASM simulations are discussed here. The first scenario is defined as improved dairy under current adoption rates, and includes four dairy production systems: Zebu cattle, cross breed cattle, dairy breed cattle with semi zero-grazing, and dairy breed cattle with zero-grazing. The second scenario is called traditional dairy and only allows the traditional Zebu cattle dairy production technology. The third scenario is the improved dairy under full adoption conditions. Native grasses, Napier grass, and maize residue are allowed as feed alternatives for dairy cattle under the two improved dairy scenarios. Under the traditional dairy scenario, only the native grasses and maize residue provide feed for the dairy cattle. The detailed scenario definitions and adoption rates for each system in the regions are listed in Table 2.7.6.1.

Three alternative dairy production technology scenarios using the four dairy production systems in the Kenya ASM simulations are discussed here. The first scenario is defined as improved dairy under current adoption rates, and includes four dairy production systems: Zebu cattle, cross breed cattle, dairy breed cattle with semi zero-grazing, and dairy breed cattle with zero-grazing. The second scenario is called traditional dairy and only allows the traditional Zebu cattle dairy production technology. The third scenario is the improved dairy under full adoption conditions. Native grasses, Napier grass, and maize residue are allowed as feed alternatives for dairy cattle under the two improved dairy scenarios. Under the traditional dairy scenario, only the native grasses and maize residue provide feed for the dairy cattle. The detailed

The basic idea of ASM can be expressed by mathematical equations as follows: suppose there are I commodities (Q_i), i=1,2,...,I, which are produced by production activity (X_{ik}) in region k (k=1,2,...,K). Production activity requires land (L), labor (R), and other resource (O). In addition, suppose both an integral inverse regional demand function and many integral inverse supply functions exist. The integral inverse regional demand function is

$$P_{ik}^{Q} \qquad Q(RQ_{ik}), \qquad i\ \ 1,...,I,\ \ k\ \ 1,...,K.$$

The integral inverse supply functions for inputs are

$$P_{k}^{L} \qquad {}_{k}(L_{k}), \qquad k\ \ 1,...,K,$$

$$P_{k}^{R} \qquad {}_{k}(R_{k}), \qquad k\ \ 1,...,K.$$

$$P_{k}^{O} \qquad 7_{k}(O_{k}), \qquad k\ \ 1,...,K,$$

The inverse export supply and import demand curves are defined as follows:

$$P_{i}^{EQ} \qquad ED(EQ_{i}), \qquad i\ \ 1,...,I,$$
$$P_{i}^{MQ} \qquad ES(MQ_{i}), \qquad i\ \ 1,...,I.$$

The objective function of the model is

(1) $$Max:\ \sum_i \sum_k \int \phi(RQ_{ik})dQ_{ik} \quad \sum_i \sum_j \sum_k C_{ijk}X_{ijk} \quad \sum_k \int \phi^k(L_k)dL_k$$

$$\sum_k \int \phi^k(R_k)dR_k \quad \sum_k \int \tau(O_k)dO_k$$

$$\sum_i \int ED(MQ_i)dMQ_i \quad \sum_i \int ES(EQ_i)dEQ_i$$

$$\sum_i \sum_k \sum_{k1} TRAN_{ikk1}CST_{ikk1}$$

$$\sum_j \sum_k PDIF_{ik} \ (TN_{ik} \ \ FN_{ik}).$$

The constraints are

(2) $$HQ_{ik} \quad RQ_{ik} \quad TN_{ik} \quad \sum_{k1} SQ_{ikk1}$$
$$\sum_j \sum_k Y_{ijk}X_{ijk} \quad \sum_{k1} SQ_{ik1k} \quad FN_{ik} \quad 0, \quad for\ all\ i,\ k,$$

(3) $$EQ_i \quad \sum_k FN_{ik} \quad MQ_i \quad \sum_k TN_{ik} \quad 0,\ for\ all\ i,$$

(4) $$\sum_i \sum_j X_{ijk} \quad L_k \quad 0, \quad for\ all\ k,$$

(5) $$\sum_i \sum_j f_{ijk}X_{ijk} \quad R_k \quad 0, \quad for\ all\ k,$$

(6) $$\sum_i \sum_j g_{ijk}X_{ijk} \quad O_k \quad 0, \quad for\ all\ k,$$

(7) $$\sum_i HQ_{ik} \quad NUT_{in} \quad MINNUT_n, \quad for\ all\ n,\ k,$$

(8) $$\sum_j X_{ijk} - TOTCOW_{ik} = 0, \quad for\ all\ i,k,$$

(9) $$X_{ijk} \leq MAXR_{ijk} * TOTCOW_{ik}, \quad for\ all\ i,j,k,$$

(10) $$X_{ijk} \geq MINR_{ijk} * TOTCOW_{ik}, \quad for\ all\ i,j,k,$$

where

i	:the index of products,
j	:the index of alternative production activities,
k	:the index of regions,
n	:the index of nutrients,
X_{ijk}	:the producing activity of the i^{th} product with j^{th} production process in region k,
$TOTCOW_{ik}$	:the total production activity of the i^{th} product in region k,
C_{ijk}	:the cost per hectare of producing the i^{th} product with j^{th} production process in region k,
Y_{ijk}	:yield per hectare of the i^{th} product with j^{th} production process in region k,
f_{ijk}	:the labor per hectare used for producing the i^{th} product with j^{th} production process in region k,
g_{ijk}	:the other input per hectare used for producing the i^{th} product with j^{th} production process in region k,
$MAXR_{ijk}$	:the regional maximum adoption rate of the i^{th} product with j^{th} production process in region k,
$MINR_{ijk}$	:the regional minimum adoption rate of the i^{th} product with j^{th} production process in region k,
NUT_{in}	:the coefficient of nutrient component n for the i^{th} product,
RQ_{ik}	:the regional consumption of the i^{th} product in region k,
HQ_{ik}	:the home consumption of the i^{th} product in region k,
EQ_i	:the export quantity of the i^{th} product,
MQ_i	:the import quantity of the i^{th} product,
P_{ik}^{RQ}	:The regional demand price of the i^{th} product in region k,
P_i^{EQ}	:The export price of the i^{th} product,
P_i^{MQ}	:The import price of the i^{th} product,
L_k	:land supply for region k,
R_k	:labor supply for region k,
O_k	:other input supply for region k,
SQ_{ikk1}	:the shipment of the i^{th} product from region k to k1,
TN_{ik}	:the shipment of the i^{th} product from region k to nation,
FN_{ik}	:the shipment of the i^{th} product from nation to region k.

The objective function of this model (equation 1) is the summation of all areas under the commodity demand curves minus the summation of all areas under the factor supply curves plus the area under the export supply curve minus the area under the import demand curve and minus the production and transportation costs. Equation (2) is the regional marketing balance constraint for each commodity while equation (3) is the national marketing balance constraint. The demand side for the regional product balance constraint includes farmer self-consumption (or home consumption), local market demand, and shipment to other regions and the national market. The supply side includes regional production and shipment from other regions and the nation. Exports and imports will be shipped from and to regions. Equations (4), (5), and (6) are land, labor, and other resource constraints, respectively. The land constraint also includes a forage constraint by region requiring that the forage production in each region not exceed the maximum forage land area. Equation (7) is the minimum nutrient constraint that requires agricultural production satisfy minimum nutrient requirements for home consumption. Equations (8), (9), (10) are bounds on maximum and minimum adoption rates for each dairy production system and production technology alternative.

Mali ASM Description

The general structure of the stochastic ASM is mathematically described as follows. Suppose there are I commodities (Q_i), i=1,2,...,I, which are produced by production activity (X_{ik}) in region k (k=1,2,...,K). Production activity requires land (L), labor (R), and other resource (O). In addition, suppose both an integral inverse regional demand function and many integral inverse supply functions exist. The integral inverse regional demand function is

$$P_{ik}^{Q} \qquad (RQ_{ik}), \qquad i \;\; 1,...,I, \;\; k \;\; 1,...,K.$$

The integral inverse supply functions for inputs are

$$P_{k}^{L} \qquad {}_{k}(L_{k}), \qquad k \;\; 1,...,K,$$

$$P_{k}^{R} \qquad {}_{k}(R_{K}), \qquad k \;\; 1,...,K,$$

$$P_{k}^{O} \qquad {}_{k}(O_{k}), \qquad k \;\; 1,...,k.$$

The inverse export supply and import demand curves are defined as

$$P_{i}^{EQ} \quad ED(EQ_{i}), \qquad i \;\; 1,...,I,$$

$$P_{i}^{MQ} \quad ES(MQ_{i}), \qquad i \;\; 1,...,I.$$

The objective function of the model is
(1)

$$Max: \; M_{s} \, Prob(s) \; [\; M_{i} \;\; M_{k} \;\; P(RQ_{iks})dQ_{iks}$$

$$M_{i} \;\; M_{j} \;\; M_{k} \, C_{ijk}X_{ijk} \quad M_{k} \;\; P_{k}(L_{k})dL_{k}$$

$$M_{k} \;\; P_{k}(R_{k})dR_{k} \quad M_{k} \;\; P(O_{k})dO_{k}$$

$$M_{i} \;\; P(ED(MQ_{is})dMQ_{is} \quad M_{i} \;\; P\,ES(EQ_{is})dEQ_{is}$$

$$M_{i} \;\; M_{k} \;\; M_{k1} \; TRAN_{ikk1s}CST_{ikk1}$$

$$M_{j} \;\; M_{k} \, PDIF_{ik} \;\; (TN_{iks} \;\; FN_{iks})]$$

$$M_{k} \, RAP_{k} \;\; DEV_{k}.$$

The constraints are

(2)
$$HQ_{iks} \quad RQ_{iks} \quad TN_{iks} \quad M_{k1}\, SQ_{ikk1s}$$
$$M_j \quad M_k\, Y_{ijk} X_{ijk} \quad M_{k1}\, SQ_{ik1ks} \quad FN_{iks} \quad 0, \quad for\ all\ i,\ k,\ s,$$

(3) $EQ_{is} \quad M_k\, FN_{iks} \quad MQ_{is} \quad M_k\, TN_{iks} \quad 0, \quad for\ all\ i,\ s,$

(4) $M_i \quad M_j\, X_{ijk} \quad L_k \quad 0, \quad for\ all\ k,$

(5) $M_i \quad M_j\, f_{ijk} X_{ijk} \quad R_k \quad 0, \quad for\ all\ k,$

(6) $M_i \quad M_j\, g_{ijk} X_{ijk} \quad O_k \quad 0, \quad for\ all\ k,$

(7) $M_i\, HQ_{iks} \quad NUT_{in} \quad MINNUT_{n}, \quad for\ all\ n,\ k,\ s,$

(8) $\sum_j X_{ijk} - TOTHECT_{ik} = 0, \ for\ all\ i,k,$

(9) $X_{ijk} \leq MAXR_{ijk} * TOTHECT_{ik}, \quad for\ all\ i,j,k,$

(10) $X_{ijk} \geq MINR_{ijk} * TOTHECT_{ik}, \ for\ all\ i,j,k,$

where

i :the index of products,
j :the index of alternative production activities,
k :the index of regions,
s :the index of states of nature,
n :the index of nutrients,
$P(s)$:the probability of state of nature occurring,
RAP_k :the risk aversion parameter in region k,
X_{ijk} :the producing activity of the i^{th} product with j^{th} production process in region k,
$TOTHECT_{ik}$:the total production hectareage of the i^{th} product in region k,
C_{ijk} :the cost per hectare of producing the i^{th} product with j^{th} production process in region k,
Y_{ijk} :yield per hectare of the i^{th} product with j^{th} production process in region k,
f_{ijk} :the labor per hectare used for producing the i^{th} product with j^{th} production process in region k,
g_{ijk} :the other input per hectare used for producing the i^{th} product with j^{th} production process in region k,
NUT_{in} :the coefficient of nutrient component n for the i^{th} product,
$MAXR_{ijk}$:the regional maximum adoption rate for the i^{th} product with j^{th} production process in region k,
$MINR_{ijk}$:the regional minimum adoption rate for the i^{th} product with j^{th} production process in region k,
RQ_{ik} :the regional consumption of the i^{th} product in region k,
HQ_{ik} :the home consumption of the i^{th} product in region k,
EQ_i :the export quantity of the i^{th} product,
MQ_i :the import quantity of the i^{th} product,
P_{ik}^{RQ} :The regional demand price of the i^{th} product in region k,
P_i^{EQ} :The export price of the i^{th} product,
P_i^{MQ} :The import price of the i^{th} product,
L_k :land supply for region k,
R_k :labor supply for region k,
O_k :other input supply for region k,
SQ_{ikk1} :the shipment of the i^{th} product from region k to k1,
TN_{ik} :the shipment of the i^{th} product from region k to national market,
FN_{ik} :the shipment of the i^{th} product from national market to region k.

The first three lines in the objective function of this model (equation 1) is the summation of all areas under commodity demand curves minus the summation of all areas under factor supply curves. The fourth line is the area under the export supply curve minus the area under the import demand curve while the fifth and sixth lines are the production and transportation costs. The last line in this objective function is the risk aversion parameter times the standard deviation of production income which represents a risk cost. Equation (2) is the regional marketing balance constraint for each commodity while equation (3) is the national marketing balance constraint. The demand side for the regional product balance constraint includes farmer self-consumption (or home consumption), local market demand, and the shipment to other regions and the national market. The supply side includes regional production and shipment from other regions and the nation. Exports and imports will be shipped from and to regions. Equations (4), (5), and (6) are land, labor, and other resource constraints, respectively. Equation (7) is the minimum nutrient constraint which requires that agricultural production satisfy a minimum nutrient requirement for home consumption. Equations (8), (9), and (10) are bounds on maximum and minimum adoption rates for each production activity and alternative production technology.

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