Assessing the Impact of Agricultural Research on Rural Livelihoods: Achievements, Gaps, and Options

Approaches, challenges, and results during the twenty-sixth Conference of the International Association of Agricultural Economists, 12–18 August 2006, Gold Coast Convention and Exhibition Center, Brisbane, Australia

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International Institute of Tropical Agriculture – Institut international d'agriculture tropicale – www.iita.org

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Scientific papers presented in the Symposium Session organized by IITA on Assessing the Impact of Agricultural Research on Rural Livelihoods in Developing Countries: Approaches, Challenges, and Results during the twenty-sixth Conference of the International Association of Agricultural Economists, 12–18 August 2006, Gold Coast Convention and Exhibition Center, Brisbane, Australia

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Within Nigeria:
PMB 5320, Oyo Road
Ibadan, Oyo State

ISBN 978 131 321 8

Printed in Nigeria by IITA

Correct citation: Alene, A.D., V.M. Manyong, S. Abele, and D. Sanogo (editors). 2007. Assessing the impact of agricultural research on rural livelihoods: achievements, gaps, and options. Scientific papers presented during the twenty-sixth conference of the International Assoociation of Agricultural Economists, 12–18 August 2006, Brisbane, Australia. IITA, Ibadan, Nigeria. 80 pp.

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Preface

Impact assessment of public agricultural research is an important activity to ensure accountability, maintain credibility, and improve internal decision making processes and the capacity to learn from past experiences. It enhances our understanding of the extent to which the many different products of agricultural research-for-development (R4D) affect the livelihoods of the target population. Whether it is evaluating the impacts of past R4D investments or projecting the benefits of current and future interventions, impact assessment facilitates strategic R4D priority setting and the efficient allocation of available resources. The focus and methods of impact assessment have evolved over time in response to donor interest and research mandates. From a rather narrow emphasis on adoption of new varieties in the 1970s, the focus of impact assessment activities expanded to estimating rates of return to research investments in the 1980s and to examining a wider range of impacts, including environmental benefits and costs and the distribution of benefits and costs across different socioeconomic groups, in the late 1980s and 1990s.

As funds for agricultural research decline, there is now a greater demand not only for demonstrating the actual impacts of research but also for maximizing impacts through targeting research benefits to poor people. There is need to sharpen the focus of research while at the same time broadening the scope of impact assessment beyond the traditional crop genetic improvement programs to measure the impact of a wide spectrum of research products, including policy recommendations, natural resource management, postharvest technologies, participatory approaches, and training programs. Moreover, pressure from the civil society has pushed research centers to increase the portfolios of interventions at the tail of the R4D continuum. This shift has led to new paradigms of R4D—such as the Integrated Agricultural Research for Development (IAR4D) promoted by the new sub-Saharan Africa Challenge Program led by the Forum for Agricultural Research in Africa (FARA).

A lot of impact assessment work has focused mainly on showing the extent of adoption of new technologies and their impacts on farm productivity and incomes. However, poverty has persisted despite increased food supply and, in the face of declining agricultural research budgets, the challenge for agricultural research now lies in developing strategies that more explicitly address the needs of the poor. Appropriate *ex ante* impact assessment is needed to enable better targeting of research to the changing needs of the poor, whereas *ex post* impact assessment is needed to demonstrate poverty impacts, thereby ensuring the relevance of research investments. With an increased focus on poverty and environmental outcomes, there is thus need for new approaches, methods, and techniques for a rigorous *ex ante* as well as *ex post* evaluation of the impacts of various agricultural research programs.

Agricultural research products are many and different and the indicators of impacts of agricultural research are always evolving and wide-ranging, implying that no single method, product, or indicator of impact can be targeted in impact assessment. The scope and breadth of impact assessment of agricultural research is now much broader than ever before, and agricultural research organizations would benefit greatly from sharing scientific knowledge and experiences. This motivated IITA's Social Sciences program to organize a symposium on Assessing the Impact of Agricultural Research on Rural Livelihoods: Advances, Gaps, and Options at the twenty-sixth IAAE Conference in Brisbane, Australia, on 13 August 2006. The objective of the symposium was to provide a scientific forum to help develop a shared understanding of the scope and challenges of impact assessment and the options to address emerging priorities. This book is the product of the symposium and contains the selected papers that were presented.

The papers address major issues in impact assessment of agricultural research. Given the complex nature of impact assessment, contributions come from academia—Virginia Polytechnic—and international agricultural research institutions—the International Institute of Tropical Agriculture (IITA) and Africa Rice Center (WARDA). G. Norton discusses the major issues around which the symposium was organized: (1) the broadening agricultural research agenda and resulting scope of agricultural research evaluation, (2) the current situation with respect to practices followed by academic economists and other practitioners in impact assessment, (3) gaps that need the filled in our assessment approaches, and (4) some suggested options for meeting current impact assessment needs. He identifies the critical issues relating to the scope and challenges of agricultural research impact assessment and proposes an operational framework to help practitioners document—by way of a matrix—the multiple impacts of R4D interventions—both for *ex ante* priority assessment and for *ex post* impact assessment. The second paper extends an innovative poverty-based approach to priority assessment and applies to Nigeria, representing a major step forward in addressing current priority issues relating to R4D priority setting based on potential for poverty reduction. The third paper presents IITA's experiences with *ex post* social and economic impact assessment, whereas the fourth paper presents similar experiences from WARDA. The last paper presents IITA's experiences with integrating GIS and socioeconomic data in research targeting and technology scaling up and out, which essentially complement the Institute's overall priority setting efforts. It is hoped that the methods, findings, and key recommendations will be of considerable interest to impact assessment practitioners, CGIAR, donors, policymakers, and research managers in both the national and international agricultural research systems.

The editors thank IITA for providing the necessary financial support for the initial symposium and for publication of the book. Sincere thanks are due to A. Oyetunde and her staff, and particularly R. Umelo, for their unreserved scientific and editorial support.

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Assessing the impacts of agricultural research: scope, current practices, gaps, and options

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Introduction

The need to assess the impacts of agricultural research is derived from the lack of efficient markets for allocating research resources. Because many outputs of research processes have public good characteristics, they are free to users once they are available. Prices are not established and consequently there are few market signals to allocate research resources among alternative uses. Allocations are made by administrative decree, and society tends to under-invest in agricultural research in the aggregate (Schuh and Tollini 1979). Because they cannot capture many of the benefits of agricultural research, private firms under-invest and, just as importantly, so does government.

Therefore, the purpose of impact assessment is to replace missing markets by providing cost–benefit information to assist with research resource allocation and with decisions on the optimum investment in agricultural research. In addition, impact assessment can identify income, the distribution, and employment effects of agricultural research as well as effects on the environment, which may be associated with new technologies or institutions. It can also identify impacts of agricultural research on income risk or food security. If negative consequences are identified early, corrective measures can be adopted (Schuh and Tollini 1979). In summary, evaluating agricultural research can help with decisions on research resource allocation, aggregate research investments, and actions to mitigate or encourage specific distributional, environmental, or risk consequences.

Much progress has been made on refining methods for *ex post* and *ex ante* evaluation of agricultural research. But clearly, work remains to be done, both in refining methods and in understanding the context within which they are designed to be used, as few quantitative methods are routinely applied in agricultural research systems. Some might argue that a lack of such structured assessment is good, given the inherent serendipity, need for creativity, and general uncertainty involved in research. However, the fact is that research allocation decisions do get made and budget levels get set. The only question is whether impact information derived from structured assessments, particularly information generated with the assistance of economists, can improve those decisions.

My remarks today will focus on four issues: (1) the broadening agricultural research agenda and resulting scope of agricultural research evaluation, (2) the current situation with respect to practices followed by academic economists and other practitioners in impact assessment, (3) gaps that need to be filled in our assessment approaches, and (4) some suggested options for meeting current impact assessment needs.

Scope

There have been multiple goals for agricultural research for a long time, but the relative weights on goals beyond productivity and efficiency have increased in recent years. This increase may have resulted from (1) the perceived abundance of food in the world as a whole, (2) the strengthening of intellectual property rights, which enables private firms to capture an increased share of the benefits of applied productivity-enhancing research, (3) the perceived growth in environmental externalities associated with agricultural technologies or other factors, (4) the fact that adjustment costs are being borne by marginal areas as prices fall and labor is squeezed out of agriculture, and (5) the persistence of rural poverty in developing countries. Not only are there multiple goals for agricultural research but the resulting broad research portfolio includes an ever-growing array of research outputs for which it is difficult to measure a conventional per-unit cost reduction in an economic surplus model. Conceptually, the outputs may fit the model, but empirical measurement is a challenge. Social science research produces such output, but so also do many other disciplines as their research evolves to meet demands for products that improve food and nutrition security, reduce poverty, empower women, and improve health and the environment in its many dimensions.

Funding agencies increasingly ask for information on a diverse set of impacts of agricultural research, but they also want information quickly. While much work is needed in terms of refining impact assessment or priority setting methods, one must recognize that there will always be a need for a two-tiered approach to impact assessment. One approach stresses in-depth assessment of specific research programs or projects, and one provides a broader assessment of a research portfolio by combining informed subjective judgment with relatively simple systematic assessment aids. So when we speak of the need to improve impact assessment approaches, we must recognize that we are talking about a two-headed beast.

There is little question that interest by funding agencies in *ex post* and *ex ante* impact assessment information has grown over time. That interest derives both from accountability and resource allocation concerns. Funds are scarce and many administrators see impact assessment information as being useful in helping them to shape a program and respond to superiors about the impacts of agricultural research on productivity, poverty, biodiversity, and women. Unfortunately, there is a danger we may end up counting the more measurable and discounting the less measurable, if equally important, benefits.

Current practice

In practice, there are two groups involved in impact assessment, the academics and the practitioners. The academics, primarily economists, attempt to bring the latest theory and empirical methods to bear on reducing the cost of conducting credible impact assessments. The practitioners (economists and non-economists) apply methods in research systems, both for specialized studies and for systematic *ex post* or *ex ante* analyses. Especially if the practitioners are economists, they draw on the results of academic studies if the methods described are practical and well articulated.

Current practice by academic economists is to focus on the latest issues and to build on and extend previous methods to address them. Progress comes one small step at a time. For example, research impact assessment in the past ten years has focused on incorporating imperfect competition in economic surplus models, utilizing GIS to help disaggregate technology adoption and its impacts (including environmental impacts) over countries and regions, utilizing experimental economics and other means for assessing non-market values of health and environmental impacts, combining economic surplus with poverty indicators to evaluate the impacts of research on poverty, developing means for valuing information provided by social science research, improving methods for valuing agricultural research that reduces income and nutritional risks, and assessing general equilibrium effects of research. In most cases, the approaches begin with economic surplus models, which are often then combined with econometric models for part of the analysis. Standard spreadsheet, econometric, and GIS software may be used alone or combined with specialized software (such as IFPRI's DREAM model). In some cases, research impact assessment methods are a subset of methods for evaluating a broader set of public investments. The Strategic Analysis and Knowledge Support System (SAKSS) developed by the International Food Policy Research Institute (IFPRI) for application in Africa is one example.

On the other hand, impact assessment practitioners utilize economic surplus models, GIS, and econometrics at times, especially for *ex post* assessment, but just as often they develop and rely on simple indicators, combined with subjective intuition, for assessing the impacts of agricultural research, especially for *ex ante* or priority setting work. It is not that practitioners don't like the more sophisticated models, although sometimes they don't. It is that decisions must frequently be made quickly, over large research portfolios, and with relatively few resources for impact assessment. In addition, "deciders" often value simplicity and transparency. Not all impact studies by practitioners address large portfolios of research projects. Many studies focus on specific projects and utilize time-tested techniques, such as basic economic surplus analysis, GIS, and simple econometric analyses, such as technology adoption studies with corrections for selection bias. But in general, practitioners are focused on answering questions posed by administrators, and they must respond within a limited time period, often for a large set of programs or projects with diverse outputs and objectives. Hence, we see heavy reliance on simple indicators.

Gaps

Gaps in our knowledge or in the application of that knowledge in impact assessment can be identified both for academic studies and for practitioner studies. Academic analyses are important because they identify possible refinements to methods that are potentially useful for specialized studies and in some cases for use by practitioners on a broader basis. One of the more noticeable gaps in our knowledge is how to scale up certain types of impact assessments made at lower levels (plot, field, farm, watershed), especially those assessing environmental impacts, to the regional or national market level. Many micro-level studies are conducted, but they don't add up to anything useful for regional or national decision making. Secondly, we need more practical methods for evaluating the benefits of information provided by social science research (economic policy, management) in agriculture. Thirdly, we need more systematic widespread collection, and incorporation in a GIS, of data and information on production, prices, losses, and potentials for a large set of the major crops and livestock on a disaggregated level for all countries in the world. Having such a data set would facilitate agricultural research priority setting in every country. Fourthly, additional work is needed on assessing the benefits of research that reduces income risk (for example, research on drought tolerant crops that does more than raise yield). Finally, more work is needed on the aggregate benefits of natural resource management research.

One gap for practitioners is the failure to provide enough guidance to other applied agricultural scientists so they record, on a more systematic basis, the changes in yields, input costs, and other factors resulting from their research. These factors form the basis for many impact assessments, not only at the farm level, but at higher levels of assessment as well. When impact assessments are needed, it is surprising how often these data have not been routinely collected. Secondly, additional simple economic surplus analyses could provide useful information for decision makers, even if no attempt is made to address poverty and other distributional effects. In many cases, simply choosing technologies with the highest payoff will bias the research strategy to a more intensive use of relatively abundant (cheaper) factors, such as labor. Thirdly, more attention needs to be devoted to eliciting probabilities of success, in research, in obtaining regulatory approvals, and in obtaining market acceptance. One of the reasons for devoting more attention to these probabilities is that scientists tend to ignore them, particularly the latter two, and that is one reason why so many "successful" technologies sit on the shelf. Finally, simple but credible procedures are needed for assessing impacts on poverty.

Options

Impact assessment for agricultural research involves impacts at many levels (plot, field, farm-household, watershed, regional, national, international) and on many outcomes (level and variability of productivity, income, poverty, nutrition, health, and various aspects of the environment). Flexibility in choosing assessment tools, careful matching of assessments to the questions being asked, and designing assessments that meet the resource constraints imposed on the evaluation are all important. A certain minimum level of rigor must be attained in assessment (by rigor, I mean consistency with accepted theory) but fairly basic structured assessments combined with informed subjective intuition can produce useful decisions. Therefore, what can be done to improve impact assessments?

- All those involved in impact assessment must have a basic knowledge of (a) the primary factors that contribute to economic welfare and (b) the concept of expected value. The need for such knowledge may seem obvious but such knowledge is frequently lacking.
- It can be helpful to construct a matrix such as Figure 1 to help in discussions with decision makers to ascertain that assessments focus on the desired impacts. In addition, although the matrix is flexible and does not specify specific quantitative techniques for each level, it is useful to fill in the matrix with possible techniques as a means of organizing thinking about alternatives for impact assessment at various levels. Often the data and results from one level feed into subsequent levels.

Figure 1. Matrix for organizing impact assessments and for generating information on human welfare and environmental impacts of agricultural research.

Level for which impact is observed	Minimum data for impact assessment	Methods of analysis	Human Welfare Impacts			Environmental impacts
			Income	Poverty	Nutrition/ health	
International						
National						
Region/sub-sector/ ecosystem						
Farm/House-hold/ Enter-prise						
Plot/Field/…						

- Simple approaches with low transactions costs are needed when a large number of programs are assessed *ex ante* or *ex post*. Basic assumptions that lead to benefits, including per-unit cost changes, probabilities of technical success, and adoption rates, can be incorporated into a simple decision tree to explore the implications of alternative assumptions.
- Even in cases where large numbers of projects are assessed using relatively simple tools, more detailed studies of specific impacts can be used for evaluating risk, distributional or poverty impacts, or effects on nutrition, health, and environment. Many countries now have large farm-household data sets that can be helpful in assessing some of these effects.
- The CG system and its donors should devote resources to supporting basic data collection (disaggregated production, prices, trade, crop and livestock losses, crop and livestock potential) that would underpin impact assessment studies on a large set of commodities around the world. A study could be funded, building on preliminary work at IFPRI and elsewhere, that would have great social benefit.

Many other options exist, but I would start with this list.

Reference

Schuh, G.E. and H. Tollini. 1979. Costs and Benefits of Agricultural Research: the State of the Art. World Bank Staff Working Paper No. 360, Washington, DC, USA.

Setting strategic agricultural research priorities based on potential impacts on poverty reduction: the case of Nigeria

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Abstract
Declining agricultural research budgets coupled with worsening poverty have increasingly required formal priority setting of public agricultural research in developing countries to ensure that scarce research resources are allocated in ways that will have the greatest impact on the poor. This paper assessed the potential impacts of alternative commodity research programs on poverty reduction and identified strategic agricultural research priorities in three agroecological zones of Nigeria. The paper discusses the poverty reduction-based priorities and their role in sharpening the focus of agricultural research to achieve poverty reduction objectives in Nigeria.

Introduction
Poverty reduction objectives have become central to the policies of governments and aid agencies, and agricultural research plays a unique role in poverty alleviation. Since most of the poor live in rural areas and derive most of their income from agriculture, growth based on the introduction of technologies is particularly effective in reducing poverty in developing countries (Lipton 1977). To the extent that technology raises productivity, agricultural research brings about economic growth and poverty reduction. The question remains to what extent poor people have actually benefited from new agricultural technologies. Despite ongoing debates about how the benefits of technical change are distributed among subgroups within countries, it is generally believed that agricultural technologies have benefited the poor. Datt and Ravallion (1998) found that yield growth reduced poverty and the relative price of food in rural India. Using data from 48 developing countries over the

period 1985 to 1993, Thirtle et al. (2003) found that a 1% improvement in crop yields reduced by 0.6 to 1.2% the proportion of people living on less than US$1 per day.

Despite decades of investment in agricultural research and evidence of high rates of return, hunger and poverty continue to plague large areas of the developing world, especially sub-Saharan Africa (SSA). This is now the only region of the world where poverty is increasing rather than decreasing. On the one hand, agricultural research investments in SSA have long been viewed as having low returns (Lipton 1988). On the other hand, studies of rate of return to agricultural research investments in SSA have found generally positive returns (Oehmke and Crawford 1996; Masters et al. 1998; Rukuni et al. 1998). However, the absolute level of investment in agricultural research in SSA has been too low to significantly raise agricultural productivity and reduce poverty. The impact of new technologies has thus been less apparent and agricultural productivity has at best stagnated. For instance, Nkamleu (2004) investigated the changes in agricultural productivity in 16 SSA countries over the period 1970–2001 and found that total factor productivity declined in the 1970s and 1980s and showed only a slight improvement after the 1990s. Similarly, Fulginiti et al. (2004) analyzed agricultural productivity in 41 countries in SSA over the period 1960–1999 and found that the annual rate of productivity change was only 0.83%.

Clearly, research in SSA has yet to generate broad sectoral productivity growth in agriculture and it is now coming under heavy scrutiny due to unimpressive aggregate growth rates and worsening poverty. Declining research budgets, coupled with worsening poverty, have increasingly required formal priority setting of public agricultural research in developing countries to ensure that scarce research resources are allocated in ways that will have the greatest impact on the poor (Byerlee 2000). There has been a growing pressure to direct agricultural research towards the rural poor and policymakers are increasingly calling upon research managers to explicitly consider poverty reduction objectives in resource allocation (Byerlee 2000; Alwang and Siegel 2003). With an increased focus on poverty outcomes, research managers in SSA need to evaluate alternative agricultural research portfolios for their potential impacts on poverty and inequality.

Nigeria's agricultural research faces the challenge of responding to the new demands to contribute to poverty reduction in the face of declining national research budgets. In 2000, for instance, although Nigeria employed the highest total number of full-time equivalent researchers in SSA (11%), its share of spending was only 7% of the total research budget of US$1.5 billion for the countries in SSA (i.e., US$10.5 million) (Beintema and Stads 2004). There is need for a more focused research agenda to achieve greater impacts on poverty. Nigeria represents the largest share of the overall economy and total population of West Africa. Proper targeting of agricultural research investments would thus result in large pay-offs, not only for Nigeria but also for the entire subregion.

The purpose of this review is to investigate Nigeria's strategic agricultural research priorities based on the potential impacts of alternative commodity research programs on poverty reduction. In Nigeria and elsewhere in SSA, agriculture is still less capital-intensive and thus agricultural production depends largely on natural agroecological conditions, which determine the potential for agricultural growth. There are three major agroecological zones in Nigeria: the dry savannas with a length of growing period (LGP) of less than 150 days, the moist savannas with LGP of 150–270 days, and the humid forest with LGP greater than 270 days (Jagtap 1995).

Background to Nigeria's agricultural research

Agricultural research in Nigeria started almost a century ago with the establishment of research stations to promote the production and export of cocoa, oil palm, and rubber. After political independence, Nigeria inherited the agricultural research system established by the colonial powers. This focused mainly on export crops and little attention was paid to the production problems of subsistence farmers (Beintema and Stads 2004). Re-orientation of the system occurred only gradually, because governments sought to stimulate export earnings and employment growth based on large-scale commercial agriculture. Agricultural research in Nigeria, as in other countries in SSA, also relied heavily on donor support, and donors, especially through the 1970s and 1980s, were interested in using large-scale commercial farming as an engine of growth. From the mid-1980s, however, both donors and policymakers began to question the commercial orientation of agricultural research. This re-examination was due to the limited effectiveness of export-oriented growth, growing concern about poverty and inequality, and increasingly tight budgets.

The needs of small-scale farmers became more prominent in policy discussions and the use of agricultural research to reduce pressing rural poverty became imperative (Alwang and Siegel 2003).

A major reorganization and expansion of the national agricultural research system took place when various research stations and departments were upgraded to research institutes with specific mandates for research on food and industrial crops, livestock, forestry, fisheries, extension, and processing and storage. In an effort to strengthen the agricultural research system, the National Agricultural Research Project was launched in 1992 by the Federal Ministry of Agriculture and Natural Resources with the assistance of the World Bank (Shaib et al. 1997). Through this project, the National Agricultural Research Strategy Plan, 1996–2010, was formulated. The strategic objectives were to (1) achieve food self-sufficiency in basic food commodities and export crops; (2) improve agricultural production efficiency through increased research emphasis on socioeconomic issues, such as marketing, credit, improved processing methods, and the economical use of purchased inputs; (3) improve the relevance of research to client needs by focusing on the production systems of small-scale farmers; (4) strengthen research on small ruminants in the South East and South West zones; and (5) improve the output and cost-effectiveness of research through effective collaboration of the national agricultural research institutes (NARIs) with universities and the international agricultural research centers (IARCs).

Agricultural research is now principally carried out by 18 NARIs. Six of these deal with arable crops, four with forestry and tree crops, three with livestock, two with fisheries, and one each with extension, processing, and storage. Each has a national mandate for specific major commodities in each agroecological zone. Nigeria's agriculture has also benefited greatly from the research carried out by the Nigeria-based International Institute of Tropical Agriculture (IITA). In partnership with NARIs and other collaborative institutions, IITA has developed and released to Nigerian and other farmers in SSA numerous improved varieties of cassava, yam, maize, cowpea, plantain and banana, and soybean. IITA has also been supplying improved germplasm to NARIs and has strengthened their research capacity, mainly through collaborative research, short courses, and the long-term training of their staff at MSc and PhD levels. Nigeria is now the world's largest producer of cassava, yam, and cowpea (Manyong et al. 2005).

Analytical method and data

Analytical method

Despite growing concern and the interest in explicitly considering poverty alleviation in research planning, conceptual and methodological challenges have limited priority setting based on the potential impacts of agricultural research on poverty alleviation. Most priority setting works have used the economic surplus approach (Alston et al. 1995) and emphasized only efficiency objectives by prioritizing research programs according to the net present value (NPV) of projected research benefits (e.g., Mills 1997; Nagy and Quddus 1998; Mutangadura and Norton 1999). In particular, the challenge relates to the complexity of the links between agricultural research and poverty alleviation (Kerr and Kolavalli 1999). Kerr and Kolavalli (1999) review the available evidence and conclude that the poor are simultaneously producers, wage earners, and consumers, with technological change having complex direct and indirect and often offsetting effects on their real income. In SSA, where a significant share of the farm output is consumed on-farm, recent empirical work has shown that the direct impacts on producers—in the form of increased home consumption—are more important than the indirect effects on consumers (de Janvry and Sadoulet 2002).

With household-level data, income growth associated with crop-specific yield changes can be aggregated to create measures of changes in poverty. A model of income determination for small-scale agricultural producers facilitates the determination of such income changes associated with the adoption of agricultural technologies and the resulting yield changes in each agroecological zone (Alwang and Siegel 2003). Income is defined to be the sum of farm income (I), off-farm income, and monetary and in-kind transfers to a household. For the *i*th household in the *j*th agroecological zone (suppressing all subscripts for notational simplicity), farm income can be defined as

$$\mathrm{I=H(YP-C)} \tag{1}$$

where H is a vector of hectares of land allocated to each of the crops or number of head of livestock raised, Y a diagonal matrix of yields, P a vector of prices, and C is a vector of per-hectare or per-animal costs of production. Changes in farm incomes can be decomposed as

$$\Delta\mathrm{I} = \Delta\mathrm{H}(\mathrm{YP}-\mathrm{C}) + \mathrm{H}\Delta\mathrm{YP} + \mathrm{HY}\Delta\mathrm{P} - \mathrm{H}\Delta\mathrm{C} \tag{2}$$

Eq. (2) shows the four major effects that commodity-specific research has on household income and poverty. The first is through changing the allocation of land to each crop or the number of head raised of each livestock type. Research produces new technologies that change the relative profitability of crops and livestock and induce land reallocations or livestock mixes. The second is the change in yields due to the new technology. The third component of the effect of research is the effect of changed supplies on prices received by farmers. Price changes depend on the tradability of the commodity, which is reflected in the elasticity of demand. With more tradable commodities, research-related supply shifts are not likely to affect producer prices (Alwang and Siegel 2003). Moreover, an increasing population, such as that in Nigeria, could counteract the negative price effects of new technologies (Smale and Heisey 1994). The final effect in eq. 2 is through the impact of research and the new technologies that generally require more inputs and hence greater costs per-hectare or per-animal than traditional technologies. Exceptions in this regard include technologies, such as integrated pest management (IPM), that reduce chemical applications and hence reduce per-hectare costs. Alwang and Siegel (2003) associate the final effect of research with per-hectare cost decreases. It should be noted, however, that while research reduces per-unit production costs, it generally increases per-hectare costs.

From the four major effects of agricultural research on farm incomes, the effects through yields, prices, and cost changes are the most important. In the economic surplus framework, the yield and cost changes are used to produce the supply shift. On the other hand, changes in land allocations and livestock compositions are difficult to predict and can only be examined in an *ex post* fashion (Alwang and Siegel 2003). The expected change in farm incomes due to agricultural research is thus modeled as follows

$$E(\Delta I) = \Pr H(P\Delta Y - \Delta C) + HY\Delta P \tag{3}$$

where $\Pr$ is a diagonal matrix of probabilities of adoption of the agricultural technology. A Probit model of adoption of purchased inputs, including fertilizer, herbicides, pesticides, and improved planting materials, was estimated to predict adoption probabilities. Because households either adopt or do not adopt a technology, the 25th percentile probability cutoff point (Alwang and Siegel 2003) was used as an adoption threshold so that yield and cost changes were applied to a household only if this threshold was reached or exceeded.

Finally, eq. (3) was used to compute the expected changes in farm income for each household. Expected changes in farm incomes were added to initial household income and the resulting incomes were compared to a poverty line and aggregated to form expected changes in poverty incidence. Following Foster et al. (1984), poverty measures were derived as

$$\frac{1}{N}\sum_{i=1}^{q}\left(\frac{z-y_i}{z}\right)^0 \qquad (4)$$

where *N* is the total number of households, *q* is the number of poor households, y_i is the income or expenditure of the *i*th poor household, and z is the poverty line.

Data

Two types of data were needed for the household-level poverty analysis: household survey data and forecasted changes in yields and production costs and adoption potentials of technologies. Since the outcome of research investments will not be realized for many years, *ex ante* technology generation and adoption parameters can be based only on the opinions of experts in research and development who draw on a wealth of experience and knowledge in making informed predictions. In this study, data relating to agricultural research and technologies were obtained primarily from researchers, research managers, and extensionists through extensive discussions and interviews using a detailed set of questionnaires.

A total of 144 scientists and research managers from IITA and more than ten NARIs were involved in generating the research and technology data. Expert opinions were elicited regarding likely changes in important parameters, such as yields and production costs. Potential yield gains and cost changes were specified in terms of the most likely changes. Benchmark historical yield and cost changes were used to guide the estimation of these parameters. Key research program areas of the respective NARIs were identified and, within each program, stocks were taken of the production and postharvest technological innovations that would be developed if sufficient research budgets were made available. On average, this was equivalent to a 50% increase in agricultural research budgets on the basis of the budgets submitted to the Federal Government of Nigeria for funding every year. The second step involved using a bottom-up approach to generate the research and technology data whereby program-specific data were obtained based on the detailed information on a set of technological interventions. Table 1 presents the basic technology-related data on expected net yield changes (per-hectare yield change net of per-hectare cost change—each elicited separately) following a 50% increase in agricultural research budgets.

Household survey data collected in 2001 and 2002 from a nationally representative sample of 3180 households were used to estimate the household-level impacts of agricultural research. The sample households were drawn using multi-stage stratified random sampling technique from 12 States, representative of the three major agroecological zones: dry savanna, moist savanna, and humid forest (Kormawa et al. 2003). Data were collected on a range of variables, including household characteristics, agricultural production and input use, off-farm incomes, monetary and in-kind transfers, food and nonfood expenditure, and adoption of modern inputs. In the household income determination framework presented earlier, the survey data and the data on yield and production cost changes were used to derive the various poverty measures.

Table 1. Net yield changes following a 50% increase in agricultural research budgets in Nigeria.

Commodity	Net yield change (%)	Commodity	Net yield change (%)
Maize	73	Irish potato	29
Cassava	66	Sugarcane	49
Yam	49	Cocoa	50
Cowpea	72	Natural rubber	49
Sorghum	30	Oil palm	50
Millet	32	Cotton	32
Rice	68	Cashew nut	30
Wheat	21	Citrus	32
Groundnut	32	Plantain	33
Soybean	31	Pineapple	31
Sesame	62	Mango	33
Leafy vegetables	33	Poultry	34
Onion	32	Beef	32
Pepper	33	Dairy	34
Ginger	34	Sheep	35
Tomato	33	Goats	33
Melon	29	Pigs	34
Sweetpotato	30		

Source: Alene et al. (2006a).

Table 2 presents summary statistics of the variables predicting adoption of new technologies, including household headship, age, human capital, availability of family labor, off-farm employment, assets, and farm size. A site dummy variable was included to account for agroecological differences in technology adoption. Adoption was found to be lower in the dry savannas where poverty is more prevalent. Furthermore, despite lower education, family labor, off-farm employment, and credit access, households in the dry savannas have greater access to land and assets probably due to a relatively lower population pressure and higher livestock population.

Results

Poverty measures and income sources

Disaggregated household income data, including farm income, off-farm income, and monetary and in-kind transfer income, were used to set relative poverty lines for each agroecological zone following World Bank (1996), where two-thirds of the mean per capita income was used to set the poverty line for Nigeria. Alene et al. (2006a) found that poverty is pervasive among rural Nigerians, most pronounced in the dry savanna (69.6%) and relatively less in the moist savanna (54%) and the humid forest (53.8%). FOS (2004) also reports a poverty incidence of 57.8% for all Nigeria.

Table 2. Summary statistics of variables used in the adoption model[a].

Model variables	Description	Dry savanna	Moist savanna	Humid forest
Dependent variable	Use of purchased inputs=1; No=0	0.41 (0.49)	0.65 (0.48)	0.53 (0.50)
Male-headed	Yes=1; No=0	1.00 (0.00)	0.99 (0.12)	0.98 (0.13)
Head’s age	Years	48.00 (11.00)	49.00 (12.00)	55.00 (12.00)
Head’s education	Years of schooling	2.45 (5.04)	4.73 (5.36)	7.49 (5.12)
Adult male labor	No. of adult males	1.72(2.24)	2.12 (2.33)	1.95 (1.92)
Adult female labor	No. of adult females	0.73 (1.31)	1.48 (1.82)	1.95 (1.89)
Off-farm work	Members employed	0.50 (1.18)	0.74 (1.67)	1.07 (2.53)
Cooperative member	Yes=1; No=0	0.29 (0.46)	0.27 (0.44)	0.18 (0.38)
Credit union member	Yes=1; No=0	0.12 (0.32)	0.25 (0.43)	0.41 (0.49)
Assets owned	Value (‘000 Naira)	133 (352)	45 (128)	51 (77)
Land size	Hectares cultivated	4.39 (4.77)	2.67 (6.87)	2.71 (4.23)
N		935	1864	381

[a] Figures in parentheses are standard deviations.

Table 3. Sources of rural household income for all households and poor households.

Source	Share of income source in total income (%)					
	Dry savanna		Moist savanna		Humid forest	
	All	Poor	All	Poor	All	Poor
Farm	56	58	72	70	82	80
Non-farm	44	42	28	30	18	20

Source: Alene et al. (2006a).

The important determinant of the impact of agricultural research on poverty is the share of farm income in total household income. Table 3 presents the sources of rural household incomes for all and poor households. Clearly, poor rural households derive more than two-thirds of their incomes from farming, with little variation across agroecological zones. Non-farm incomes—non-agricultural incomes and in-kind and monetary transfers (e.g., remittances)—are the second important source of rural livelihood, especially in the dry savannas. This is partly due to growing urbanization and increased rural–urban migration. Since farm incomes are the single, most important sources of rural household incomes, agricultural research holds considerable promise to contribute to poverty reduction in Nigeria.

Although the potential of agricultural research for poverty reduction depends on the share of farm incomes in the total incomes of the poor, the issue of which crop and livestock research programs would have the highest poverty reduction potential, and hence, which programs should be given priority, depends on the share of the poor in the total production of the various crops and livestock. Table 4 presents the share of the poor in major crops and livestock production by agroecological zone in Nigeria.

Maize is an important staple food crop produced by most of the poor in the moist savanna. About 48% of the maize in this zone is produced by 83% of the poor. A high share in total maize production means that maize has a high potential for poverty reduction in Nigeria, particularly in this zone. On the other hand, 90% of the poor in the humid forest produce cassava and thus cassava and other root and tuber crops, such as yam, have greater potential for poverty reduction there. Maize, cowpea, rice, sorghum, millet, groundnut, and livestock have greater potential in the savanna.

Table 4. Major crops and livestock production by poor households in Nigeria.

	Dry savanna		Moist savanna		Humid forest	
	% Poor	% Production	% Poor	% Production	% Poor	% Production
Crops						
Maize	17	11	83	48	78	35
Cassava			19	8	90	26
Yam			34	9	51	32
Sorghum	62	36	55	36		
Soybean			11	73		
Groundnut	27	41	19	61		
Rice	17	37	25	29		
Cowpea	53	36	22	54		
Millet	87	41	15	21		
Livestock						
Cattle	38	50	14	74		
Sheep	55	66	26	62	14	48
Goats	65	59	61	64	71	51
Poultry	61	83	66	59	56	39

Source: Alene et al. (2006a).

Adoption model results

The survey data and the projected commodity-specific yield and production cost changes provide a good means of examining how agricultural research might affect smallholder incomes and how, in turn, income changes affect poverty. A Probit model was used to create household-specific forecasts of the probability of adoption of new technologies. The adoption model is similar in structure to other models of technology adoption, with household and farm characteristics as determinants (e.g., Feder et al. 1985). Adoption was set as a binary variable taking the value of 1 if the forecasted probability of adoption exceeded the 25th percentile cutoff value (Alwang and Siegel 2003) of 0.45.

Table 5 presents the Probit adoption model estimates. The model yielded an acceptable fit and reasonable parameter estimates. Age is negatively related to adoption, implying that older farmers are less likely to adopt new technologies. Farmers who are more educated, members of credit unions, and households with more labor adopt new technologies more readily. That is, education and access to credit and labor have a positive and significant influence on technology adoption. Households in the moist savanna are more likely to adopt new technologies than those in the dry savanna and humid forest. On the other hand, off-farm work, land size, and access to assets are not significantly related to adoption.

Table 5. Probit model estimates of adoption of new technologies.

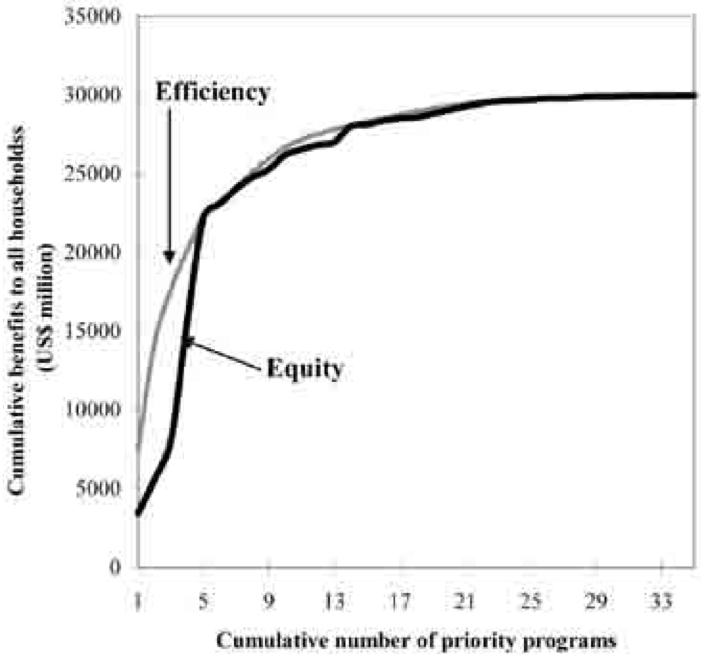
Variables	Estimate (t-ratio) [a]	Marginal effect
Male-headed	0.033 (0.13)	0.012 (0.13)
Head's age	−0.004 (−1.62)*	−0.001 (−1.62)*
Head's education	0.008 (1.75)*	0.003 (1.75)*
Adult male labor	0.033 (2.44)***	0.012 (2.44)***
Adult female labor	0.069 (3.73)***	0.025 (3.73)***
Off-farm work	−0.064 (−1.37)	−0.024 (−1.37)
Cooperative member	0.031 (0.57)	0.012 (0.57)
Credit union member	0.028 (2.47)***	0.011 (2.47)***
Assets owned	0.001 (0.61)	0.001(0.61)
Land size	0.004 (1.04)	0.001 (1.04)
Moist savanna [b]	1.731 (14.19)***	0.613 (14.19)***
Humid forest	0.057 (1.09)	0.423 (11.09)***
Likelihood Ratio	341 (Chi-square statistic=24.72)***	

[a] *,**, and *** represent significance at 0.1, 0.05, and 0.01 levels.
[b] Dry savanna is the comparison group.

Impact measures and program priorities by agroecological zone

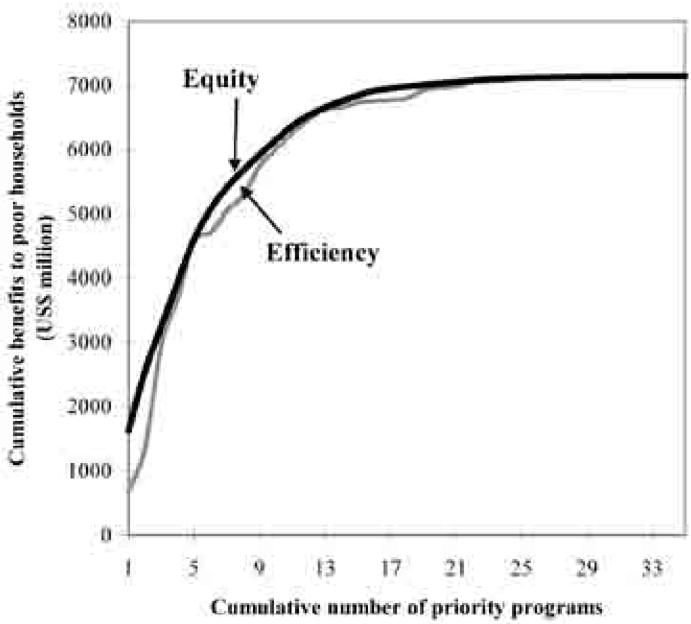
There is a growing interest in sharpening the focus of agricultural research, but there has been no consensus on whether priorities should be based on economic surplus or poverty reduction. This is largely due to the lack of empirical evidence on the nature and magnitude of the efficiency–equity tradeoffs. To contribute to this debate and to develop an approach to be used by IITA, Alene et al. (2006b) examined the issue of whether the poor benefit more from agricultural research that pursues objectives of efficiency or objectives of equity. The potential impacts of agricultural research on economic surplus as well as on poverty reduction in Nigeria were first estimated and strategic priorities identified according to both efficiency and equity criteria. They showed that, although introducing a poverty dimension does not result in a significant shift in strategic priorities, greater benefits to the poor, as much as US$155 million, are possible through poverty-based targeting without compromising total benefits (Figs 1, 2). It was noted, however, that efforts made towards the realization of potential benefits to the poor from pursuing either efficiency or equity objectives would be more important than mere targeting of research.

Figure 1. Cumulative benefits to all households from adding research programs according to efficiency and equity criteria.



Source: Alene et al. (2006b).

Figure 2. Cumulative benefits to poor households from adding research programs according to efficiency and equity criteria.



Source: Alene et al. (2006b).

Table 6 presents commodity research program priorities by agroecological zone based on their potential impacts on poverty reduction. The results show substantial differences in priorities across zones. In the dry savannas, cowpea and millet turned out to be the top commodity programs, with potentials to reduce poverty by over 6%, followed by sorghum, rice, groundnut, and livestock (i.e., poultry, beef and dairy cattle, and sheep). As expected, livestock have a high potential for poverty reduction in the dry savannas. In the moist savannas, maize and yam are the top priority programs, with a potential to reduce poverty by as much as 8% and 6%, followed by rice, cassava, and cowpea. In the humid forest, cassava and yam are the top priority commodity programs, with a potential to reduce poverty by over 7% and 2%. Because of the greater agricultural diversification in the savannas, which support the production of a range of crops and livestock, several programs are more promising for poverty reduction in the savannas than in the humid forest. On the other hand, most commodity programs are more important in one zone than in the others. For example, a maize research program would generate greater benefits in the moist savanna and a cassava program in the humid forest. Cowpea, sorghum, and millet research programs should be targeted to the dry savanna.

It is important to note that the poverty reduction approach to priority setting may not effectively rank all the research programs. This is because some research programs simply have no significant impact on poverty. The lack of noticeable impact is again due to several factors. First, smallholder farmers allocate a smaller share of their land to fruits, vegetables, industrial crops, and livestock. Secondly, predicted yield changes are generally lower for these categories. This is mainly because of poor research capacity, especially in the area of plant and animal breeding that would allow NARIs to generate high yielding varieties and animal breeds. Thirdly, although agricultural research has a high impact in terms of the number of people lifted out of poverty, the impact could be relatively small in terms of the percentage reduction in poverty. Fourthly, many of the poor could just be so far below the poverty line that income changes would have to be large enough to lift them out of poverty. Nevertheless, as long as continued pressure on public research budgets will require research to concentrate on fewer programs with potentials for poverty reduction, the poverty-based approach will be an important tool in identifying these programs.

Table 6. Agricultural research priorities by agroecological zone in Nigeria based on poverty reduction following a 50% increase in agricultural research budgets.

Dry savanna			Moist savanna			Humid forest		
Commodity	Poverty reduction (%)	Rank	Commodity	Poverty reduction (%)	Rank	Commodity	Poverty reduction (%)	Rank
Cowpea	6.604	1	Maize	8.004	1	Cassava	7.604	1
Millet	6.302	2	Yam	5.670	2	Yam	2.343	2
Sorghum	3.502	3	Rice	4.604	3	Melon	2.203	3
Rice	3.483	4	Cassava	4.064	4	Poultry	0.504	4
Groundnut	2.901	5	Cowpea	3.003	5	Goat	0.503	5
Poultry	2.502	6	Melon	1.403	6	Maize	0.384	6
Beef	2.304	7	Sorghum	1.304	7	Cocoa	0.303	7
Dairy	2.303	8	Groundnut	1.002	8	Sheep	0.302	8
Sheep	2.003	9	Poultry	0.704	9	Cowpea	0.009	9
Maize	1.804	10	Cocoa	0.603	10	Rice	0.008	10
Goats	1.703	11	Goats	0.501	11	Plantain	0.007	11
Onion	0.108	12	Sheep	0.402	12	Sesame	0.006	12
Wheat	0.008	13	Beef	0.304	13	Leafy vegetables	0.005	13
Soybean	0.007	14	Dairy	0.303	14	Onion	0.004	14
Sesame	0.006	15	Millet	0.204	15	Pepper	0.003	15
Leafy vegetables	0.005	16	Soybean	0.102	16	Ginger	0.002	16
Pepper	0.004	17	Irish potato	0.009	17	Tomato	0.001	17
Ginger	0.003	18	Plantain	0.008	18	Sweetpotato	0.000	18
Tomato	0.002	19	Sesame	0.007	19	Irish potato	0.000	18
Citrus fruit	0.001	20	Leafy vegetables	0.006	20	Sugarcane	0.000	18
Sweetpotato	0.000	21	Onion	0.005	21	Natural rubber	0.000	18
Irish potato	0.000	21	Pepper	0.004	22	Oil palm	0.000	18
Sugarcane	0.000	21	Ginger	0.003	23	Cotton	0.000	18
Cotton	0.000	21	Tomato	0.002	24	Cashew nut	0.000	18
Cashew nut	0.000	21	Sweetpotato	0.001	25	Citrus fruit	0.000	18
Melon	0.000	21	Wheat	0.000	26	Pineapple	0.000	18
Pineapple	0.000	21	Sugarcane	0.000	26	Mango	0.000	18
Mango	0.000	21	Natural rubber	0.000	26	Beef	0.000	18
Pigs	0.000	21	Oil palm	0.000	26	Dairy	0.000	18
Cassava	0.000	21	Cotton	0.000	26	Pigs	0.000	18
Yam	0.000	21	Cashew nut	0.000	26	Millet	0.000	18
Plantain	0.000	21	Citrus fruit	0.000	26	Sorghum	0.000	18
Natural rubber	0.000	21	Pineapple	0.000	26	Soybean	0.000	18
Cocoa	0.000	21	Mango	0.000	26	Wheat	0.000	18
Oil palm	0.000	21	Pigs	0.000	26	Groundnut	0.000	18

Source: Alene et al. (2006a).

Conclusions and implications

Agricultural research in SSA has come under growing pressure to explicitly consider poverty reduction objectives in setting its research agenda in an effort to ensure that scarce research resources are allocated in ways that will have the greatest impact on the poor. As Nigeria's agricultural research faces the challenge of responding to the new demands, there is a need to sharpen the focus. In the present review, we investigated the strategic research priorities in the major agroecological zones, based on the potential impacts of alternative commodity research programs on poverty reduction.

In view of the need for agroecological targeting of research for greater impact on poverty, the study identified priority commodity research programs for each zone. The priority setting results suggest that cowpea, millet, sorghum, groundnut, and livestock research would have greater impact in the dry savannas. In the moist savannas, research should focus on maize, yam, and rice. Increased cassava and yam research would have greater impact on poverty in the humid forest and moist savannas. The greater agricultural diversification in the dry and moist savannas in the production of a range of crops and livestock means that research should focus on more crops and livestock in the savannas than in the humid forest.

The research priorities by agroecological zone are also consistent with the organization of agricultural research in Nigeria. In each of the three zones, there is at least one Institute with a research mandate for commodities identified as high priority in this study. However, many NARIs work on a large portfolio of commodities and hence do not concentrate on those that are promising. Therefore, greater impact on poverty reduction could be achieved if NARIs in each zone concentrated research efforts and funding on the respective high priority commodities. The Institute for Agricultural Research (IAR) has a mandate for maize, sorghum, groundnut, cotton, and cowpea. This implies that IAR and IITA could focus on developing appropriate maize technologies, primarily for the moist savanna, and cowpea technologies for the dry savanna. The Lake Chad Research Institute has a mandate for millet, wheat, and barley in the dry savanna and could concentrate research efforts on millet. The National Cereals Research Institute has mandates for rice, soybean, sugarcane, and other crops in the moist savanna and could concentrate on rice. The National Root Crops Research Institute and

IITA have mandates for cassava and yam research. The results suggest greater benefits from increased cassava and yam research, both for the moist savanna and the humid forest.

It should be noted that the research results reported in this paper are not a result of a decision making process within the national agricultural research system in Nigeria. They are rather a result of research aimed at providing information to assist the national research system with strategic priority setting and resource allocation in its efforts to respond to the demands to contribute to poverty reduction in the face of declining budgets. The results constitute information on commodity research program priorities to help research managers and funding agencies to have an informed dialog, aiming at sharpening the focus of agricultural research. The information provided is consistent with commonly used measures of poverty and this should facilitate and enhance dialog between policymakers and research managers when deciding on resource allocations.

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Ex post impact assessment of agricultural research in sub-Saharan Africa: the IITA experience

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Abstract

The International Institute of Tropical Agriculture (IITA) and its research-for-development partners have made substantial contributions to food security, poverty reduction and environmental protection in sub-Saharan Africa. Technologies developed and largely diffused include high yielding varieties (cassava, cowpea, yam, maize, soybean, plantain/banana), Integrated Pest Management of varieties resistant and tolerant to pests and diseases, biological control of pests and alien invasive species, eco-friendly biopesticides, improved crops, natural resource and postharvest management practices. IITA has also a sound track record in capacity building of partners including farmers, the public and private sectors, field and laboratory technicians, NGOs, national agricultural research scientists, and rural development project managers. This review highlights a few case studies of *ex post* and *ex post*/*ex ante* impact assessment, using time series and cross-section data of some of these technologies, and finds a significant contribution to productivity, incomes, gender/equity, and nutrition at household, farm, community, country, and regional levels. It makes recommendations for strategies for a higher diffusion of the technologies through access to input and output markets and a sound partnership between research and development including a private-public partnership to achieve the highest returns on agricultural research investments.

Background

IITA and challenges

Major challenges yet to be effectively addressed in sub-Saharan Africa are those of improving food and nutritional security (higher production and effective demand through incomes) and ensuring sustainable livelihoods for an increasing population while protecting a fragile environment. The decreasing per capita food production and increasing rural poverty are further compounded by land degradation, an increase in the cultivation of marginal and fragile land, losses in biodiversity, resurgence of pests, and secondary pest outbreaks causing additional crop decline (quantity and quality) and threatening the sustainability of cropping systems. Human and environmental hazards associated with harmful pesticide regimes lower nutritional and economic benefits and obstruct international trade opportunities. Strategies to reduce poverty and food insecurity are limited by the lack of a cohesive framework for knowledge and information exchange among the sources and the users of technologies that could make decisive contributions to agricultural productivity and incomes. Scientists, rural development institutions, the private sector, and the government are challenged to develop and diffuse cost-effective technologies, to create optimal institutional arrangements, make conducive policy decisions, and create an economic environment (with access to input and output markets) to increase agricultural productivity and profitability for sustainable livelihoods. IITA's research has made significant contributions in pushing forward the production frontiers of its mandate crops (maize, cassava, cowpea, soybean, yam, banana/plantain) and related biophysical and socioeconomic systems. IITA has also made significant contributions to empowering its partners through capacity building, individual and group trainings of national agricultural research scientists, the private sector, NGOs, and rural development agents through specific crop or management-related workshops, farmer field schools (FFS), and fora for effective knowledge and information exchange to diffuse best practices.

Agricultural research and development: concepts of impact

Agricultural research and development (R&D) generates various types of output: technologies embodied in a physical object (e.g., improved seeds), management tools and practices, information, and improved human capacity. These results affect the effectiveness of the R&D institutes themselves through training and enhanced partnership, and the range of end-users who may benefit from technologies and institutional arrangements. Various issues can be considered in a comprehensive impact assessment of a typical agricultural research and development outcome. Three broad categories are usually considered. The first is the direct outcome of the research activities (research results). The second is related to the intermediate impact, where the organizational strategies and methods used by researchers and other actors in conducting more effective technology development and transfer are concerned. The third is referred to as the people-level impact. This refers to the effect of the technology/action on the welfare of the ultimate users or target groups. The people-level impact is actually the most important for CGIAR centers but also the most challenging in terms of measurement. People-level impact can be economic, socioeconomic, socio-cultural, and/or environmental.

This review considers some fairly recent *ex post* impact assessment work undertaken by IITA's scientists in various fields. It does not intend to document the entire substantial work on impact carried out by IITA or dwell on the stock and state of impact assessment research conducted by IITA scientists, but rather to point out and synthesize a representative sample of recent accomplishments, especially by economists and sociologists in the area of impact assessment. Different methodologies and approaches are used, even shortcuts because of problems of data availability in some sites and locations. Recent impact assessment studies representing different perspectives are synthesized. For each perspective, a case study is presented by revisiting the background and the objectives, the methodology used, and the results obtained.

For the purpose of this review, IITA's impact assessment research is divided into five categories.

Crop varieties

High yielding varieties of maize, cowpea, cassava, banana and plantain have made a significant impact on crop yields, food production, and incomes. New varieties of cowpea developed by IITA and its partners and released to farmers are widely used in Nigeria, Niger, Mali, Bénin, Cameroon and Senegal (Adeoti et al. 2003; Alene and Manyong 2006). Dual–purpose (grain and fodder) cowpea and pest resistant varieties, (for example KVx 396-4-5-2D, IAR/180-4-5-1, KVx 421-2J) are now common in Burkina Faso; IT97K-818-35, IT95M-1072-57, and

C94-23-2 are grown in Mali because of their earlier maturing/drought escape trait. Adoption studies carried out in each country have established the level and types of cowpea technologies diffused and have identified the factors affecting their adoption. Results from surveys show that improved varieties are used by 25 to 98% of farmers in the cowpea producing areas of the West African Sahel (Aitchedji et al. 2003).

The partial budgeting and policy analysis matrix used to assess the financial and economic profitability of improved cowpea technologies has shown that the improved variety drives both financial and economic benefits. The most profitable systems combine high yielding improved varieties with effective pest control techniques. The increase of the opportunity cost of capital or limited access to financial resources reduces significantly the profitability of the new technologies of cowpea. Increases in financial returns are US$56 and economic returns (conducive economic environment) are US$141 over local varieties. Local varieties have a long cycle and do not fit into the highly risky environment of the Sahelian countries, dominated by frequent early and end of season droughts (Aitchedji et al. 2003).

Economic impact of classical biological control

The early work of IITA on impact assessment focused on adoption studies and limiting factors to the diffusion of technologies. It was concerned with the effects of the spread of modern plant varieties, agroforestry practices, crop management, and pest management on farm productivity (Adesina et al. 1999; Nkamleu and Adesina 2000; Nkamleu and Coulibaly 2000; Nkamleu and Manyong 2005).

Recent *ex post* economic impact assessment work is of a more comprehensive type, looking beyond mere yield and crop intensities to the wider economic effects of the adoption and spread of new technology. These studies generally estimate the economic benefits produced by research in relation to associated costs, and estimate a rate of return (ROR) to research investments (Norgaard 1988; Zeddies and al. 2000; De Groote et al. 2003; Coulibaly et al. 2004). Research is treated as an investment for which ROR can then be estimated. Norgaard (1988) analyzed the impact of the biological control of the cassava mealybug based on extrapolation of data from a few West African countries over the entire continent, and estimated a benefit–cost ratio of 149:1 for the reasonable least favorable scenario.

Zeedies et al. (2000) on the other hand estimated a benefit–cost ratio ranging from 170:1 to 800:1. De Groote et al. (2003) analyzed the economic impact of water hyacinth and its biological control using survey data in Benin Republic and estimated a benefit–cost ratio of 124:1. Other work also applies a more refined economic surplus model to evaluate the impact of an individual research program (Coulibaly et al. 2004). Economic surplus model measures the benefit to society from the production and consumption of a good (resulting from the research). Research is supposed to significantly increase the production (yield) of the commodity or shift the supply curve out. The change is the measure of the social benefit or economic surplus. Economic surplus is divided between consumers (who capture part of the benefit through lower prices) and the producers (who benefit from the difference between increased total receipts and the marginal cost of production).

Case study: *Impact assessment of classical biological control of cassava mealybug (CMB) and green mite (CGM) in West Africa*

Cassava is the key staple food crop in much of sub-Saharan Africa (SSA) with yearly production exceeding that of all other crops (FAO 1998). It plays a key role in food security as it provides over 50% of the daily caloric intake for more than 200 million people and generates a substantial income for producers and other agents involved in the marketing system. Cassava also provides the raw material for local industries, such as starch processing (Onabolu and Bokanga 1998). Cassava can grow in relatively marginal soil conditions and with erratic rainfall. Its large production potential and the possibility of providing continuity of food supply throughout the year make cassava a key crop in the farming systems of many areas of SSA.

In the early 1970s, two major pests were inadvertently introduced into Africa from South America: cassava mealybug (CM, *Phenacoccus manihoti*) and cassava green mite (CGM, *Mononychellus tanajoa)*. Over the years, CM and CGM spread throughout the cassava belt of Africa, with the exception of Madagascar. They caused considerable reductions in cassava yields and appeared a potential cause of famine in the region. The damage caused by CM and CGM differed among countries and years. In Ghana, for example, yield losses due to CM and CGM were estimated at 70%, equivalent to 0.8 million t of tubers. The economic cost of such crop losses to Ghana valued in maize equivalents ranged from US$56 to US$106 million. Food supplies throughout SSA, where hunger and malnutrition are already commonplace, were soon seriously affected. However, in one of the most successful examples of classical biological control ever undertaken, IITA achieved control of CM across most of Africa's cassava producing areas (Herren and Neuenschwander 1991; Neuenschwander 1996). An economic analysis found that the benefit–cost ratio for this program ranged from 200:1 to 740:1. Once CM had been brought under control, CGM became the most important pest of cassava and the next threat to food security in the cassava producing areas in SSA. From the early 1970s, CGM began spreading throughout the cassava belt from east to west, reaching West Africa in 1979 (Yaninek et al. 1989; IITA 1997). It caused major yield losses and affected both the quality and the quantity of cassava planting materials. The area infested by CGM in West Africa has been estimated to be about 1 817 000 km^2 across Bénin, Nigeria, Ghana, and Cameroon. Losses in yield caused by CGM vary between 15 and 80% for susceptible local cultivars (Yaninek et al. 1992).

In 1983, IITA initiated a classical biological control program against CGM in collaboration with partner institutions in Africa, South America, and Europe. This program achieved a major breakthrough (IITA 1999). A phytoseiid predator, *Typhlodromalus aripo,* was identified and imported from South America to Africa (Yaninek et al. 1989) and proved to be very effective. The effectiveness of biological agents for the control of CGM is technically well documented (Yaninek and Herren 1989). These beneficial impacts included substantial increases in crop yields, large reductions in mite populations, and unquantified, but probably large, environmental benefits since persistent chemical insecticides were not used. An investigative work was undertaken to investigate economic returns from the biological control of CGM in Nigeria, Ghana, and Bénin.

Returns to investment show that the Net Present Values (NPV) from the investments over the simulated period from 1983 to 2010 (a conservative period) are about $54 million ($150/ha/yr) in Bénin, $305 million ($268/ha/yr) in Ghana, and $1 367 million ($244/ha/yr) in Nigeria, using a discount rate of 10% (Table 1). When subjected to sensitivity analysis at higher discount rates, i.e., in a less optimistic scenario, the results show that the NPV, for example in Ghana, are quite robust and would have dropped only to $185 million at 13% and to $134 million at 15%.

Table 1. Economic returns to the biological control of cassava green mite in Bénin, Ghana, and Nigeria, West Africa (1983–2010).

	NPV					
	Bénin		Nigeria		Ghana	
Discount rates	$ 000	$ /ha	$ 000	$ /ha	$ 000	$ /ha
10%	53,605	149	1,366,978	244	305,459	268
13%	32,028	89	802,971	143	184,915	162
15%	23,106	64	571,227	102	134,419	118
	Internal Rates of Return					
IRR	101%		125%		111%	

Similar levels of robustness were indicated also for Nigeria and Bénin. The results further demonstrated that the internal rates of return or break-even discount rates are substantially higher than for most public investments: 111% in Ghana, 125% in Nigeria, and 101% in Bénin. Sensitivity analysis shows that returns to biological control of CGM are still very important, even under a higher discount rate of 15% or under lower yield gains. The results clearly demonstrate that investing in classical biological control is highly profitable and an economically rational alternative to other forms of pest control in SSA.

Intra-household distributional impact

People-level impact is one of the central issues in agricultural research. It refers to the effect of the technology/action on the ultimate users or target group for which the technology was developed. Impact begins to occur when there is a behavioral change among the potential users. People-level impact deals with the actual adoption of the research output and subsequent effects on production, income, or whatever the development objective may be.

While studying the impact of intervention on the household is a common practice, a sometimes incorrect hypothesis has been to consider that the effect is evenly distributed among household members. Theoretical literature, empirical research, and methodological advances have increasingly demonstrated that any attempt to extrapolate from household data to individuals is highly misleading. This is particularly evident in the gender literature but applies equally to other dimensions of intra-household inequality: age, disability, and other dimensions of discrimination. Intra-household inequalities can affect the feasibility and sustainability of research interventions because of differing degrees of support and resistance to interventions, which may have a positive or an adverse impact on the interests of particular individuals. Failure for a research intervention to address differences and inequalities within households is not only "gender-blind", it can also lead to significant inaccuracies in impact measurement. Therefore, understanding the intra-household impact of interventions on the household is an area of human concern that should be considered for the comprehensive impact assessment of agricultural research. Moreover, intra-household relations are also of themselves the subject of impact assessment as a key element of human rights and sustainable livelihoods. Impact assessment work at IITA also looks at the impact of new technologies on factors that influence the daily life style and behavioral dimension of the individuals and families, their attitudes toward the policy, perceptions of risk, health, and safety, community cohesion, income distribution, the household decision making process, family characteristics, friendship networks, and social integration.

Case study: *Intra-household distributional impact of an improved cowpea technology package in Nigeria*

The International Livestock Research Institute (ILRI) and IITA have developed dual-purpose cowpea varieties. Efforts to disseminate these varieties to farmers started in 1993/1994. Studies reported that the adoption level was quite encouraging and showed multiple benefits from this flexible leguminous crop, some of which were related to the fodder and soil fertility-enhancing aspects. A household impact study was undertaken to assess the resulting intra-household benefits to adopting farmers (Tipilda et al*.* 2005).

The study was conducted in Kano and Kaduna States, northern Nigeria, during the 2003/2004 cropping season. The rate of adoption and intra-household impact of the improved varieties were assessed using a gender approach. Data on socioeconomic characteristics, crop production and cropping systems, adoption and diffusion of improved cowpea varieties, and the constraints and benefits in cowpea production were collected through focus group discussions.

Results

Higher yields were found among adopters (1200 kg/ha versus 500 kg/ha for non-adopters) and incomes increased by 134%. The wives of adopters had access to more income, first from the household head who sold more grain and fodder and then from their own processing of the improved cowpea. Apart from investing supplemented incomes in food security and human capital (the education of children and health care), women also made savings and subsequently used them for investment in petty trading, or in the purchase of other assets, such as livestock. They also contributed to their husband's purchase of farm inputs. With increasing savings and petty trading, women were able to form little credit groups with other women. This built up social networks to which they could revert in times of hardship within the family. These networks also promoted collective action and community activities.

Also, increased participation in social events raised the family's status. This was seen as the most important aspect. In the household, not much had changed in terms of the roles played by the men or women. What, however, had changed was that there was less conflict in the household over limited resources and how these were allocated. This was important for the women. They felt they had more independence and there was more stability with fewer incidences of conflict.

The women considered indicators such as happy, active, and plump children as the most striking features in improved health care from the adoption of improved cowpea. These perceptions were confirmed by the results on anthropometric indices for children (Z scores of weight-for-age or WAZ, height-for-age or HAZ, and weight-for-height or WHZ), as shown in Tables 2–4. The results were calculated under three groupings of households: 2 years of adoption of improved cowpea (ADOP2), 3 years of adoption (ADOP3), and 4 years of adoption (ADOP4). Overall, the average Z scores are within the ranges of a good nutritional status. These results also show that as sustainable adoption occurs over time, differences are observed between the children of adopters and those of non-adopters.

Impact on household food supply and effective demand

At IITA, there have been some efforts to document the impact of technological change and the consequent increase in food supplies at the household level (Alene and Manyong 2006). Raising the availability

Table 2. Nutritional status of children (2 years adoption dummy).

	Z Scores		
	WAZ	HAZ	WHZ
Adopters	–0.97	–2.09	0.31
Non-adopters	–1.13	–2.09	0.12
Level of Significance	*NS*	*NS*	*NS*

Table 3. Nutritional status of children (3 years adoption dummy).

	Z Scores		
	WAZ	HAZ	WHZ
Adopters	–0.90	–2.19	0.47
Non-adopters	–1.17	–2.00	–0.02
Level of Significance	*NS*	*NS*	***

Table 4. Nutritional status of children (4 years adoption dummy).

	Z Scores		
	WAZ	HAZ	WHZ
Adopters	–0.75	–2.20	0.52
Non-adopters	–1.19	–2.04	0.06
Level of Significance	***	*NS*	*

***$P < 0.01$; **$P < 0.05$; *$P < 0.10$; *NS* = Not significant

of food to the household will enable farmers to generate more income. Most of the investigations found that adoption of improved technologies helps to ensure food security through increased production that translates into increased incomes and increased food stocks for home consumption. Other work on the impact of new technologies, particularly improved varieties, was directed towards understanding its effects on market prices and food demand.

Case study: *Impact of improved cowpea adoption on food security in northern Nigeria*

Cowpea is an important component of the cropping systems of the semiarid and marginal areas of West and Central Africa. Nigeria is the largest producer and consumer of cowpea. In the dry savannas of Nigeria, cowpea plays a key role as a source of cash, protein-rich food, and fodder for livestock. It has a considerable potential to enhance the productivity, sustainability of the crop–livestock systems, and food security. Improved varieties IT90K-277-2, IT89KD-288, and IT93K-452-1 are among those developed by IITA to help farmers as food security is strengthened in the region. These varieties have potential grain yields of over 1 t/ha and fodder yields of 4–10 t/ha (Singh and Tarawali 1997). Earlier adoption and impact studies (Inaizumi et al. 1999; Kormawa et al. 2002) have shown the multiple benefits of improved cowpea varieties in northern Nigeria, such as increased household food supply during the critical food shortage period of the year as the varieties are early maturing, and the generation of income from the sale of cowpea at favorable prices at a time of shortage of supply on the market. However, the impacts of the improved varieties on the food security of the adopting households were still an area needing scrutiny. An investigative study was undertaken to examine the impact of adoption of improved cowpea varieties on household food security in northern Nigeria (Alene and Manyong 2006).

Methodology

The study was conducted in Kano and Kaduna States in northern Nigeria during the 2003/2004 cropping season. A total of 24 villages growing improved cowpea varieties (16 villages from Kano and 8 villages from Kaduna) were randomly selected for the survey. Regardless of their status as adopters or non-adopters, 20 farmers were randomly selected from each of the selected 24 sample villages.

Food security at the household level is defined as sufficient year-round availability of food for all members of the household. The access to food in rural households depends on whether the households have enough income to purchase food at prevailing prices or sufficient land and other resources to grow their own food. They can also receive assistance from formal programs or informal networks to compensate for any shortfall. That is, the total amount of food rural households can command is determined by factors that influence their own food production and the quantity of non-produced food. Household food security status is conceptualized in this work as the people's own assessment and perception of the sufficiency and diversity of food that the household commands in a particular period, given its endowments and characteristics, technology, and other exogenous factors. The determinants of food security are examined by specifying a food security status equation of a household in a given period as a function of the adoption of improved cowpea varieties plus several other factors, such as possession of productive assets (e.g., land and its quality), labor, household characteristics, the shares of major food crops in cultivated land, and any external source of income. The method of instrumental variables was used to account for endogeneity of improved cowpea adoption.

Results

The Probit instrumental variable estimation reveals that the adoption of improved cowpea varieties has a positive and highly significant impact on food security in northern Nigeria. Mere adoption of improved cowpea varieties increases the household’s probability of being food-secure by 32.5%.

Socio-cultural impact

Social impact assessment includes the processes of analyzing, monitoring, and managing the intended and unintended social consequences, both positive and negative, of research and development interventions and any social change processes invoked by those interventions. Its primary purpose is to bring about a more sustainable and equitable biophysical and human environment. Broadly speaking, socio-cultural impact assessment evaluates the effects of research on the attitude, beliefs, resource distribution, status of women, and income distribution. The nutritional and community-level institutional implications of the research are also assessed. Socio-cultural impact assessment can be done through socioeconomic surveys and careful monitoring. However, there are different levels by which to understand and approach this analysis. The consensus is that socio-cultural impacts are important and need to be considered along with the economic and environmental impacts. They can enrich the impact analysis as well as providing a clearer identification of issues for research planning, prioritization, and implementation.

A look at IITA’s work on the area of socio-cultural impact shows that the challenge is usually to focus on some specific social issues and then explore the effects of R&D on them. The concerns are usually on the maximization of social utility and development potential, while ensuring that such development is acceptable to the community, equitable, and sustainable. Many conceptualizations of this work are related to protecting individual property rights, with view to identifying whether a project or piece of research work affects groups differently. The emphasis is given to gender impact and the effect on children.

Given that socio-cultural parameters have a strong link with African rural livelihoods, socio-cultural impact can be seen as an important component of the evaluation of the overall effects of research on the people and the ways in which they interact with their socio-cultural, economic, and biophysical surroundings.

Case study: *Impact of Farmers' Field Schools on child labor in the cocoa farms in West and Central Africa*

The International Labor Organization (ILO) has been concerned about the role of children in commercial agriculture for a long time and has developed a number of conventions to set standards for their employment. According to the ILO (ILO/SIMPOC 2002), the highest rate of child labor is in SSA. Most of these children are involved in agricultural work, predominantly on farms operated by their families, and are not paid for their labor. In particular, since 2000, children working in the cocoa sector of SSA have found themselves in the media spotlight, with persistent reports of the worst forms of labor. This situation has assumed particular importance because SSA produces more than 60% of the world's cocoa.

Investigations by IITA in Côte d'Ivoire revealed that most of the children employed on cocoa farms belonged to the household, whether as family or foster children (IITA report 2002; Nkamleu and Kielland 2006). The study also highlights the competition between child labor and participation in schooling. Childhood is probably the best time to acquire knowledge from formal education. In this sense, addressing the problematic issue quickly appears to be vital to the development of many young people who are the future of SSA. IITA, ILO, and other partners developed measures and actions to address these educational and hazardous labor issues. As one of these measures, IITA has incorporated protocols dealing with child labor in its FFS Program.

Experiences from Asia and elsewhere showed that the FFS approach is an effective way to introduce farmers to knowledge of intensive practices such as integrated crop and pest management (ICPM). The FFS in tree crops production was introduced by IITA in West and Central Africa. This encourages discovery learning to strengthen farmers' knowledge of ICPM and improve their decision-making capacity on a broad range of technical issues. The FFS were later used as a platform for empowerment and now have incorporated an advocacy agenda on social issues, such as the use of child labor in agriculture. After two years of FFS implementation, an investigative survey was undertaken to evaluate its social impact. Social impacts were measured by comparing FFS participants to non-participants in terms of the frequency of use of child labor and the level of school enrollment (Gockowski 2006).

Table 5. Impact of FFS on utilization of family child labor in potentially hazardous tasks, children age group 0–17 years, 2005.

	Non-participant farmers (%)	Participant farmers (%)	Test of independence (Chi -square, 1 d.f.)
Côte d'Ivoire	33	30	0.159
Cameroon	36	30	0.164
Ghana	43	30	0.00

Table 6. School enrollment rates for FFS' participant and non-participant households in 2005.

	Non-participant farmers (%)	Participant farmers (%)	Test of independence (Chi -square, 1 d.f.)
Cote d'Ivoire	25	29	0.00
Cameroon	36	41	0.40
Ghana	42	43	0.76

Three potentially hazardous tasks have been highlighted by the ILO, which could pose unacceptable risks for children without adequate supervision. These are carrying heavy loads, assisting in pesticide application, and cleaning fields using machetes. Factors that affect farmers' decisions across different categories of child labor were identified. This helps in designing policy instruments and identifying target groups for the promotion of good child-use practices.

Results

The study reveals a statistically significant decline in the proportion of children undertaking hazardous work, particularly in Ghana (Table 5). For every 1000 farmers informed about the bad effects of child labor in FFS, 210 children were removed from hazardous work on cocoa farms. Ghana was also the first country to include a learning exercise on the use of child labor in their curriculum in 2003. In other countries, the learning exercise began one year later in 2004. The study also revealed that participation in FFS significantly increased the enrollment of children in school (Table 6). The higher enrollment rates could be attributed both to the increased income generated by the positive yield gains following FFS training, and to the social messaging on the fundamental rights of children to formal education that is embedded in the protocols on child labor.

Macro-, nationwide, and regional impacts

Agricultural productivity increased greatly world-wide during the second half of the twentieth century, through the combination of improved biological potential of crops and intensive crop management techniques (wheat yields quadrupled in Mexico, and rice production tripled over a 20-year period in South Asia). However, yield increases were minimal in Africa and fell dramatically behind those in other developing regions (cereal yields in SSA fell from 65% of developing countries' average in 1967 to only 43% by 1997). Therefore, productivity performance is a main focus of the research agenda of virtually all the national and international research organizations working on African agriculture.

Many studies have attempted to explain the lack of growth in Africa. Research analyses usually highlight the fact that limited technology had constrained agricultural productivity in the region. This brings the question: What has been the contribution of agricultural research to overcome the technology constraint of the agricultural sector? It is always said that the role played by the public sector and international agencies in research and extension activities in collaboration with farmers has been crucial in raising productivity of the agricultural sector significantly. Raising the productivity of the agricultural sector is supposed to be made possible, either by bringing new technologies to farmers or by improving the managerial ability of farmers.

Studies at IITA have tried to capture what impact these two components have on the growth of the productivity of the agricultural sector with a view to providing empirical support to the proposition that technological progress generated by the research has positively affected the growth of the agricultural sector. Many of these researches investigating the productivity and total factor productivity at the very aggregate-level use international macro-data and index numbers procedure to measure the contribution of technological change and efficiency change on productivity growth.

Case study: *Impact of efficiency change and technological progress on productivity growth in African agriculture*

In most African countries, because of its importance in overall GDP, export earnings and employment, as well as its forward and backward linkages to the non-farm sector, growth in the agricultural sector will continue to be the cornerstone of the poverty reduction program. A key factor for a sustained increase of agricultural production is improvement of productivity. The productivity performance of the agricultural sector is a main focus of the policy agenda in virtually every African country because it directly affects the country's living standards. In particular, looking for strategies that would lead to higher levels of productivity is regarded as a determinant to increase the production of agriculture and release a surplus to be used in other sectors. For years, various efforts have been undertaken to enhance the productivity of African agriculture. The research for development efforts by IITA and other international and national institutions have aimed at improving productivity, either by improving technical efficiency (managerial ability) and/or by improving technological level (a shift in the production frontier). A relevant question for researchers and agricultural policymakers has been the impact of past efforts on agricultural productivity. Investigative studies were undertaken to measure the productivity growth of the agricultural sector of African countries, and quantify the effect of technological progress and human capital accumulation on the productivity growth in the course of the last three decades (Nkamleu 2004).

Empirical analyses were undertaken using panel data on 26 countries, drawn from the Food and Agriculture Organization of the United Nations and covering the period 1970–2000. The countries included in the data set were evenly distributed and grouped into five conventional geographical classifications; Northern, Western, Central, Eastern, and Southern Africa. Malmquist index methods were used to measure and analyze total factor productivity, technology, and efficiency change in African agriculture. The method calculated total factor productivity indexes using efficiency measures. The approach used DEA-like linear programs and the Malmquist total factor productivity (TFP) index to measure productivity change and to decompose this productivity change into technical change and technical efficiency change. This method involved non-parametric estimations of aggregate production functions. Data used in the analysis consisted of information on agricultural production and conventional and non-conventional inputs. The specific variables used in the study included agricultural production, agricultural labor, number of tractors in use, quantity of fertilizer used, area of agricultural land, and number of livestock.

Results

For the studied period (1970–2000), the results revealed that the change in total factor productivity of the agricultural sector of the study countries had been positive. On average, total factor productivity had increased by 0.2% annually (Table 7). The study found that that technological

Table 7. Mean total factor productivity change of the African agricultural sector by region (1970–2000).

Africa	Overall Efficiency Change	Technical Change	Total Factor Productivity Change
Northern	0.996	1.011	1.008
Western	0.995	1.002	0.997
Eastern	1.002	1.007	1.009
Central	1.000	0.997	0.997
Southern	0.998	1.007	1.005
All Africa	0.998	1.004	1.002

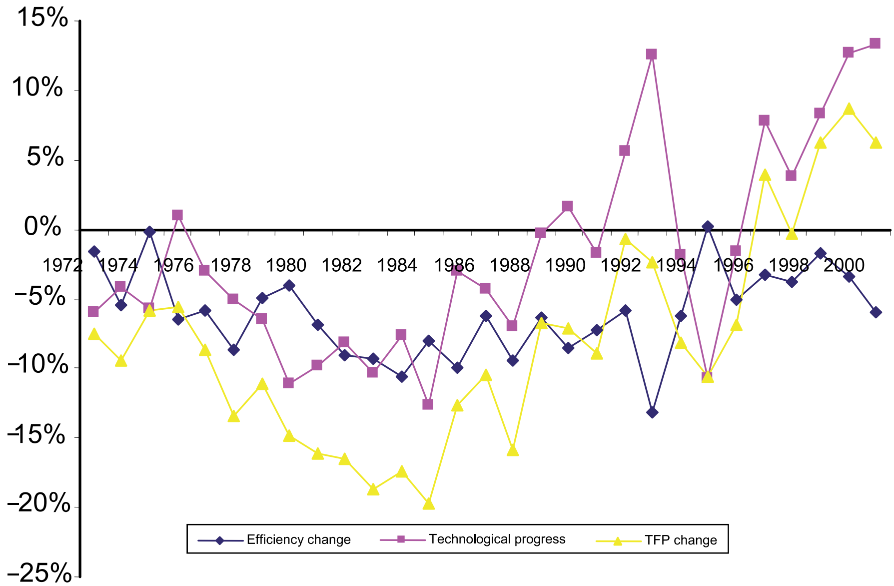

Figure 1: Cumulative performance of the agricultural sector in Africa.

progress had been the main driving force. The overall average annual technological change was 0.4%, while efficiency change was negative over the period (–0.2% per year). As presented (Fig. 1) the study also depicted changes in cumulative efficiency, technology, and total factor productivity from 1971 to 2000, and pointed out that the rate of technological change and productivity change was globally negative from 1970 until around 1985 and then turned positive during the remaining period. This suggested that research and development had been more active and more efficient between 1985 and 2000.

Conclusions

From the experience of IITA in *ex post* impact assessment of agricultural research, it is clear that economists and sociologists have been engaged in the work. The diversity of the commodity mandate of the Institute made room for a variety of subjects and approaches in the impact assessment effort.

The scope of impact work has expanded over the years from a narrow effort to measure adoption to researches quantifying a wide array of impacts on society, households, individuals, as well as socio-cultural aspects. Although IITA scientists have a good record in impact assessment research, the communication of their results to a wider audience still needs additional efforts. Furthermore, as there continues to be a need and a pressure to further broaden the agenda of impact research, there will still be concerns and challenges to address to increase the effect of the impact assessment of agricultural research at IITA. Issues such as partnerships and knowledge sharing with NGOs, farmers' organizations, and public and private small-scale enterprises will be important in the delivery of inputs, to increase productivity and incomes and should therefore be assessed.

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Assessing the impact of agricultural research using the counterfactual outcomes framework: the WARDA experience

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Abstract

Once disparate, approaches to impact assessment and analysis of causal effects encompassing various subdisciplines of economics, statistics, computer science and sociology are now converging to provide a single unified methodological framework within which the impact of various types of programs, policy changes, and technologies on various behavioral, environmental, and welfare outcomes can be quantitatively assessed with a satisfactory level of rigor from the perspectives of all of these disciplines. This review considers the methods and tools that underlie modern evaluation theory and practice with a particular focus on their applications to assess the impact of agricultural research as it has been practiced at WARDA since 2000.

Introduction

Impact assessment has been an integral part of WARDA's economic research program since 1990 (Matlon et al. 1996; Lancon and Kassam 2000). A number of adoption studies and the estimation of internal rate of returns to varietal improvement research were carried out in the 1990s by WARDA and the economic task force of the *Réseau ouest et centre Africain du riz* (ROCARIZ) (Adesina and Zinnah 1993; Adesina and Seidi 1995; Fisher et al. 2000; Dalton and Guei 2003).

The adoption survey results were used to estimate the return to rice research in the mangrove ecologies of Sierra Leone and Guinea-Bissau (Adesina and Zinnah 1993) and in the irrigated ecology of the Senegalese river valleys (Master et al. 2000). These were followed by a study of the impact of improved rice varieties from both national and international research centers on all West African rice ecologies. The study estimated that genetic enhancement and transfer had increased the value of rice production by US$93/ha (Dalton and Guei 2003). The study also confirmed that while irrigated and rainfed lowland ecologies had largely benefited from varietal improvements, upland rice-farming systems had lagged behind, due to a much lower rate of adoption and the limited gain in yield. Results from more recent surveys conducted by WARDA confirm the very low uptake of modern varieties in upland ecologies as a result of their very low diffusion (Diagne et al. 2006a, 2006b; Adegbola et al. 2006b).

This review provides a summary of the impact assessment research conducted at WARDA since 2000 with its objectives, scope, major outputs, and an evaluation of the counterfactual outcomes methodology as it has been applied at WARDA.

Objectives and scope of impact assessment research at WARDA

Following a strong recommendation from WARDA's External Program and Management Review in 2000 and recognizing that impact assessment has become a strategic issue for WARDA and its NARS partners and the CGIAR, WARDA created in 2000 the position of Impact Assessment Economist to streamline impact assessment in its research program for the purposes of priority setting and informing its stakeholders and the wider development community on the impact of its work. However, the emphasis put on poverty reduction now requires going beyond the usual adoption studies and estimation of internal rates of return to research. Consequently, the focus of the impact assessment research since 2000 is on providing information on the *ex ante* and *ex post* impact of the rice technologies generated by WARDA and NARS on various household and community welfare and environmental outcomes, including poverty, food security, nutrition, health, and biodiversity.

Impact assessment research is conducted under four broad themes: (1) Impact of modern varieties on farmers' livelihoods and rice biodiversity, (2) Impact of improved crop management practices on farmers' livelihoods, (3) Impact of improved grain quality and postharvest technologies on the rice sector, and (4) Developing regional capacity in impact assessment through training and the joint implementation of collaborative projects. Much of the work started in 2001 has focused on themes 1 and 4. The research issues being investigated under theme 1 include (1) the uptake pathways of improved rice varieties and the institutional constraints for rapid uptake; (2) the socioeconomic determinants of farmers' choice of rice varieties and the adoption rates of the different types of varieties; (3) the farmers' demand for the major biophysical and consumption traits of the different rice varieties and their marginal rates of substitution; (5) impact of the adoption of the modern varieties on rice yield, farm income, food security, and rice biodiversity; and (6) impact of the biophysical and consumption traits of the different rice varieties on rice yield, farm income, food security, and rice biodiversity. Although all varieties are considered in the research, at present the focus is mostly on the NERICA varieties because of the high demand for information on them.

The work under theme 4 involves the development of the individual and institutional capacity of national agricultural research and extension system (NARES) in the region in impact assessment through training and the joint implementation of impact studies with NARS. For that purpose, WARDA has been organizing an Impact Assessment Methodology course for ROCARIZ Economist Task Force members regularly since 2002. Up to 60 participants from Bénin, Burkina Faso, Cameroon, Côte d'Ivoire, The Democratic Republic of Congo, Gabon, The Gambia, Ghana, Guinea, Mali, Mauritania, Niger, Nigeria, Senegal, Tanzania, Uganda, Togo, and IITA have attended the courses in Bouaké, Côte d'Ivoire (2002), Conakry, Guinea (2003), Cotonou, Bénin (2005), and Dar es Salaam (2006). The topics covered in the training workshops have included concepts and methods of impact assessment and the econometric methodology underlying modern evaluation theory and practice. A very important part of the training workshops has been the hands-on training on the statistical packages SPSS and STATA and the practical exercises involving the estimation of adoption models, and of impacts on productivity, technical efficiency, and poverty using the data WARDA has collected in Côte d'Ivoire and Guinea.

Methodology

The counterfactual outcomes framework

The impact assessment methodology followed at WARDA is grounded within the "counterfactual" outcomes or Average Treatment Estimation (ATE) framework underlying modern evaluation theory and practice. For a review of the literature see: Moffit (1991); Imbens and Angrist (1994); Angrist et al. (1996); Heckman (1996); Heckman et al. (1999); Blundell and Costa Dias (2000); Wooldridge (2002); Imbens (2004);

and Heckman and Vytlacil (2005). Recent methodological advances in this area have set new standards of rigor for impact assessment that emulates the set-up of controlled experiments in way such that the results of the analysis of observational data from surveys can be given similar causal interpretation. The ATE framework is at the center of the impact assessment training course conducted since 2002 for the NARS economists. The main components of the methodology consist of (1) Community and household surveys on knowledge and adoption of varieties and on seed acquisition; (2) household and plot levels surveys to collect data on areas and yield by variety, input use, income, food intake, children's schooling; (3) country-wide census or survey data on rice areas and farm populations; (4) estimation of dynamic models of adoption and impact based on the ATE methodology; and (5) estimation of *ex ante* and *ex post* impact on economic and environmental outcomes at the national and continent-wide levels.

The fundamental evaluation problem and its solution

The fundamental evaluation (impact assessment) problem results from the simple fact that one cannot observe the *counterfactual* corresponding to any technological or policy change being considered. In other words, if a technological or policy change does occur, one cannot observe what would have happened to the various outcomes in the absence of the change; and if it does not occur, then one cannot observe what would have happened if the change did actually take place. More formally, for a technological or policy change from a state s_0 to another state s_1, one can only observe for any outcome *Y* of a household *i* either $Y_i(s_0)$ or $Y_i(s_1)$, but not both at the same time. Hence, it is impossible to evaluate $Y_i(s_1) - Y_i(s_0)$ for any given household. This impossibility is illustrated (Fig. 1) where the thick lines represent the observable outcome path and the doted lines the unobservable ones.

This inability to observe the counterfactual in any impact assessment study is the reason why impact assessment is viewed from a statistical perspective as a problem of missing data (the counterfactual). In fact, the statistical procedures used to derive unbiased estimates of impact outcomes are in essence designed to create an environment or a set of data that reflect as closely as possible the missing counterfactual. The fundamental problem to solve is how one can evaluate the aggregate impact $\Delta Y = \sum_{i=1}^{N} \left(Y_i(s_1) - Y_i(s_0) \right)$ when every element in the summation has missing data.

Econometric and statistical approaches for estimating impacts

One “naïve” approach to deal with the missing data problem consists of taking a random sample of program participants and non-participants (or technology adopters and non-adopters) and then using the simple difference of the mean observed outcomes of the two groups as estimate of the program or technology impact. Figure 2 illustrates the bias in the estimated impact that can result from such procedure. This bias is positive in the example of an agricultural technology that is mostly adopted by so-called “progressive” or “model” farmers (Fig. 3); and negative in the case of a successfully targeted poverty program (Fig. 4).

The missing counterfactual problem is solved by the counterfactual or potential outcomes framework, which is the conceptual framework that underlies standard methods for establishing the causal effects

Figure 1. The Fundamental Evaluation problem: observed and unobserved outcomes under mutually exclusive states.

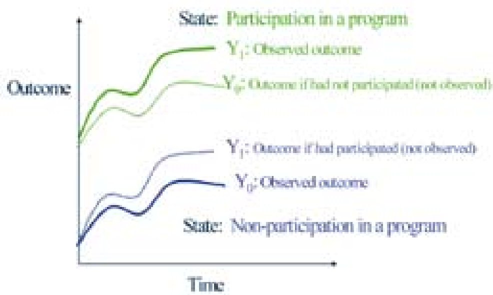


Figure 2. The naïve approach to impact assessment: simple difference of participant and non-participant outcomes.

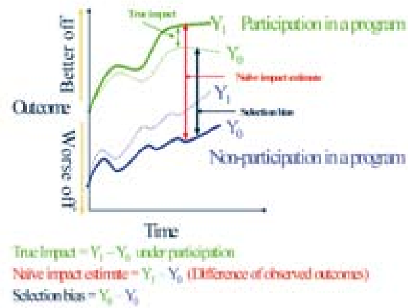


Figure 3. The naïve approach to impact assessment: example of over-estimation of impact of a technology.

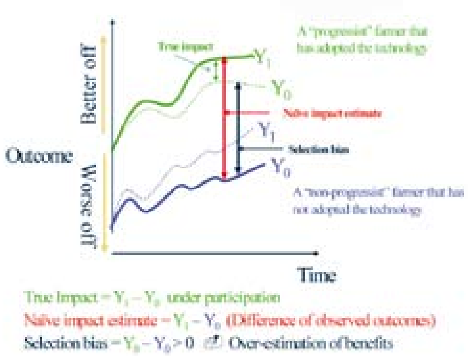
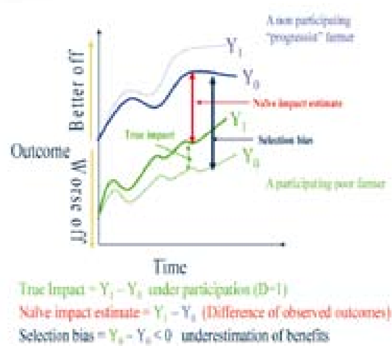


Figure 4. The naïve approach to impact assessment: example of under-estimation of impact of a program targeted to poor farmers.



of treatments on observed outcomes in the experimental sciences. In particular, it underlies the design of agricultural experiments and justifies the statistical procedures used to analyze the data from such experiments. In fact, the potential outcomes framework was formulated by Fisher in 1920 in the context of agricultural experiments (Rubin 1973; Holland 1986). Under this framework, every observational experimental unit with an *observed* outcome has *ex ante* two *potential* outcomes: an outcome when receiving a treatment that we denote by $Y_1 \equiv Y(s_1)$ and an outcome when not receiving a treatment that we denote by $Y_0 \equiv Y(s_0)$. In the agricultural experimental context (on-station or on-farm) the observational units are the plots or subplots to which different treatments (varieties, doses of fertilizer, etc.) are applied. If we let the binary outcome variable w stands for treatment state with $w = 1$ meaning receipt of treatment and $w = 0$ otherwise, we can write the *observed* outcome y of any observational unit as a function of its two potential outcomes: $y = wy_1 + (1-w)y_0$. For any observational unit the causal effect of the treatment on its observed outcome y is simply the difference of its two potential outcomes: $y_1 - y_0$. But, because the realizations of the two potential outcomes are mutually exclusive for any observational unit (i.e., only one of the two can be observed *ex post*), it is impossible to measure the effect of the treatment on the observed outcome of any observational unit. This “missing data” problem is solved in the experimental sciences by the use of various experimental design mechanisms that result invariably in the *random assignment* of each observational unit to one of the two mutually exclusive states: the “with” and the “without” treatment states. With such random assignment the difference of the mean observed outcomes of treated units and that of untreated units is an unbiased estimate of the mean causal effect of the treatment on observed outcomes. More formally, we have $E(y \mid w = 1) - E(y \mid w = 0) = E(y_1 \mid w = 1) - E(y_0 \mid w = 0) = E(y_1) - E(y_0) = E(y_1 - y_0)$; where the first equality follows by substituting the expression of the observed outcome and the second equality follows from the independence between the treatment state w and the potential outcomes y_1 and y_0 resulting from the random assignment of observational units to treatments. Thus, while the causal effect of the treatment on any observational unit cannot be estimated, one can estimate the mean causal effect of the treatment across all observational units, which is also called the Average Treatment Effect (ATE).

Wooldridge (2002, chapter 18) provides a succinct summary of the different estimators available for the consistent estimation of ATE (see also Imbens 2004; Cobb-Clark and Crossley 2002; Heckman 1996). The ATE estimators are classified in two broad groups based on the assumption they are required to be consistent. The first class of estimators is based on the conditional independence assumption. This assumption, which is also called in the literature the *ignorability of treatment* assumption (Rosenbaum and Rubin 1983), states that the treatment status *w* is independent of the potential outcomes y_1 and y_0 conditional on an observed set of covariates *x*. The second class of estimators is based on *instrumental variable* (IV) methods and assumes the existence of at least one instrument **z** that explains treatment status but is redundant in explaining the outcomes y_1 and y_0, once the effects of the covariates *x* are controlled for. Different estimators are available within each class depending on functional form assumptions and assumptions regarding the unobserved heterogeneities. The estimators using the conditional independence assumption are either a pure parametric regression-based method, where the covariates are interacted with treatment status variable, or they are based on a two-stage estimation procedure, where the conditional probability of treatment $P(w=1 \mid x) \equiv P(x)$, called the *propensity score*, is estimated in the first stage and ATE is estimated in the second stage by parametric regression-based methods or by non-parametric methods, which include various matching method estimators (Heckman et al. 1997). The propensity score-based estimators exploit the fact that the conditional independence assumption implies the independence of *w* and of the potential outcomes y_1 and y_0 conditional on $P(x)$ as well (Rosenbaum and Rubin 1983). They also use the additional assumption that $0 < P(x) < 1$.

Application of the ATE framework to estimate adoption rates and determinants

The ATE estimation framework has been used at WARDA to develop a new methodology for estimating adoption rates and their determinants. The new methodology is based on the counterfactual outcomes framework and enables one to assess the intrinsic merit of a new technology in terms of its potential *demand* by the target population, separated from issues related to dissemination and access to the technology (which are usually beyond the realm of research). Diagne (2006a) contains all the technical details of the new methodology including (1) the formal demonstration (i.e., mathematical proofs) of the statistical properties of the new estimators of adoption rates and determinants, (2) the reasons why the classical adoption models yield biased and inconsistent estimates of adoption rates and extremely small and statistically insignificant estimates of socioeconomic determinants of adoption, and (3) a side-by-side comparison of empirical results (using the NERICA data) obtained from the new methodology and from the classical model (see also Diagne 2006b).

Software tools for impact assessment

Two general purpose impact assessment software tools in the form of STATA modules (the standard and most popular econometric software) have also been developed at WARDA using the counterfactual outcomes framework. The first STATA module which we have called **Adoption** implements the new ATE methodology as developed in Diagne (2006a). The module works as a STATA add-on command that allows users to easily estimate ATE adoption rates and determinants (for any technology) in a way similar to the way a classical adoption model or an ordinary regression is estimated in STATA. The add-on command adoption also gives the user the option to estimate a classical adoption model and to compare the results side-by-side with that of the ATE method.

The second STATA add-on command, which we have named **Impact** implements the latest theoretical results and estimation methods in the counterfactual outcomes framework and automates the estimation of the impact of any change (including the adoption of a technology) on any behavioral and welfare outcome including the non-economic (yield, production, income, consumption, schooling indicators, etc.).

The rigorous estimation of impact (and the ATE adoption), normally require a certain amount of sophisticated programming in general purpose statistical software, such as STATA. The students and NARS colleagues with whom WARDA works had difficulties even in adapting and making small modifications in the programmes written by WARDA’s Impact Assessment Economist. Now, with these two tools, the NARS collaborators and students no longer need to have some knowledge on programming to estimate ATE-based adoption models and impact. “Beta” versions of the two tools are already operational and available for NARS to use. They have been used to redo quickly all the adoption and impact analyses for Côte d’Ivoire, Guinea, and Bénin. The tools are being refined and prepared for submission for publication in the STATA Journal (a peer-reviewed publication outlet for tools of that kind).

Implementation of WARDA's impact assessment research

In terms of implementation, except the work for Côte d'Ivoire for which WARDA is fully responsible, the work in all other countries is being conducted by the NARS economists themselves in the ROCARIZ Network, with WARDA providing the funding (through the ROCARIZ funding mechanism), the training and tools for analysis, and the backstopping on the field work and data analysis. A common methodology is being used in all countries so as to facilitate comparability and aggregation of adoption and impact across countries. For that purpose, questionnaires and sampling methodology already developed and used in Côte d'Ivoire and Guinea have been shared with all the NARS partners who make some adaptation, depending on country specificities. Data entry template, statistical analysis programs and tools developed by the WARDA team are also shared with all the NARS partners. Also, in addition to the organized group training courses mentioned above, WARDA's Impact Assessment Economist is spending a significant amount of his time backstopping (physically and by e-mail) the Economics Task force members in the design and implementation of their impact studies. He is also providing them with the questionnaires and statistical analyses programme developed for the Studies in Côte d'Ivoire and Guinea. The draft papers on the adoption and impact of the NERICAs in Bénin and Guinea (see references) co-authored by the NARS and the WARDA Impact Economist are illustrations of WARDA's collaboration and capacity development work with the NARS.

Progress and summary of results

WARDA and its NARS collaborators are presently carrying adoption and impact studies (focusing mostly on the NERICAS) in nine member countries: Bénin, Côte d'Ivoire, Guinea, The Gambia, Ghana, Mali, Nigeria, Sierra Leone, and Togo. The following summarizes the status of the work in the various countries (see Table 1). In Côte d'Ivoire, a low diffusion rate (9%) limited the adoption of the NERICA lines to only 4% in 2000. But the adoption rate in the population could have been up to 23% if the whole population were exposed to the NERICA. The rate of NERICA diffusion was 44% in Guinea, a diffusion rate much higher than in Côte d'Ivoire. The NERICA population potential adoption rate (if all the farmers in Guinea were exposed to the NERICA) is 58%, double the actual adoption rate observed in the sample (24%). Up to 53% of farmers who were exposed to NERICA lines had adopted them in 2001. In Bénin, the NERICA diffusion rate in 2004 was 26%. NERICA lines

Table 1. ATE estimates of NERICA population adoption parameters in Côte d'Ivoire, Guinea, and Bénin.

Parameters	Côte d'Ivoire	Guinea	Bénin
Diffusion rate	.09**	0.44***	0.26***
Population potential adoption rate (ATE)	0.23	0.58***	0.57***
Adoption rate among the exposed (ATE1)	0.36	0.59***	0.70***
Adoption rate among the exposed (ATE0)	0.21*	0.57***	0.53***
Joint Exposure and adoption rate (actual adoption rate)	0.04	0.23***	0.18***
Population Adoption gap : (ATE – actual adoption rate)	–0.19*	–0.35***	–0.39***
Population Adoption Selection bias (ATE1– ATE)	0.13**	0.01	0.13*

Note: * significant at 5%; * * significant at 1% ; *** significant at 0.1%.

were adopted by 18% of the farmers in the sample in 2004, an adoption rate three times less than estimated potential adoption rate (57%). Up to 70% of farmers who were exposed to NERICA lines in Bénin in 2004 have adopted them. The impact of NERICA adoption on farmers' well-being in Bénin has also been estimated. For example, the impact of NERICA adoption on child schooling was a 3% increase in school attendance rate, a 3% increase in school retention rate, and about 5000 FCFA *(US$1 = 500 FCFA)* increase per child in school expenditure (Adekambi et al. 2006).

Conclusion

In summary, impact assessment has been an integral part of WARDA's Economic Research Program since 1990 and is designed to address the informational need of both outside stakeholders and WARDA's researchers and management. A number of adoption studies and estimation of internal rate of returns to varietal improvement research were conducted in the 1990s by WARDA and ROCARIZ's Economic Task Force members. However, with the current emphasis on poverty reduction, the focus of impact assessment research at WARDA has, since 2000, shifted to providing information on the *ex ante* and *ex post* impact of WARDA- and NARES-generated rice technologies on various household welfare and environmental outcomes, including poverty, food security, nutrition, health, and biodiversity. The methodology followed at WARDA is the "counterfactual" outcomes or ATE framework underlying modern evaluation theory and practice. The framework unifies disparate approaches to impact assessment and the analysis of causal effects encompassing various subdisciplines of economics, statistics, computer science, and sociology. The counterfactual outcomes framework has been applied at WARDA to develop a new methodology for estimating adoption rates and their determinants independent of issues related to access to information and to technologies. The WARDA impact assessment work also includes the development of individual and institutional capacity in impact assessment of NARES in the region through training and the joint implementation of impact studies with NARS. In terms of implementation, except for the work for Côte d'Ivoire where WARDA is fully responsible, the work in all other countries is being conducted by the NARS economists themselves in the ROCARIZ Network, with WARDA providing the funding, the training and tools for analysis, and the backstopping on the field work and data analysis. A common methodology is being used in all countries so as to facilitate comparability and aggregation of adoption and impact across countries.

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Targeting agricultural research for development in Tanzania: an example of the use of GIS for *ex ante* impact assessment at IITA

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Abstract

GIS targeting, combining a range of different datasets including climate, topography, population, protected areas, road networks, agricultural production, and markets, is becoming an important tool in planning agricultural research for development. The impact of agricultural investments can be maximized by targeting them to areas where biophysical conditions are optimal for selected crops, and where population densities and market access maximize the economic possibilities. Targeting can be tailored to specific institutional requirements, for example, to emphasize improved nutrition or export-orientated cash crops.

Tanzania is the fifth most populous country in Africa, with a very high percentage of its population dependent on agriculture. The incidence of poverty and child malnutrition is high, but large areas of potentially productive agricultural land are only partly developed. There is great scope for increased agricultural production through the introduction of improved crop varieties and novel farming systems, but these must be concentrated in the areas where they will have the greatest impact.

Areas of cultivable land were identified by combining topographic data (slopes and altitude) with climate data (eliminating arid areas) and maps of protected areas (no farming in national parks). These were then further processed to remove those areas where predictions of climate change indicate a significant reduction in rainfall by 2025. Relative ease of access to markets (settlements with populations in excess of 20 000) was calculated using maps of land cover, road networks, and slope maps. A combination of cultivable land with ease of access to markets and medium-to-high population densities defines prime targets for agricultural development. For each target area, crop suitabilities were assessed, based on biophysical parameters.

Introduction

Tanzania is the fifth most populous nation in Africa (Table 1). Smallholder agriculture is critical to the health and well-being of its inhabitants, 70.7% of whom are engaged in agriculture (Fig. 1) (NBS 2005). In addition, 36% of the population live below the national poverty line and 29% of children are malnourished (FAO statistics). The International Institute for Tropical Agriculture (IITA) has been active for many years in Tanzania, particularly in the field of plant health management. The IITA team in Dar es Salaam has recently been substantially increased, and the targeting exercise reported here was undertaken to stimulate discussion on future agricultural development.

The history of agricultural development in Tanzania graphically illustrates the need for targeting, based on the best available data on the biophysical environment, suitabilities of different crops, and the infrastructure. The Groundnut Scheme of the late 1940s, designed to supply post-war Britain with vegetable oils, was a disastrous failure, for a combination of factors, but particularly the unsuitability of the natural environment for the target crop (Wood 1950)

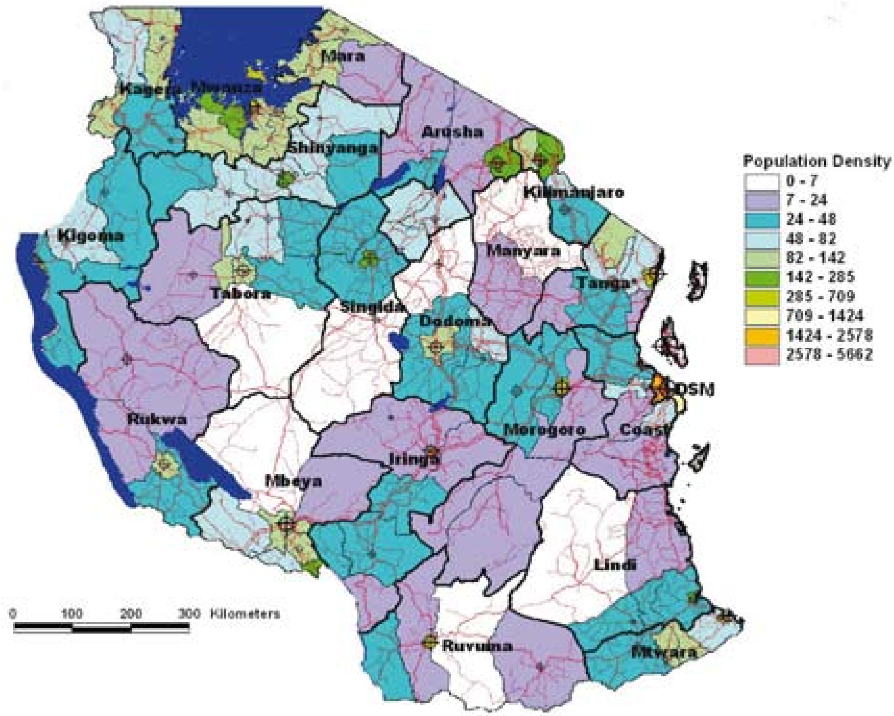
GIS has been used for targeting of many kinds. The initial impetus was for commercial uses in developed countries, where GIS was used to select the best sites for shopping complexes and public utilities, then also for healthcare facilities (Black et al. 2004). Its use in agriculture in developing countries is more recent, but it has rapidly become an important tool for *ex ante* analysis and target selection (Wood et al. 1999; Fan et al. 2000).

Table 1. Ten most populous countries in Africa, 2003.

Country	Population
Nigeria	124 009 000
Ethiopia	70 678 000
Dem. Republic of Congo	52 771 000
South Africa	45 026 000
Tanzania	36 977 000
Sudan	33 610 000
Kenya	31 987 000
Uganda	25 827 000
Ghana	20 922 000
Mozambique	18 863 000

Source – FAO Database 2006.

Figure 1. Population density in Tanzania. Data from National Bureau of Statistics, Tanzania.



The technique basically consists of overlaying, in a digital fashion, a series of different factors which contribute to the success of the action proposed, and extracting those areas with the highest score of combined factors. One of the layers will often be an indicator of accessibility to markets, essential for the evolution from subsistence to cash-crop agriculture (Deichman 1997).

Data sources

Agricultural production statistics by region for 2002 were obtained from the Ministry of Agriculture and Food Security in Dar es Salaam (MAFS 2005), and the latest available census data, as well as administrative boundaries, from the National Bureau of Statistics (NBS 2005), also in Dar es Salaam. Climate data was obtained from the Climate Research Unit of the University of East Anglia (New et al. 1999, 2000), digital elevation models from the Shuttle Radar Topography Mission (SRTM), population grids from Gridded Population of the World version 3 (GPW3) and the Global Rural–Urban Mapping Project (GRUMP) (Center for International Science Information Network—CIESIN—Website), and climate change predictions from Jones and Thornton (2004).

Background to agriculture

Tanzania is a predominantly agricultural country, with 45% of GDP generated from agriculture (WRI 2006). Most of the agriculture is at a smallholder subsistence level, and nomadic and semi-nomadic pastoralists are also important in drier areas. The average area of cropland per household is small, at about 0.8 ha (WRI 2006). Because of the diversity of agroecozones (Fig. 2), determined mainly by the topography which is dominated by the two branches of the East African Rift Valley and associated, usually volcanic, highlands (Fig. 3), the range of crops grown is very wide. Highland areas promote orographic rainfall, and result in rain-shadows in adjacent lowland valleys, causing rapid spatial changes in rainfall, while the highlands also result in greatly lowered temperatures. Staple starch crops are maize, millet, cassava, sweetpotato, and sorghum (Table 2; Fig. 4). Cash crops include coffee, tea, and cashew nuts (Table 3). There are few large-scale commercial farms or plantations in the country, with the exception of sisal along the coast and inland from Tanga, and tea in the southern, north-eastern and western highlands.

Climate change

In common with many other parts of Africa, Tanzania is predicted to become warmer and drier during this century, with some serious implications for agriculture. Peter Jones of CIAT (Jones and Thornton 2003, 2004) was commissioned as part of the preparatory phase of the Sub-Saharan Africa Challenge Program (Thornton et al. 2006) to prepare maps for the whole of Africa for predicted lengths of growing season in 2025 and 2050. The predicted changes, between 2005 and 2025, in the length of growing season in Tanzania are shown (Fig. 5). Large areas will be essentially unaffected by climate change, at least in the medium term, but the Coast Region will be seriously affected as the growing season in some areas will decrease by as much as two months. Parts of Tanga, Manyara, Mara, Morogoro, Lindi, and Iringa Regions will also be affected, but not so seriously.

While efforts should be made to ensure that farmers in the areas likely to be worst affected (see Fig. 6) are able to modify their agriculture by planting drought resistant varieties and possibly even by changing their farming systems, new agricultural development should be targeted primarily to parts of Tanzania where climate change will have the least impact.

Figure 3. Topographic zones in Tanzania, derived from SRTM 90-m DEM of Africa.

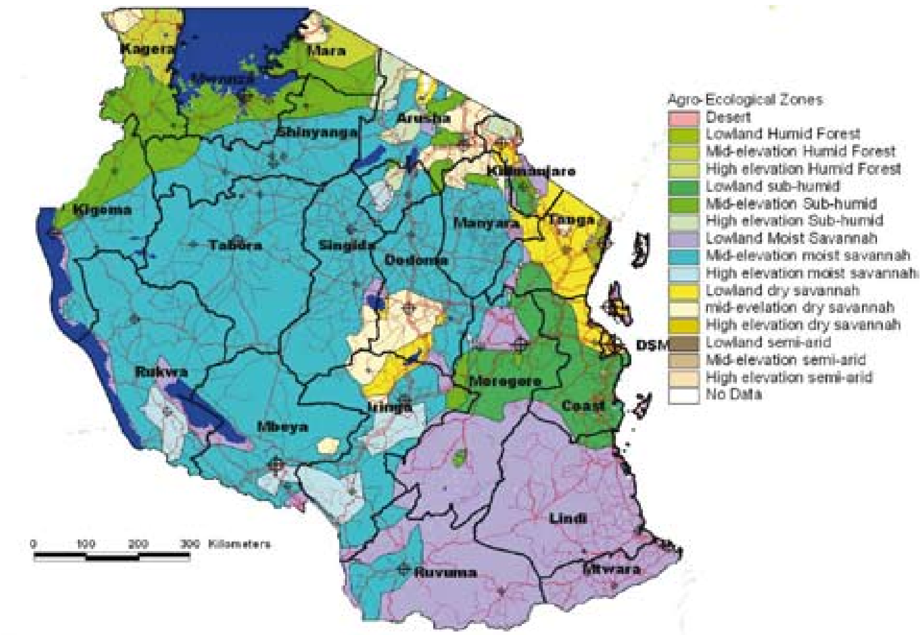


Figure 2. Agroecological zones in Tanzania (Legg 2004). Based on data from FAO, CRU, and ICRISAT.

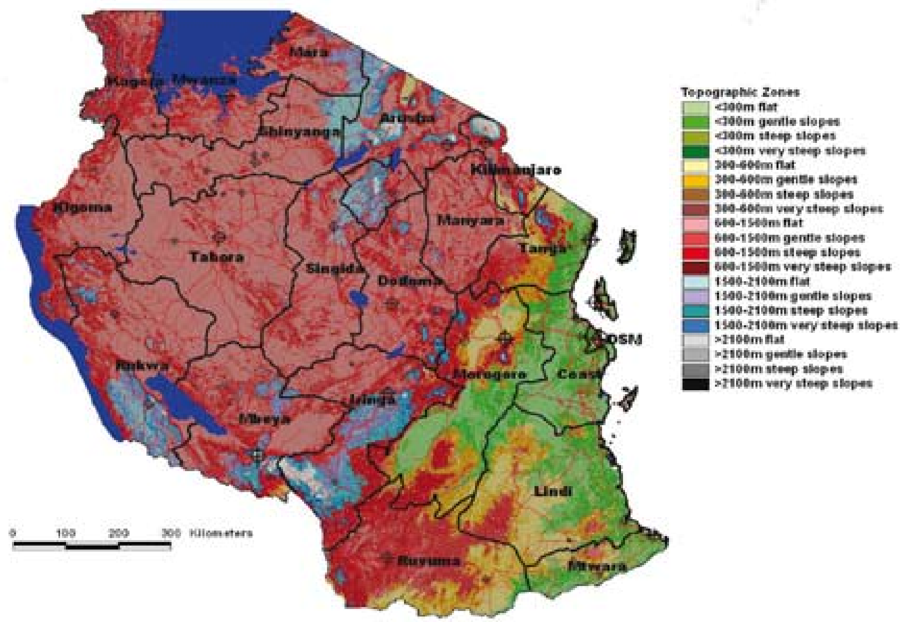


Table 2. Production of staple foods by region 2003 ('000 t).

Region	Maize	Sorghum	Millet	Rice	Wheat	Sweet-potato	Pulses	Banana	Cassava	Ground-nut	Beans
Arusha	60.4	1.6	0.6	5.4	10.8	4.5	44.0	61.8	2.2	–	12.9
Coast	26.6	–	–	8.0	–	8.2	23.8	–	302.5	–	–
DSM	2.1	–	–	2.1	–	27.7	3.8	1.0	37.5	–	–
Dodoma	61.2	53.0	57.9	3.7	–	12.9	45.2	–	90.9	26.2	1.0
Iringa	304.1	3.1	3.5	8.1	20.0	7.5	32.7	7.0	56.8	7.9	35.3
Kagera	125.9	4.3	9.2	14.2	–	69.5	45.4	496.6	112.8	8.2	9.3
Kigoma	166.1	8.7	4.0	39.1	–	233.4	33.2	293.6	222.2	8.2	68.0
Kilimanjaro	67.9	4.4	2.6	55.3	4.4	6.2	19.8	561.2	35.6	1.3	12.8
Lindi	13.7	12.3	–	5.8	–	–	4.9	–	60.2	1.2	–
Manyara	148.4	14.2	5.8	35.6	8.0	3.7	–	0.6	1.3	0.7	66.5
Mara	59.4	49.2	5.4	14.1	–	29.1	17.1	19.0	82.1	1.5	3.8
Mbeya	597.2	18.7	11.3	259.6	1.3	47.0	27.4	321.1	144.8	–	50.1
Morogoro	400.0	51.6	0.9	259.6	–	53.1	35.8	45.5	274.0	–	27.6
Mtwara	10.5	9.3	2.5	12.6	–	0.0	10.2	–	306.0	–	–
Mwanza	240.7	90.7	12.8	242.6	–	150.8	97.1	–	290.4	17.2	–
Rukwa	330.0	15.3	17.6	65.4	0.6	87.9	38.9	–	193.8	17.2	41.9
Ruvuma	207.3	0.4	6.5	63.3	–	11.9	24.4	–	106.0	5.2	14.6
Shinyanga	117.2	30.2	3.8	128.3	–	164.1	66.0	–	96.1	79.8	34.6
Singida	134.0	82.0	55.8	1.4	–	22.6	50.5	–	151.6	10.2	6.7
Tabora	112.7	12.5	–	48.5	–	43.4	32.5	–	99.0	70.3	–
Tanga	258.9	–	–	21.0	–	5.6	29.5	90.8	177.7	0.1	63.5

Source: Statistics Unit, Ministry of Agriculture and Food Security.

Table 3. Production of export crops by region 2003 ('000 t).

Region	Cotton	Coffee	Tea
Arusha	–	1.51	–
Coast	0.1	–	–
DSM	–	–	–
Dodoma	–	–	–
Iringa	0.1	0.22	20.5
Kagera	1.6	21.47	0.3
Kigoma	0.3	0.68	–
Kilimanjaro	–	4.79	–
Lindi	–	–	–
Manyara	0.1	0.23	–
Mara	11.4	0.78	–
Mbeya	–	10.89	3.1
Morogoro	0.3	–	–
Mtwara	–	–	–
Mwanza	43.7	–	–
Rukwa	–	–	–
Ruvuma	–	8.38	–
Shinyanga	119.1	–	–
Singida	–	–	–
Tabora	11.4	–	–
Tanga	0.1	0.37	6.2

Source: Statistics Unit, Ministry of Agriculture and Food Security.

Figure 4. Production of major staple crops by region. Data from Ministry of Agriculture and Food Security, Tanzania.

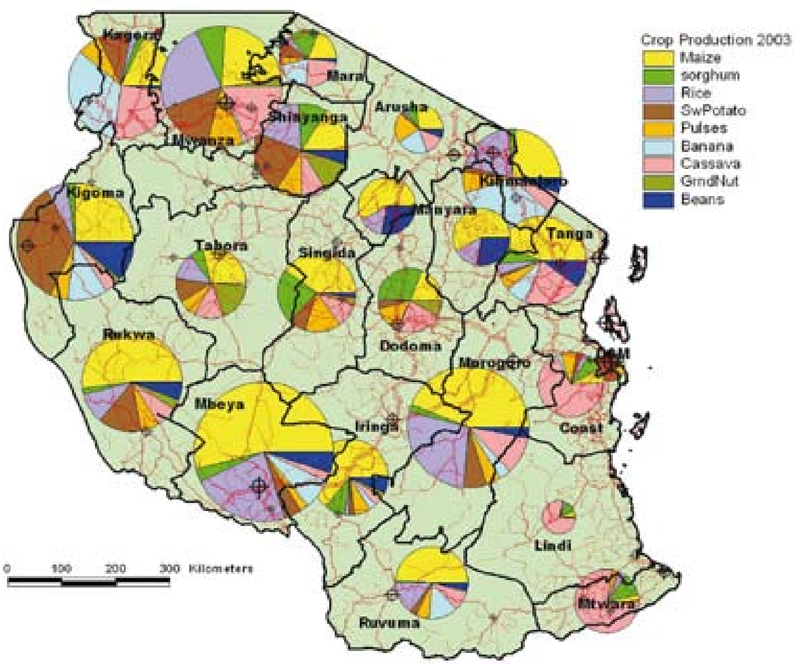


Figure 5. Predicted climate change (length of growing season) 2005–2025. Data from Jones and Thornton (2004).

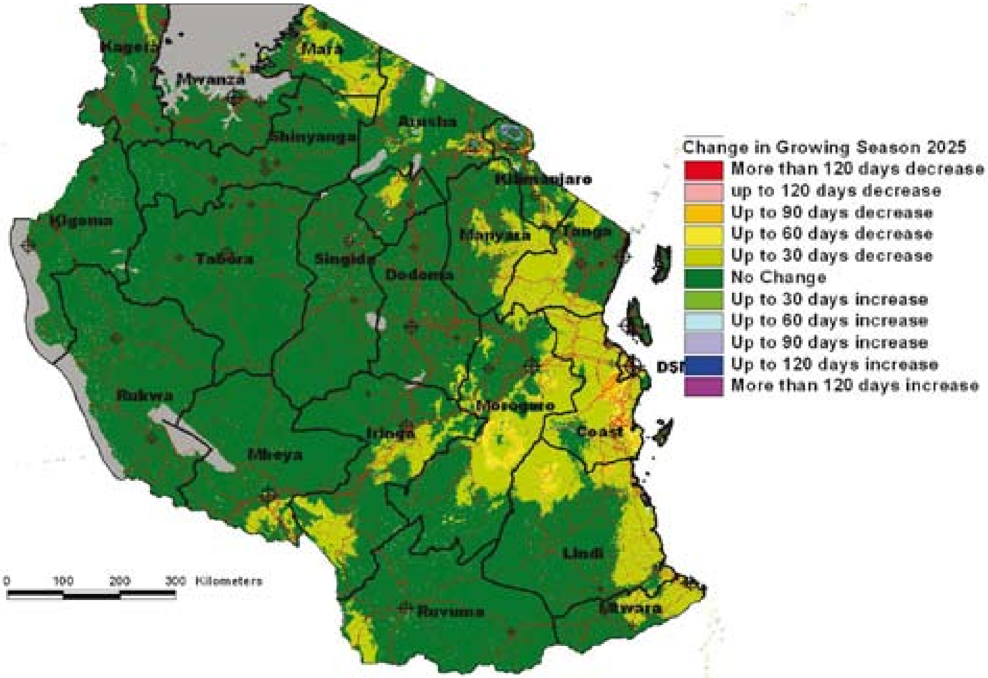
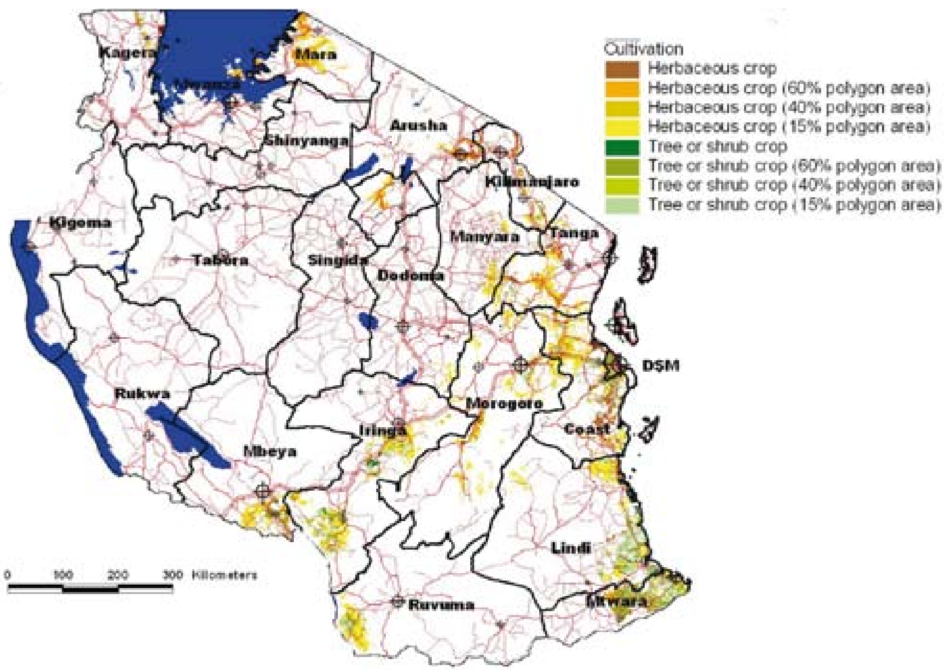


Figure 6. Current agricultural areas in Tanzania predicted to be effected by decreased length of growing season as a result of climate change.



Development domains

Development domains, sometimes also known as recommendation domains, are, in terms of agricultural development, those areas where a combination of favorable circumstances makes agricultural investment economically attractive and sustainable. For the purposes of this study, accessibility to markets was considered a key factor for subsistence farmers to transform themselves into cash-earning smallholders. Distance to markets, in terms of travel time, was calculated using cost–distance analysis, with a surface travel speed based on topography and vegetation cover, and the best available road map. Market access was coded qualitatively, as poor, moderate, and good access to local markets (towns with more than 20 000 people). Land suitable for agricultural development must lie outside protected areas (national parks, etc., of which there are many), and should also be relatively flat, since sustainable farming on steep slopes requires substantial investment of money and manpower. The STRM digital elevation model (Fig. 3) was used to extract flat and gently sloping land, and this was further screened by the removal of protected areas. This was then combined with market access zones to produce the development domain map (Fig. 7).

Figure 7. Access to markets towns with more than 20 000 inhabitants.

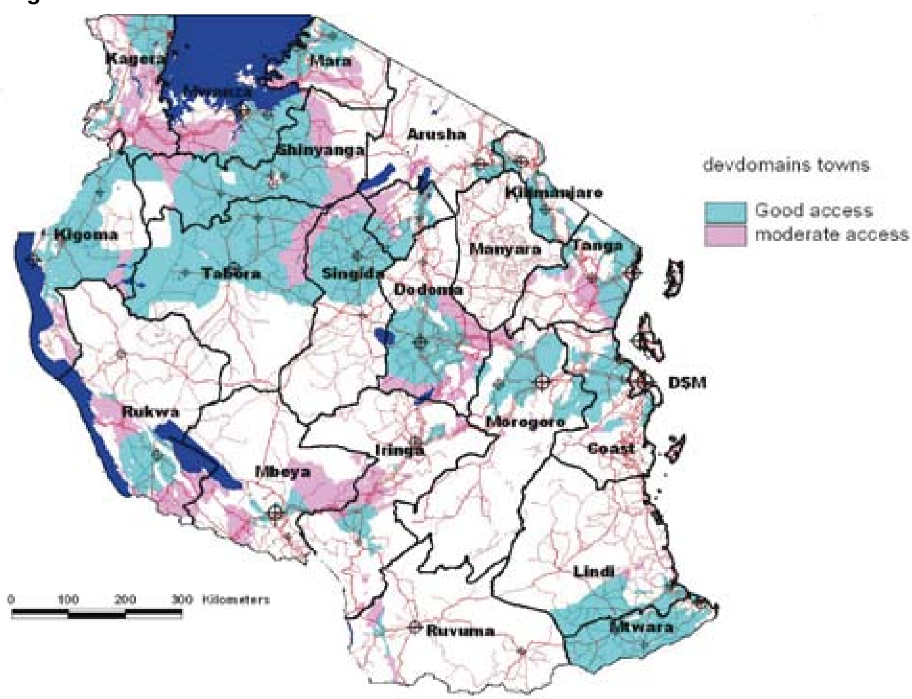
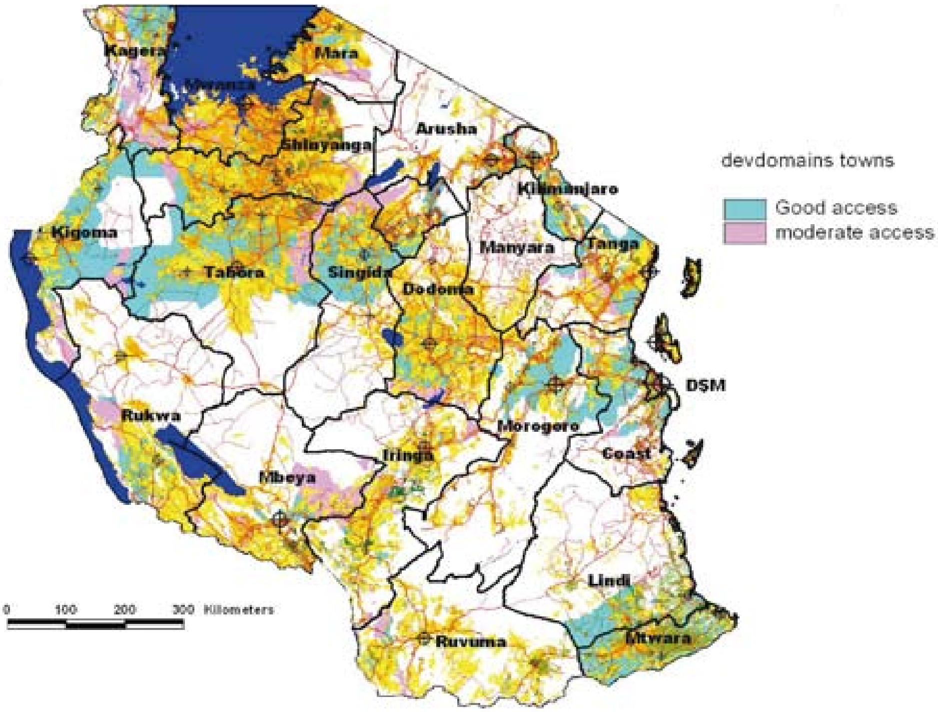


Figure 8. Existing cultivation (from AfriCover) and areas of good market access.



Comparison of development domains with a map of existing cultivation from AfriCover (Fig. 8) shows that there is much existing cultivation outside market-driven development domains, as would be expected in a country dominated by subsistence agriculture. Conversely, there are many areas of agriculturally suitable land with good access to local markets without intensive cultivation, suggesting that there is still room for agricultural expansion.

Crop suitability

The suitability of any site for cultivation of a particular crop depends on a range of biophysical factors as well as on the incidence of pests and diseases and human cultural practices. The most important biophysical factors are climatic, especially availability of water, as indicated by precipitation or the length of the growing season, and minimum temperature, but soils are also very important. The DIVA GIS software package (Hijmans et al. 2001), developed within the CGIAR primarily for studies of crop biodiversity, includes the FAO ECOCROP database (http://ecocrop.fao.org/) with climatic parameters for most of the world's major crops. The parameters include the temperature and precipitation limits within which growth of the crop is possible, and also the maximum and minimum limits for optimum growth. Using the WorldClim climatic databases packaged with DIVA (DIVA 2006), the software can produce maps showing four suitability classes for selected crops (Fig. 9). The data in ECOCROP are sufficient to give broad impressions of the suitability for major crop species, but the database does not yet contain data on the marginal and optimal limits for different crop varieties which may have been bred for different biophysical conditions. The suitability evaluation does not yet include the use of soils data, so that within areas designated as “suitable” or “very suitable” for a particular crop, differing soil characteristics may actually render some areas completely unsuitable.

Figure 9 presents suitability assessments for cassava and Figure 10 for millet. Because of their very different climatic requirements, these two crops show contrasting patterns of suitability. Cassava can be grown in two broad zones, one in the west of the country and the other parallel to the coast, corresponding with areas of relatively higher rainfall. Millet suitability is highest in the central more arid portions, with relatively low rainfall and high mean temperatures. The same suitability analysis was run for a range of other crops, including maize, groundnut, cowpea, soybean, banana, tea, and coffee. The results were used to assign crops to the development domains with the highest potential.

Figure 9. Suitability for cassava, based on FAO EcoCrop data processed in DIVA.

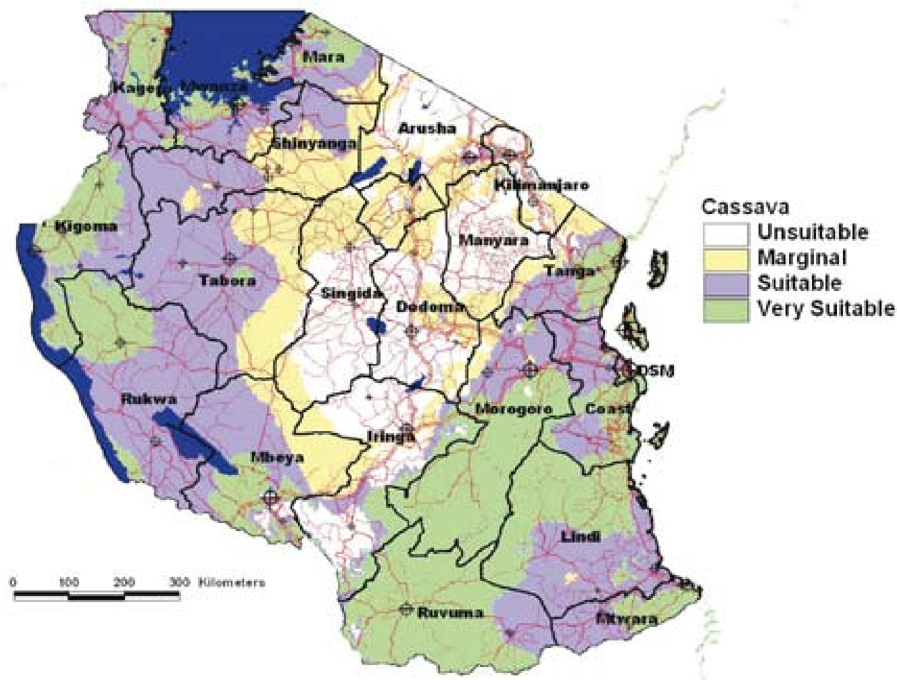
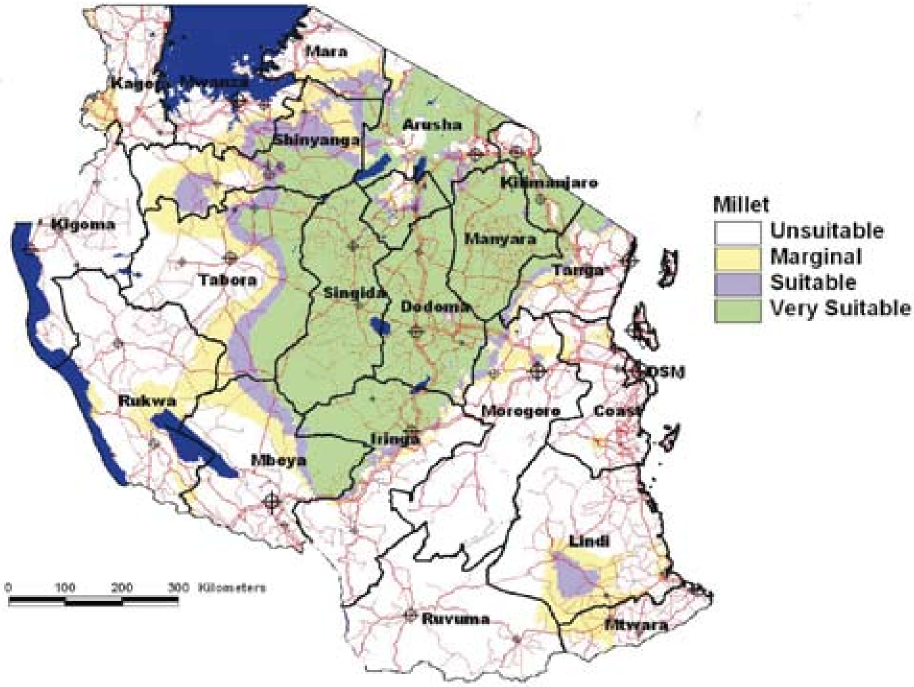


Figure 10. Suitability for millet, based on FAO EcoCrop data processed in DIVA.



Development recommendations

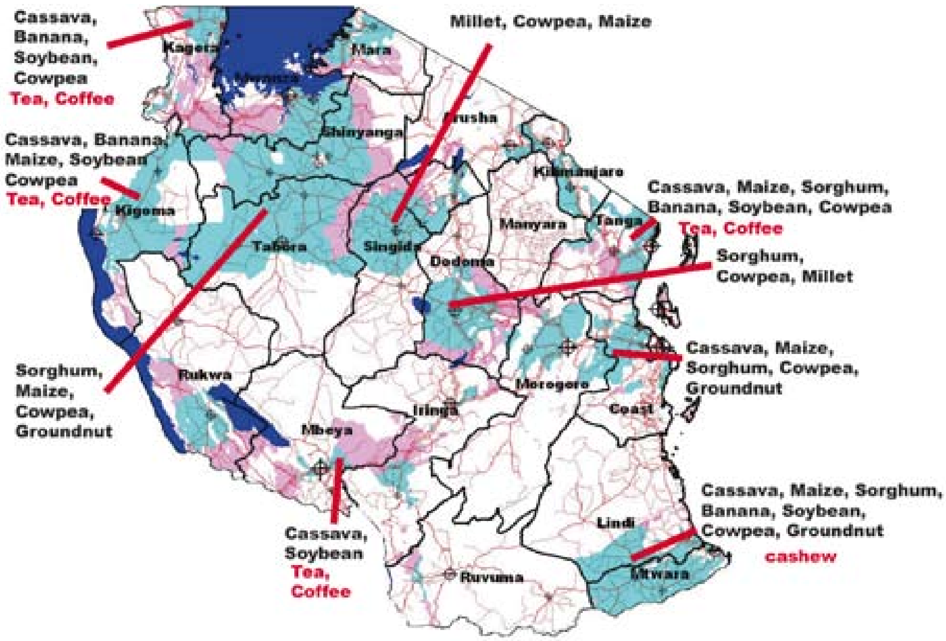
Crop suitability maps can be combined with development domain to suggest which crops it would be best to promote in each area. In many cases, these crops are already grown, but yields are below optimum levels because of disease, poor soil fertility, and possibly also poor agronomic practices. Introduction of new varieties tolerant to diseases, such as cassava resistant to CMD, can improve yields and food security, while increasing crop diversity in areas where traditional crops are liable to failure in drought years. For example, cassava in predominantly maize-growing areas can also improve food security.

The recommendations of this study are shown (Fig. 11) against a background of the market-orientated development domains.

Conclusions

This study has demonstrated how GIS techniques, combined with an assessment of the biophysical suitability of individual crops, can target agricultural development assistance to the areas of a country where this can have greatest impact. Introduction of new crops and improved varieties in favorable agricultural zones within reach of local markets is a cost–effective approach with the greatest possibility of improving the

Figure 11. Recommended crops in development domains.



food security and livelihoods of smallholder farmers in the medium term. This process can be improved and refined as more detailed information becomes available on the biophysical envelopes for specific crop varieties, bred for tolerance to specific conditions. A primary requirement is the availability of reliable and detailed digital soil maps, since soil suitability is a vital part of the predictive process.

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