Research Priority Assessment for the CIP 2005-2015 Strategic Plan:

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Priority
Assessment

Projecting Impacts on Poverty, Employment, Health and Environment

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CENTRO INTERNACIONAL DE LA PAPA
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2007

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Impact Enhancement Division
International Potato Center
Lima, Peru

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EXECUTIVE SUMMARY

Since its inception, CIP has periodically undertaken reassessments of its research program to keep its agenda on track. In 2005, all of CIP research staff participated in another priority assessment for potato and sweetpotato research at the Center. This assessment was one component of CIP's strategic planning exercise that took place at this time.

Methodologically, the research priority assessment included several innovative features:

- Evaluations of research outcomes that addressed major constraints were led by leading scientists in the relevant disciplines, while assessments of research value was based on formal socio-economic analysis;
- The assessment considered likely research contributions to several dimensions of poverty reduction, including income and employment generation, human health improvement, and environmental sustainability;
- Models were developed to assess impacts of research designed to add value to the market chain as well as increase the supply of food staples;
- Explicit attention was given to national capacities for potato and sweetpotato extension and ways of reducing constraints to information and technology dissemination;
- Leading potato and sweetpotato specialists from national agricultural research systems (NARS) in developing countries were consulted on their priorities for commodity improvement as a "check" on CIP's internal assessment.

Below, we report implications of the results of the research priority assessment for five strategic issues facing the Center:

1. Does CIP's research agenda offer significant opportunities to contribute to the Millennium Development Goals?

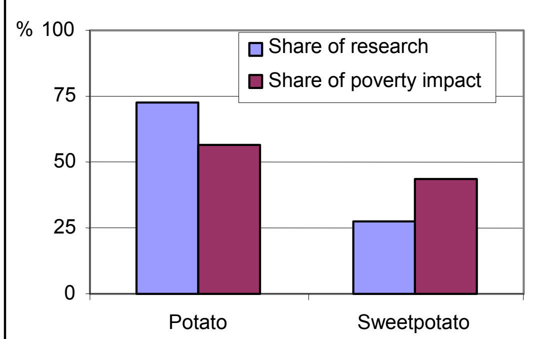
Assuming existing levels of research and extension investment are maintained, CIP scientists anticipate that the Center's potato and sweetpotato research will deliver significant economic, employment, health and other benefits over the coming decades (Table 1). Given the importance of these crops for poor, rural families, a large share of the anticipated benefits will go directly to poverty reduction.

Table 1. Anticipated impacts of CIP potato & sweetpotato research by 2020	
Adoption area ('000 ha)	3,753
Aggregate economic benefits (mil $/year)	1,247
Benefits to rural to poor (mil. $/year)	986
Number of persons out of poverty ('000)	5,620
Rural employment impact ('000 jobs/year)	275
Human health impact (DALY saved/year)	21,048

2. Is there proper balance in CIP's commodity research programs?

Historically CIP has sought to maintain about a 60-40 balance between its potato and sweetpotato research programs. In recent years the balance has shifted to about 72-25 in favor of potato. However, sweetpotato research has almost as much potential as potato to alleviate poverty in developing countries in CIP's existing program (Fig. 1). CIP could enhance its impact on poverty by restoring a more equal balance between its commodity programs, i.e., by putting more resources into sweetpotato.

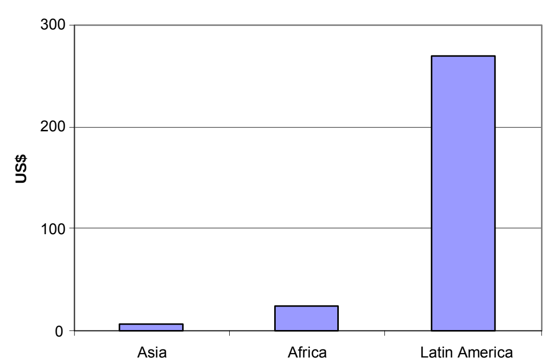
Fig. 1. Balance of CIP's commodity research



3. Is there proper balance in the allocation of CIP research to region of likely impact?

Although based in Peru, CIP has historically maintained a strong presence in Africa and Asia by outposting a sizeable portion of its research staff in these regions. However, CIP's research program is increasingly concentrated on the Andes countries. Latin America is now the target area for more than 40% of CIP's research, although accounts for only 4% of potential impact on poverty reduction. CIP could enhance its impact by shifting more resources to addressing research needs in Asia and Africa (Fig. 2).

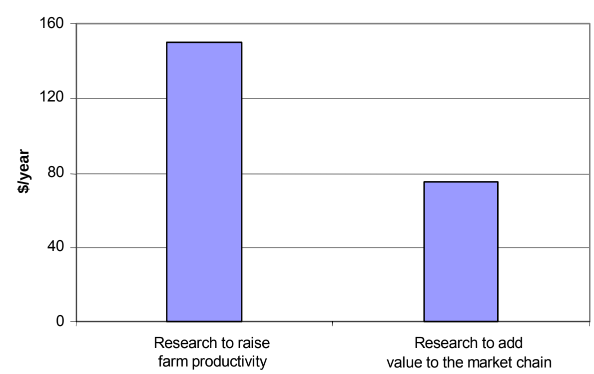
Fig. 2. CIP research expenditure required to remove one person from poverty



4. Does research designed to add value to the market chain offer greater potential for reducing poverty than research to increase the supply of food staples?

Some stakeholders have questioned the continued relevance of the CGIAR's focus on increasing productivity of staple food crops for addressing poverty. CIP has a sizeable share of its commodity research program in enhancing value-addition to the market chain of potato and sweetpotato. The technology assessments did find larger benefits of value-adding research per hectare of adoption, but far less potential for dissemination. Overall, research to raise farm productivity of potato and sweetpotato were judged to have greater returns to poverty reduction than research to add value to the market chain (Fig. 3).

Fig. 3 Economic benefits to rural poor per $1 of CIP research once technology is fully adopted



5. Are CIP and NARS potato and sweetpotato research priorities in congruence?

For potato, there is strong congruence between the priority needs identified by NARS scientists and the technologies CIP identified as having greatest potential for poverty reduction. These include

- control of late blight disease
- improved supply of disease-free and quality seed
- control of viruses, and
- varieties suitable for processing.

For sweetpotato, responses from NARS scientists revealed different sets of priorities from the two main global production centers of this crop, China and Sub-Saharan Africa. Chinese scientists placed priority on developing new varieties and technologies to support industrial processing and animal feed, while African scientists placed high priority on virus resistant varieties, control of the sweetpotato weevil, varieties high in beta carotene, improving ware storage, and developing new markets for the crop. However, both regions gave highest priority to improving the supply of disease-free planting material, which CIP also identified as having large economic and poverty impacts. There were a number of other priority needs expressed for sweetpotato by NARS scientists that are not presently on CIP's agenda.

Research Priority Assessment for the CIP 2005-2015 Strategic Plan: Projecting Impacts on Poverty, Employment, Health and Environment

I. INTRODUCTION

It has been ten years since CIP undertook a systematic priority assessment of its research program. At that time (1996), Tom Walker and Maria Collion led CIP through an exercise that combined scientists' views on potential for improving technology through research with an economic assessment of the benefits that could arise from those improvements. In an evaluation of that exercise by participants, the great majority found it useful and informative in establishing the lines of research inquiry that held the greatest promise for realizing CIP's goals of food security and poverty reduction in developing countries.

Since then the world, and CIP, have changed. For CIP, one event was the refocusing of its program on the Millennium Development Goals (CIP, 2004). One way this has been articulated in CIP's research program is through greater emphasis on agriculture-health linkages, such as crop breeding for biofortification. Another influence is the on-going CGIAR renewal, some indications of which are an increased emphasis on regional coordination of research and the recent revision of the CGIAR system priorities. Globally, changes are occurring in the way food and agricultural markets operate, in the incidence and nature of poverty, and in the capacities for employing new biological and information technologies for agriculture. All of these factors intimate that a renewed evaluation of CIP research strategy and priorities is due.

This paper describes the approach and presents the results of CIP's research priority assessment carried out in 2005. The methodology provides for evaluating potential impacts of CIP research on not only the rural economy, but also specifically on poverty reduction, rural employment, human health and the environment. The results of this analysis should enable the Center to enhance its contributions to the Millennium Development Goals. The analysis aims to help guide the allocation of CIP's resources among research themes and by global region, and also to clarify the requirements needed to move CIP along the path from research outputs to impact.

The paper is organized as follows: the next section describes two different kinds of knowledge required for determining priorities for research: the assessment of opportunities for advancing science and the social and economic valuation of research outcomes. Section III then describes the process and information requirements and sources used to construct these two kinds of assessments (details of the models used to quantify socio-economic valuation of research outcomes are described in Annex 3). Section IV presents the results of the analysis. In section V, we compare the results of CIP's internal assessment with opinions of NARS scientists on priority research needs for potato and sweetpotato in developing countries. Section VI presents some key conclusions and implications. Some additional detail on the priority assessment exercise is contained in the annexes.

II. ELEMENTS OF RESEARCH PRIORITY ASSESSMENT

In his seminal book on *Agricultural Research Policy*, Professor Vernon W. Ruttan (1982) identified two essential questions that need to be addressed in order to allocate research resources efficiently:

1. *What are the possibilities of advancing knowledge or technology if resources are allocated to a particular commodity, problem or discipline?, and*
2. *What will be the value to society of the new knowledge or the new technology if the research effort is successful? (Ruttan, 1982, p. 263).*

Ruttan argued that answers to the first question can only be answered with any degree of authority by scientists who are on the leading edge of the research problem being considered, and that answers to the second question require formal socio-economic analysis. The intuitive insights of research managers and scientists are no more reliable in answering questions of the societal value of research than the intuitive insights of research planners are in evaluating scientific or technical potential. Thus, research priority assessment is best addressed through a multi-disciplinary approach.

The process we used to assess research priorities for CIP is centered on finding answers to the questions posed by Professor Ruttan. Through consultation with CIP scientists and others, we developed quantitative and qualitative information of potential outcomes of research on specific productivity constraints facing potato and sweetpotato in developing countries. We combine this information with socio-economic data and models to assess potential impacts of these research outcomes on poverty, employment, human health and the environment. Naturally, the quality of the results is conditional on the quality of the information that goes into the exercise. But even for cases where our knowledge of the required data is limited, the exercise is useful since it forces us to make our assumptions about these parameters explicit. It also reveals where our ignorance is most acute in order to direct future data and information collection to improve the accuracy of the results. The exercise also suggests where we should focus our attention for field studies on impact evaluations. If "high impact" projects identified by the priority setting exercise do not appear to be producing actual impact within the next few years, then these projects should be priority candidates for reassessment.[1]

In addition to identifying technology opportunities and impact indicators, the priority setting process recognizes the institutional setting in which CIP operates. CIP borrows from and contributes to a global pool of knowledge, and our research organization reflects this 'innovation systems' view through our organizational structure. For example, historically CIP invested relatively heavily in building local research capacity by posting a sizeable share of its research staff regionally. Further, CIP maintains a number of 'partnership projects' with regional or global mandates that bring together diverse partners for the common purpose of improving agricultural productivity to reduce poverty. Our experience with these partnerships has revealed that local capacities for technology adaptation and dissemination are highly variable among the countries and regions where we work. In some countries, agricultural research and extension systems, rural infrastructure, and general governance are relatively strong; in other countries they may be practically non-existent. The research priority setting and impact analysis gave special attention to the prospects of and requirements for achieving successful dissemination of new technologies in this diverse global setting. What we have essentially done is to redefine Professor Ruttan's second question into the following:

> *2a. Given the research effort is successful, what is the likely level of adoption that would occur over a given time period? And, what resources, partnerships and training/extension strategies would be required to increase adoption among poor and small-scale farmers?*
>
> *2b. Given farmers adopt the technology, what will be the likely benefits to society, especially in terms of poverty reduction, rural employment, human health, and environmental quality?*

Discussion on how to build coalitions and platforms for linking scientific research to technology development and dissemination, what CIP calls "research for development," was a major component of CIP strategic planning (see CIP, 2006). It is a critical element of the way CIP intends to contribute to the Millennium Development Goals (MDG). In addition to this convening role of

[1] This was one important outcome of CIP's 1996 priority setting exercise. For example, in that assessment research on TPS, ware potato storage, and post-harvest processing of sweetpotato suggested high returns. Subsequently, when adoption did not appear to be as widespread as anticipated by the 1996 assessment, these technologies were reevaluated through field studies. With this new information, expectations on their likely impacts were significantly modified (see Chilver et al., 1999, Fuglie et al., 2000, and Walker and Fuglie, 2006, for reevaluations of TPS, ware potato storage, and sweetpotato post-harvest utilization, respectively).

the Center, CIP is also mandated to be a producer of "global public goods" – new information and technologies that address major, specific constraints to productivity faced by farmers in many parts of the developing world. The priority assessment exercise described in this paper is a planning tool for the Center to maximize the impact of its research on global public goods. It is also directly linked with CIP's "research for development" agenda through (i) the quantitative assessments of adoption potential and (ii) the multi-dimensional analysis of impact including not only income poverty, but also rural employment, human health, and environmental quality.

III. INFORMATION REQUIREMENTS FOR PRIORITY ASSESSMENT

The section describes the specific kinds of information gathered in CIP's priority assessment to answer the questions 1, 2a, and 2b posed above. The approach borrowed heavily from the constraints analysis done by Walker and Collion (1997) for CIP's 1998-2000 Medium Term Plan. Some of the main differences of the present exercise and the previous constraints analysis are (i) greater emphasis on assessing regional and country-specific needs and constraints to technology access and adoption, (ii) linking potential benefits more explicitly to the poverty indicators described by the Millennium Development Goals, and (iii) a somewhat different geographic coverage. In 2004, CIP redefined its set of priority countries and regions for targeting its research based on an analysis which combined the degree of importance of potato and sweetpotato for the local population with the extent of poverty in that country or region (CIP, 2004). Figure 1 shows the region of interest of the present priority assessment and the constraints analysis conducted a decade ago. The present exercise places less importance on Latin America and drops North Africa and the Middle East, while adding some countries in Sub-Saharan Africa, Central Asia and the Caucasus, and several more provinces of China. See Annex 2 for a complete list of countries and regions included in the assessments for potato and sweetpotato and their agro-ecological classification.

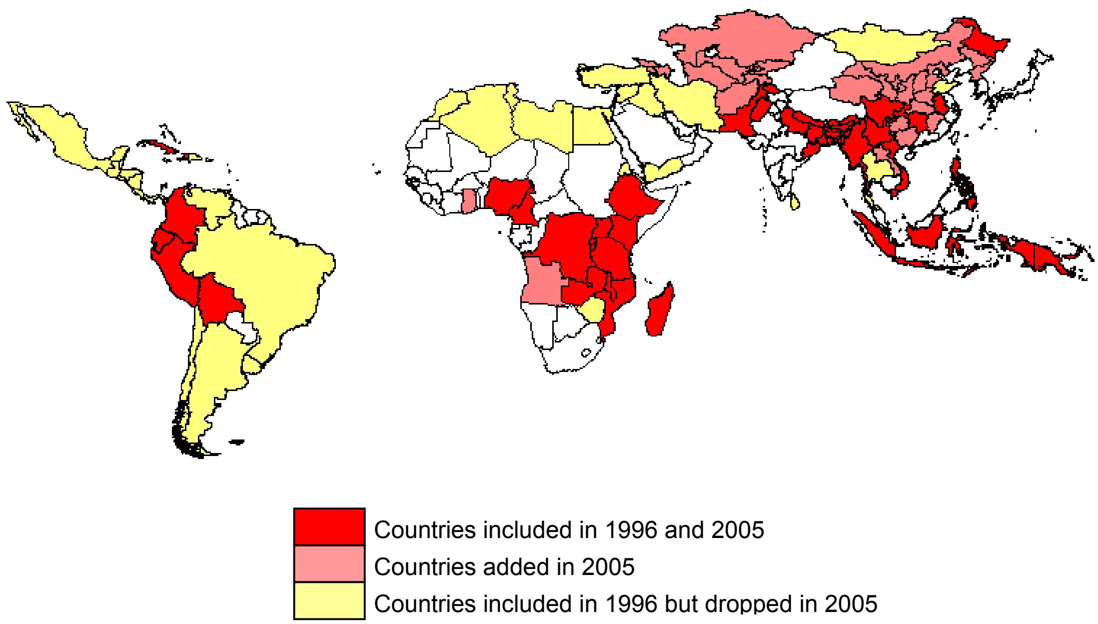


Figure 1. Geographic coverage of CIP's 1996 and 2005 research priority assessment exercises

3.1. Evaluating technology opportunity

Question (1.) posed above is about ***technology opportunity.*** In many ways technology opportunity assessment is similar to evaluating sources of the ***yield*** or ***productivity gap,*** or the difference between actual and potential crop productivity. To develop a list of significant constraints to productivity, we began by asking CIP scientists with experience working in various regions to rank the most important biotic, abiotic and other factors limiting crop productivity for each country in their region. We also examined the entire research portfolio of CIP as described by the research outputs of the 2006-2008 Medium Term Plan. And third, we sent a questionnaire to potato and sweetpotato scientists in developing countries to solicit their views on the most important crop productivity constraints in their countries. From these sources we developed a list of the potential research endeavors of international importance. These included not only constraints to yield, but also opportunities for reducing production cost and adding value to the commodities through breeding for quality traits and post-harvest utilization technologies.

Of more than 30 constraints identified through these sources, we selected 15 for formal evaluation in the priority assessment exercise and another three were identified for future evaluation once more information on technology opportunity in value could be collected (see Annex 1). Other topics were considered to of primarily local rather than global importance. For each of the selected technologies, we formed a team of scientists knowledgeable on the issue and asked them to answer a series of questions about prospects for advancing technology to address the constraint given a certain level of sustained research over a period of time. Thus, the principal source of information for assessing ***technology opportunity*** was the informed opinions of scientists who are closely involved in research on the particular productivity constraint. From their knowledge of the scientific literature, their own experiments and visits to farmers' homes and fields, they are relatively well informed on the potential for applied agricultural research to advance technological solutions to closing the productivity gap.

Returning to the first question posed by Professor Ruttan, below we describe the process we used to answer it:

Question 1. What are the possibilities of advancing knowledge or technology if resources are allocated to a particular crop productivity constraint?

In our exercise we asked teams of scientists working with a particular agro-ecosystem to estimate the likely advances in technology assuming that current level of investment in applied research is sustained over the next five years (2006 and 2010). Constraints to technology dissemination were ignored at this point in the exercise. Rather, scientists were asked to consider what technologies they expected to be at the on-farm testing stage by the end of the five-year period and how these technologies would compare to current farm productivity. The teams were asked to provide consensus estimates of the following eight parameters for each agro-ecosystem of interest to CIP:

Given a current level of research effort by CIP on **constraint a_i**, what is the most likely outcome of this research in 5 years time in each **agro-ecosystem b_j** on:

- Q1. i. Crop yield (expressed as a percent increase over current average yield)
- Q1. ii. Crop quality (expressed as a percent increase in current average price)[2]
- Q1. iii. Crop production cost (expressed as a change in inputs costs as $ per ha)
- Q1. iv. Human health (scored as -1, 0, +1 or +2)[3]
- Q1. v. Environmental quality (scored as -1, 0, +1, or +2)[3]

We then asked:

- Q1. vi. What is the total area affected by this constraint in this agro-ecosystem (expressed as percent of total crop area)
- Q1. vii. What is the likelihood of research success? (expressed as a probability)
- Q1. viii. Is there an alternative source of supply for this technology, such as a developed country NARS or the private sector? (Yes or No)

[2] Changes in quality refer to increasing the grade of potato or sweetpotato. Alternatively, prices can be affected by changes in market supply and demand conditions. The latter type of price effects is not considered here but rather is addressed using formal economic analysis (see below).

[3] A score of -1 indicates a negative impact of the technology on this indicator, 0 indicates a neutral or no effect, and a score of +1 or +2 indicates a positive or very positive effect.

One final assessment examined employment effects of the new technologies. Adoption of new technologies could affect employment in both crop production and post-harvest handling and utilization. Since none of the crop production technologies we assessed involved developing labor-saving equipment (all dealt with raising crop yield or quality or reducing chemical input use), the labor effects on farm employment would in all likelihood be positive and correlated with the increase in production. Assessments of employment effects drew heavily on evidence of labor utilization in crop production from CIP's historical set of farm surveys. Technologies on post-harvest utilization were also assessed for their likely employment effects in rural areas, but non-rural employment effects (such as urban processing and retailing) were not considered.

There were five agro-ecosystems listed for potato and four agro-ecosystems for sweetpotato. For small countries, each country was assigned to one agro-ecosystem. In the case of large countries (China, India, and Indonesia), individual provinces were assigned to agro-ecosystems. In some cases, estimates were refined for particular countries or provinces within ecosystems when there was location-specific information to justify it. For example, in countries where new technology has recently been adopted, prospects for further improving productivity may be somewhat reduced compared with other countries in that ecosystem. The assessments involved providing a large number of parameters. The task was made easier by referring to the results of the 1996 priority-setting exercise which evaluated many of the same issues (Walker and Collion, 1997). Thus, teams reviewed and updated the earlier analysis and added information for new issues not previously considered.

Once the teams had arrived at their initial estimates (done over several weeks through email and other communications), there were two occasions for further review and revision. Initial estimates were discussed and challenged by CIP science managers during a two-day workshop in August, and a second round of estimates were again reviewed in November during the CIP annual meeting in which all research staff participated.

An example of the results of this exercise is given below for the case of research to address late blight disease of potato (through crop breeding and pesticide management) in the tropical highlands of Peru:

> About 85 percent of the potato growing area of Peru is estimated to be regularly affected by late blight disease. CIP's current research on potato late blight resistance and management is likely to result in technology that will

increase average yield by 40 percent[4] and reduce fungicide applications from an average of 10 sprays/season to 5 sprays/season (or reduce costs by $250/ha). The technology is likely to have positive impacts on human health (+1) and environmental quality (+1) through the reduction in fungicide use. The probability of success in developing this technology is estimated to be 75 percent. There are no other sources of supply for this technology adapted to Peruvian highland conditions.

3.2. EVALUATING CONSTRAINTS TO DISSEMINATION

Some of the major criticisms of the high-yielding varieties of wheat and rice that characterized the "Green Revolution" centered on unequal dissemination of the new varieties. One concern was that the technology favored irrigated and more fertile cropland; another concern was that adoption favored larger, richer farmers.[5] Addressing these concerns involves not only issues of technology design but also local capacity and institutions for technology dissemination. As part of its strategic planning exercise, CIP drew upon the knowledge and experience of its regionally-based staff to discuss ways of strengthening efforts to adapt and extend new technology to poor farmers in CIP's target countries. Enabling small-scale and poor farmers to access new technology is dependent not only on the capacity of the local agricultural innovation system, but also the overall policy environment, rural infrastructure, and farmers' human capital. Discussions on the constraints to technology dissemination, and what efforts CIP could make to help overcome them, were conducted in a series of regional meetings of CIP scientists with extensive experience working in these countries.[6] These discussions centered on ways to strengthen local partnerships with both government and non-government organizations for technology development and dissemination to reach poor farmers. Specifically, CIP regional scientists were asked to answer the following questions:

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[4] In cases where a new technology involved adopting a new variety, the estimated yield increase includes the reduction in losses due to overcoming the constraint as well as a gain due to general genetic improvement. We did not isolate these sources of productivity growth since an improved variety "packages" them inseparably together.

[5] For scale-neutral technologies that characterize new crop varieties and new crop management methods, differences in technology adoption *between* regions with different environmental endowments is more important than differences in adoption *within* regions. Field research on adoption of high-yielding cereal varieties did find that the first generation of these varieties favored irrigated areas, although subsequently modern varieties of cereals and other crops were adapted to more marginal and diverse environments. However, research also found that small-size farms adopted the new varieties at nearly the same rate as larger farms and got similar levels of productivity improvement. Furthermore, there is little or no causal relationship between adoption of modern varieties and mechanization of crop production. For reviews of these issues and the empirical record, see Ruttan (1977) and Hazell and Haddad (2001). Since the technologies under evaluation in CIP's priority assessment exercise all appeared to be scale-neutral, we placed emphasis on evaluating differences in adoption rates *between* areas, and put less emphasis on evaluating differences in adoption between farms *within* areas.

[6] Regional meetings were held during August-November 2005 in Quito, Nairobi, Delhi and Harbin (China) to assess adoption potential and to discuss ways to intensify dissemination efforts in countries of the Andes region, Sub-Saharan Africa, South and Central Asia, and East and Southeast Asia, respectively. See CIP (2006) for a report of these discussions.

Question 2a. Given the research effort is successful, what is the likely level of adoption that would occur over 10 years? What would be required of an intensified dissemination strategy to increase adoption among poor and small-scale farmers?

The teams provided estimates of the "adoption ceiling", or the proportion of the crop area affected by a particular constraint on which adoption would likely take place within 10 years after the technology was released to farmers. The teams provided two estimates of the adoption ceiling: one under the existing conditions for technology dissemination (a "status quo" adoption scenario) and one if new local partnerships and new funding proposals were successfully developed (an "enhanced" adoption scenario). In virtually all cases the estimates of the adoption ceilings were significantly below the total crop area judged to be affected by the particular constraint (i.e., the potential area of impact). These limits on adoption reflected our assessments of the institutional capacity for technology dissemination.

For an example of the dissemination assessment, we take the case of virus-free planting material for sweetpotato in Uganda:

> From Question 1, diseased and poor quality planting material was thought to reduce sweetpotato yield on 100 percent of the sweetpotato crop area of the country. The technology assessment team expected research on methods and distribution systems for virus-free planting material to increase average yield by 26 percent (or about 2 tons/ha) when adopted by farmers. From the analysis of dissemination constraints, the regional team estimated that if the technology was successfully developed, improved planting material could be disseminated to 20 percent of the country's crop area (117,000 hectares) within 10 years. If new sources of funding became available and new partnerships could be developed (especially with NGO and local community organizations), the adoption rate could be increased to 60 percent over the same time period.

Separating out the evaluations of technology opportunity (made by scientists most familiar with the technologies) and adoption potential (made by research staff working in the regions) has an additional advantage in that it can serve to reduce positive bias from scientists' evaluations of the potential of their "own" research. But estimates of adoption potential probably remain the weakest part of the priority-setting exercise. Further, our understanding of how adoption of potato and sweetpotato technologies might be influenced by community and household endowments of human and physical capital and other factors is constrained by a lack of empirical research by CIP on this topic. More case studies are needed to improve our understanding of the dynamics of technology adoption, especially the extent to which poor farm households are able adopt new potato and sweetpotato technologies. We assume scale neutrality in adoption, but we recognize that the validity of this assumption for potato and sweetpotato technologies warrants further investigation.

3.3. EVALUATING IMPACTS OF ADOPTION

The final step in the process is to link the assessments of technology opportunity and dissemination to the potential impacts, in other words, to provide an answer to

Question 2b. Given farmers adopt the technology, what will be the likely benefits to society in terms of poverty reduction, employment generation, human health, and environmental quality?

Linking improvements in farm productivity to quantifiable indicators of impact is probably the most challenging part of a research priority setting exercise. Ruttan (1982) describes qualitative scoring models and quantitative benefit-cost analysis as the two main approaches for valuing outcomes from research. The principle behind a scoring model is to qualitatively assess each research project as to whether it contributes to a number of objectives, and then add up the scores by assigning a weight to each objective. The scores are then used to rank the projects in order of priority. Walker (2000) described such a scoring method for assessing CIP's potato and sweetpotato research but did not address the critical question of how to weight the various criteria for summing up. Ruttan (1982) cautions that the use scoring models for research priority setting has been limited by the difficulty of establishing an independent and objective set of weights for adding up the scores, a problem magnified when setting priorities at a macro level.[7]

Quantitative benefit-cost analysis provides an objective standard for ranking research projects but tends to be limited to a single objective such as aggregate economic impact. Our approach is to develop indicators of potential impact on a number of objectives and where possible sum up these impacts to produce an estimate of "aggregate" impact on poverty. For example, improved sweetpotato varieties that have higher yield and higher beta carotene content can impact both family income and health. We estimate the income effects by assigning market values to the yield improvement and health effects by measuring the number of DALY saved through reducing Vitamin A deficiency. By assigning an economic value to the number of DALY saved and adding

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[7] We also encountered difficulties in the qualitative scoring component of our technology assessment exercise. Scientists were asked to assign scores to whether a new technology would have positive or negative consequences for human health and environmental quality. Nearly all of the technologies under evaluation were scored as having positive impacts on these objectives. In a separate questionnaire, scientists were then asked to assign weights to the health and environmental scores. Only two questionnaires were returned out of more than 50 distributed. Ruttan (1982) notes that such high drop-out rates in the use of scoring models for setting research priorities is a common occurrence, especially when used at a very aggregate level. Thus, the qualitative scoring of impacts added very little information of value to the priority setting exercise.

this to the direct income effects of higher yield, we can combine these impact indicators on the benefit-side of this analysis.

A starting point for a quantitative assessment of research impacts is the approach used by Walker and Collion (1997) during the last CIP priority setting exercise. Their approach required no further information from what is described above except estimates of crop production, area and price for each country or province. They estimated total economic benefits after reaching an adoption ceiling from:

Eq 1

Total Expected Benefits = Benefits / hectare * Hectares of adoption * Likelihood of success

To get an annual stream of total benefits, they assumed that technology adoption occurs along a logistic diffusion curve to reach the adoption ceiling. Then, together with estimates of the research cost during the initial years of the project, they derived the Net Present Value (NPV) and Internal Rate of Return (IRR) for each project. To determine impact on poverty, they weighted total benefits by the poverty head count index of each country were adoption was expected to occur. An advantage of this approach is its simplicity: it requires very little socio-economic information and is intuitively clear to a non-economist, except perhaps for a need to explain time discounting and how to interpret NPV and IRR.

A limitation of this approach is that it ignores market forces. New technologies that increase supply or demand for commodities may have significant effects on market prices, which in turn influences who benefits from the new technology. For example, technologies that significantly increase commodity supply will likely put downward pressure on price. This will reduce the income benefits to farmers as a group as well as cause income losses among non-adopters (who face lower prices but no commiserate improvement in productivity) although consumers gain from increased consumption at lower prices. Since poverty is concentrated in rural areas, market price effects may have a significant influence on a new technology's poverty impact. These market price effects are likely to be of particular importance for commodities that are traded locally where prices are determined by local or regional supply and demand conditions. However, if a substantial portion of production is consumed by the farm household, then these households stand to gain a larger share of the economic benefits of new technology regardless of changes in market prices.

The potential negative influence of increased supply from new technology on market prices and farm income has long been recognized by the potato and sweetpotato research communities. It has been of particular concern where these crops are important food staples of the poor but where per capita consumption declines (or grows only slowly) with increases in per capita income, such as with sweetpotato in much of Asia and Africa and potato in the Andes region. These concerns have been given expression by the research community through interest on developing technologies to create new uses and markets for these crops, such as breeding varieties suitable for making into processed products and ways of improving efficiency in animal feed utilization. Of the nine potato technologies assessed in the priority-setting exercise, two concerned improving utilization and demand. For sweetpotato, two out of six technologies assessed focused on expanding post-harvest utilization.

Economic models to account for price effects of changes in agricultural technology are described in Alston, Norton and Pardey (1995). In the terminology of economic welfare analysis, changes in "total economic surplus" measure the value of increased output at lower cost to both producers and consumers that results when new technology is adopted. Models of market supply and demand and used to allocate changes into total surplus to producers and consumers of the commodity (i.e., into "producer surplus" and "consumer surplus," respectively). To implement this approach requires information on how market supply and demand respond to changes in price and how the commodity is used. The basic model can be adapted to evaluate technologies that improve post-harvest utilization or expand market demand for a commodity (Fuglie, 1995).

The economic surplus approach assumes that market prices fully reflect the societal value of crop production at the margin.[8] Not reflected in economic surplus are the effects of market externalities (i.e., good or bad indirect effects that are not priced). These possibly include costs of natural resource degradation due to an intensification of agricultural production (or, conversely, the benefit from reducing this degradation), as well as benefits of society's expressed preference for eliminating poverty and other forms of human depravation. Economic surplus may also not fully capture the value of changes to human health from new agricultural technology, such as benefits from improved nutrition. Although in principle, if individuals value their health they would be willing to pay more for more nutritious food (and in many cases they do), market prices will only reflect the full value of the health benefits if consumers are fully aware of the health consequences of their food choices and have alternative choices available to them. This is unlikely to be true for many forms nutritional deficiencies, especially in developing countries. For

[8] The economic interpretation of market prices is that they reflect the value society places on the last unit of the good that is produced. From the standpoint of the producer, price reflects the cost of resources used to produce that last unit of that good. From the standpoint of the consumer, price reflects the preference for the consumption of that last unit over other goods. However, prices do not reflect the societal value of the entire quantity of a good that is produced and consumed. This value is given by the economic concepts of consumer surplus and producer surplus, which when summed give total economic surplus. Thus, prices reflect relative scarcity rather than relative aggregate value of a good to society.

example, although Vitamin A deficiency is widespread among the very poor (especially among children), this condition may not exhibit obvious signs except in its most extreme forms where it can result in corneal scarring and blindness. However, even less extreme Vitamin A deficiency depresses the immune system and may lead to increased mortality and morbidity from other diseases. Since breeding well-adapted sweetpotato varieties rich in beta carotene (a precursor to Vitamin A) was identified as an important technological opportunity for poverty alleviation in our assessment exercise, we developed a separate approach to quantify health impacts of reducing Vitamin A deficiency among target populations if this technology is successfully developed and adopted. These benefits are derived by estimating the number of Disability-Adjusted Life Years (DALY) saved through a nutrition intervention (adoption of biofortified sweetpotato). Weighting DALY by a monetary "value of life" allows potential health benefits to be included with changes in economic surplus in a common impact metric for determining research priorities.

We develop two indicators of the poverty impact of new technology. The first indicator is the economic surplus, or net income benefits that are likely to accrue to poor households in rural areas. This welfare indicator only includes benefits to producers and excludes consumer benefits from lower market prices, since buyers of potato and sweetpotato are generally (with some important exceptions) non-rural and non-poor. [9] The producer benefits are then weighted by the World Bank's poverty headcount index for per capita income below one international dollar per day to get an estimate of the benefits to poor households.

Our second indicator of poverty impact is an estimate of the net number of rural people who are likely to be lifted above the poverty line from technology dissemination. We count not only the gains achieved by technology adopters but also income losses of non-adopters who may face lower prices for their farm products. Using World Bank data on poverty head counts, poverty gaps, and some simplifying assumptions on income and farm size distribution, we estimate the number of adopters likely to be lifted out of poverty and the number of non-adopters who may be pushed below the poverty line through negative price effects of technological change.

Both indicators of poverty impact suffer from certain limitations but overall we think they are conservative. Assuming rich and poor farm households adopt the new technology at about the same rate could overstate the gains achieved by poor households but assuming that poverty

[9] In some countries, a large share of the marketed surplus of potato and sweetpotato production is purchased by food deficit farm households in rural areas. This is especially true for sweetpotato in Sub-Saharan Africa and to a lesser degree for potato in the Andes countries. In these two situations we do not exclude consumer benefits from lower food prices in estimating the share of total project benefits accruing to poor households, but we still weight total benefits by the poverty headcount index to derive an indicator of poverty impact.

rates of potato and sweetpotato farm families are similar to the national average poverty rate is likely to substantially underestimate poverty impacts since in most countries poverty rates by these families is higher than the national averages. One of CIP's *ex post* impact studies of sweetpotato technology adoption in China, for example, found that impact per farm was higher in poorer communities than in richer communities because poorer farm households had more cropland devoted to sweetpotato and had comparable adoption rates with the relatively well-off communities (Fuglie *et al.*, 1999).

Valuation of research outcomes requires formal socio-economic analysis and additional data. These specific models used for this analysis are described in detail in Annex 3. In Table 1, we describe additional data requirements and sources to implement these models.

Table 1. Socio-economic data requirements for quantitative research priority setting

Data requirements	Sources
Current estimates of potato and sweetpotato annual production, harvested area, yield and price	1. National average annual production, area and yield during 2001-2003 are from FAO (2005), but modified for some African countries where we have evidence that FAO data are in error: for Malawi FAO "potato" data refers to both potato and sweetpotato, but we were able to disaggregate these by crop using data from USAID's Famine Early Warning System (Jan Low, personal communication, 2006); for Mozambique, we use sweetpotato production data from the 2020 national agricultural survey (Government of Mozambique, 2002); for Ethiopia, we use estimates of potato production and area from PRAPACE; for Uganda and Tanzania we assume FAO sweetpotato area but an average yield of 8.0 tons/ha. For China, India and Indonesia we use provincial or state-level crop data from national statistical publications. 2. Following Walker and Collion (1997), we value current potato production at $200/ton and sweetpotato production at $125/ton for all countries included in the analysis.
Elasticities of supply and demand	Demand elasticities are drawn from a review of potato demand studies (Fuglie, 2006b). For market demand, demand elasticities range from 0.3 in countries where the crops are important food staples to 0.6 where they are primarily consumed as vegetables. The demand elasticity for home food consumption is assumed to be 0.0 and for on-farm use as animal feed 1.10. Very little information exists on potato or sweetpotato supply elasticities in developing countries, so we assume a value of 0.8 for all countries.
Crop commodity utilization	FAO (2005) Food Balance Sheets for 2001, except for cases where we have direct evidence on utilization from representative farm surveys
Poverty headcount and poverty gap at $1/capita/day in international dollars.	National data are from the World Bank (2005). Provincial estimates for China and from Xian and Sheng (2001) and state-level estimates for India are from Deaton and Dreze (2002).
Farm employment in crop production	These are drawn from CIP farm surveys from countries in Asia, Africa and Latin America. Based on these data we use the following days worked per hectare of potato production: 100 in SSA, 200 in LAC and CAC, 300 in ESEAP and South Asia. This results in an average of about 20 days/ton of production (ranging from 10 to 40 days/ton). For sweetpotato, we assume 75% of the per hectare potato labor values.
Average potato and sweetpotato area per farm and per poor household; average household size	These are estimated from CIP farm surveys from countries in Asia, Africa and Latin America.
Importance of marketed surplus to poor consumers	Potato is assumed to be a major staple of poor net buyers of the commodity in the Andes countries. Sweetpotato is assumed to be an important purchased staple of poor consumers in SSA countries. Note that these commodities figure as a staple food of poor producing households in a larger set of countries.
Data needed to measure health impact of reducing VAD	See Fuglie and Yanggen (2006) for a complete description of methods and data sources.

3.4. Assessing research and dissemination costs

The final piece of information required for a quantitative benefit-cost analysis is an estimate of the cost of research and extension to develop and disseminate new technology. Since this research and extension effort is done in collaboration with NARS, we include both CIP and national agricultural research systems (NARS) investments that are necessary to make the technology available to poor farmers.

For CIP's research expenditure per research project, we initially sought to extract from CIP's budget information current spending by research project, but since CIP underwent an internal reorganization in 2003 this kind of information is no longer available. Instead, we sent a survey to all CIP research staff at the MSc levels and above and asked them to allocate their time spent in 2005 (i) by research activity, and (ii) according to the region they expected their research to have impact. We then divided CIP's annual budget of around $20 million among all of these research areas in proportion to a weighted share of research staff time allocated to it. Staff time was weighted by degree and discipline to reflect differences in cost per scientist. Scientists' time was weighted as follows: 1 full-time Science-Year (SY) PhD in natural sciences received a weight of 1.00; 1 SY PhD in social sciences received a weight of 0.67; and 1 SY M.S. received a weight of 0.67 of the PhD weight in their respective discipline. The lower weight assigned to the social sciences reflects the lower average expenditures per scientist compared with natural sciences research (Fuglie, 2006a).

The second cost item is the complementary research investment by NARS. Although we have no direct evidence on expenditures on potato or sweetpotato research in developing countries, we infer this from a CIP survey of national potato programs in 1999. This survey collected information on the number of scientists in national systems working on potato research for 30 developing countries. Using those results and similarly weighting the number of PhD - and MSc -level scientists indicates that there were about 187 PhD-equivalent SY working in potato research in these countries. This compares to 50 SY at CIP itself working on potato in 2005. Based on this simple comparison, it would appear that for potato, CIP accounts for about 20 percent of potato research being conducted in developing countries. But the numbers are not directly comparable for several reasons. First, compared to CIP, NARS have a larger share of research staff at the BSC level which was not included in the counts of science-years. Second, expenditures per SY are likely to be much lower in NARS than CIP due to lower average staff costs. And finally, not all of the SY in NARS were working on the same research topics as CIP staff so the proportional allocations among topics is likely to be different. For our benefit-cost analysis we assume that the total NARS expenditures on the projects included in the assessment are roughly equivalent to

CIP's own investment (and higher in terms of SY). We do not have similar data for sweetpotato but make the same assumption regarding the complementary NARS investment in these research projects.

The final cost item is the cost of extending the technology to farmers. To help assess these costs we drew upon the lessons from CIP's case studies of ex-post impact assessment (see Walker and Fuglie, 2001, for a review of these impact studies). One lesson from these case studies is that dissemination systems for root and tuber crops in developing countries are generally weak. Most of CIP's impact success stories required significant public-sector subsidy for scaling up technology dissemination, usually in the form of a specially-funded donor project targeted to disseminate the particular technology in a country or region. The relatively weak extension systems for root and tuber crops are due to a number of factors, including lower priority on root and tuber crops vis-à-vis cereal grain crops, a lack capacity to multiply quality planting material of vegetatively-propagated crops, and lack of interest by the private sector. The seed constraint in vegetatively-propagated crops is especially critical: Virus disease and other degenerative factors build up over time in planting material and reduce its quality and yield. But since it is difficult to distinguish quality seed from bad by visual inspection, farmers are often unwilling to pay more for quality seed. Thus public and private seed companies cannot recover the higher costs of producing quality (disease-free) planting material. In high income countries this source of market failure in seed is overcome through the establishment of credible seed-certification schemes. But such schemes are difficult to establish in low-income countries with weak regulatory institutions (Fuglie *et al.*, 2006). Thus, in low-income countries successful dissemination of improved seed may require a large subsidy.

A second lesson from the case studies is that dissemination costs varied by type of technology (Table 2). Costs of extension and training per hectare of adoption were highest for knowledge-intensive technologies like integrated crop management which trained farmers using field schools (about $80/hectare of adoption area). Technologies in which the primary intervention was a new variety cost the least to disseminate (about $16/hectare), while the cost of disseminating technologies to improve clonal seed systems fell in between (about $50/hectare). These costs include the value of staff time and fixed assets in extension services devoted to farmer extension and training. For the benefit-cost analysis, we classified each technology as either variety-, seed-, or information-intensive, and applied average values from impact case studies of dissemination cost. The total extension cost was the cost per hectare times the eventual adoption ceiling (in hectares). The extension effort was assumed to last for 10 years once the technology was released to farmers regardless of the time assumed to reach the adoption ceiling. The annual extension cost during this period was simply the total cost divided by 10.

Table 2. Evidence on the costs of technology dissemination from CIP impact case studies

Case	Technology	Location	Research time (years)	Extension time (years)	Adoption ceiling (ha)	Extension cost ($/ha)
1	Potato variety (CIP-24)	China	6	9	40,000	14.15
2	Potato varieties (Cruza 147, etc.)	East Africa	3	12	55,000	15.00
3	Sweetpotato varieties	Peru	4	8	7,000	18.20
4	Potato clean seed	Tunisia	5	4	7,800	14.00
5	Sweetpotato clean seed	China	5	6	460,000	48.00
6	Potato TPS	Vietnam	4	5	3,500	87.00
7	Potato IPM (Andean weevil)	Peru	4	4	3,750	165.00
8	Potato IPM (tuber moth)	Tunisia	4	9	3,400	27.00
9	Sweetpotato IPM (weevil)	Dominican Rep.	2	6	3,000	46.00
10	Sweetpotato IPM (weevil)	Cuba	13	8	50,000	1.11 *
Average for Varieties			4.33	9.67		15.78
Average for Seed			4.67	5.00		49.67
Average for IPM			5.75	6.75		79.33

*The extension cost estimate for sweetpotato IPM in Cuba did not account for all costs and is excluded from the average.

3.5. Interpreting results and limitations of analysis

The priority assessment exercise generated quantitative estimates of the anticipated returns to investments in the various components of CIP's research portfolio. The methodology can also be used as a management tool to help evaluate new research endeavors for their likely impacts. The principal value of the exercise is that it forces scientists and science managers to make explicit their assumptions about technology opportunity, potential impact, and constraints to dissemination, and puts these assumptions into a common framework.

The internal rate of return, net present value, and benefit-cost ratio are three commonly used summary measures to compare and rank investment alternatives. All of these measures involve ***time discounting*** of cost and benefits: they favor projects that are likely to deliver benefits in the near term compared with projects that won't yield benefits until farther into the future. The internal rate of return, measured as a percent, is probably the most widely used measure and is straightforward to interpret. As an illustration, a one-time investment of $100 that generated a stream of benefits of $10/year each year in the future would yield an internal rate of return of 10%. The internal rate of return, however, does not give any indication of the size of the research project: a small investment that yields a small stream of benefits could have the same rate of return as a larger investment that yields a large benefit stream. The net present value provides an indicator of the size of the net benefits from a project. The benefit-cost ratio indicates the total dollars of benefits per dollar of investment: a benefit-cost ratio of 1.5 means that every dollar spent on research will likely result in an economic benefit of $1.50 (again, with future benefits discounted). Generally, the benefit-cost ratio is not a reliable tool for comparing among alternative investments, although it is useful for conveying information on the value of a project to potential donors. A project that yields a positive net present value or a benefit-cost ratio greater than 1.0 would generally indicate a worthwhile investment.

For the priority assessment exercise, the main use of these measures is to compare and rank alternative research investments. Research endeavors that are projected to yield higher returns are better candidates for enhancing CIP's impact than those that yield relatively low returns. But since research is usually subject to diminishing returns, this does not imply that endeavors that give relatively low returns should be completely discontinued. Rather, the comparisons indicate the best use of the ***marginal dollar*** of research resources given our present information and knowledge. In other words, CIP should consider shifting some resources to or at least giving priority to resource mobilization for high-payoff research areas. Diminishing returns implies that as more resources are devoted to a high-payoff project, the added benefits from the additional resources is likely to fall, and as resources to low-payoff projects are reduced the returns to the remaining resources are likely to rise. Thus, a large, low-pay project could be transformed into a small, high-payoff project through judicious adjustment in resources allocated to the project.

Another reason for keeping some investment in apparently low payoff research endeavors is that the information for making these assessments is imprecise. While the scientific judgments used to construct the assessments represent our present state of knowledge regarding these parameters, over time these values may change as we learn more about a project's potential. This is particularly true for relatively young projects where there may be considerable uncertainty about the likely research outcomes. This was certainly the case in the 1996 priority assessment exercise, where later information revealed much less potential for research on TPS and post-harvest utilization and greater potential for sweetpotato virus-free seed than were anticipated at that time. As new information becomes available, the impact assessments can be updated and expanded as part of the on-going planning and management process at the Center.

IV. RESULTS OF THE RESEARCH PRIORITY ASSESSMENT

The following tables summarize some of the results from the impact assessments of CIP research investments in potato and sweetpotato technologies conducted during August-November 2005. These assessments generated information on the likely outcomes of CIP research investments in potato and sweetpotato improvement and their likely adoption areas. Preliminary results were presented at the CIP annual meeting in November and some of these results were subsequently revised.[10] In addition, a survey of CIP staff time allocation conducted in December-January generated information on the cost of research investments. Cost estimates included in the benefit-cost analysis consist of CIP research costs, complementary research investments by NARS partners to adapt technology to local environments, and cost of extension to disseminate technology to potential adopters. Dissemination costs are derived from the experiences of the CIP impact case studies are vary by type of technology.

The results presented here focus on the aggregate economic and poverty impacts of CIP's potato and sweetpotato research endeavors. Aggregate impacts include estimates of economic surpluses from production and post-production technologies, human health benefits from biofortification measured by the value of DALY saved, and weighted qualitative estimates of other environmental and health benefits. Time and resource constraints prevented the full application of the model presented above. Not completed were the quantitative assessment of impact on agricultural sustainability and a broader set of development indicators including employment effects and the number of persons removed from poverty.

4.1. The allocation of CIP scientific resources

Probably the most critical decisions on research resource allocation concern the number of scientific staff employed at the Center and the allocation of their time to specific research endeavors. Staff costs typically constitute 60-70 percent of a Center's total expenditure, and their numbers, disciplines, and quality are what drive a successful research agenda. In this section we first review trends in Center research staff over time and then describe in detail the allocation of Center research staff by research activity in 2005. We use the time allocation shares in 2005 to allocate all of CIP's annual expenditure and derive estimates of annual research investment for each activity.

4.1.1. Trends in CIP research resources over time

CIP faced serious budget tightening during the mid-1990s and again in the early 2000s and the numbers of internationally-recruited research staff (IRS) employed at the Center reflect this trend. The number of PhD-level IRS employed at CIP fell from 78 in 1990 to 49 by 2001, and had only slightly recovered to 53 by 2005 (Figure 2). Moreover, an increasing share of CIP's budget (and research staff assignment) is in the form of project funding: core-funded staff constituted 62 percent of IRS positions in 1990 but only 44 percent by 2005.

[10] Revisions include: (i) adding "participatory market chain approach" to the list of potato technologies assessed for potential impact, and (ii) adjusting estimates of poverty impacts by including benefits to poor consumers of potato and sweetpotato of increased supply/lower food prices, in cases where marketed surpluses of these commodities are purchased as staple foods by very poor rural or urban consumers. The latter revision primarily affected estimates of poverty impact from improved potato productivity in the Andes countries and improved sweetpotato productivity in Sub-Saharan Africa.

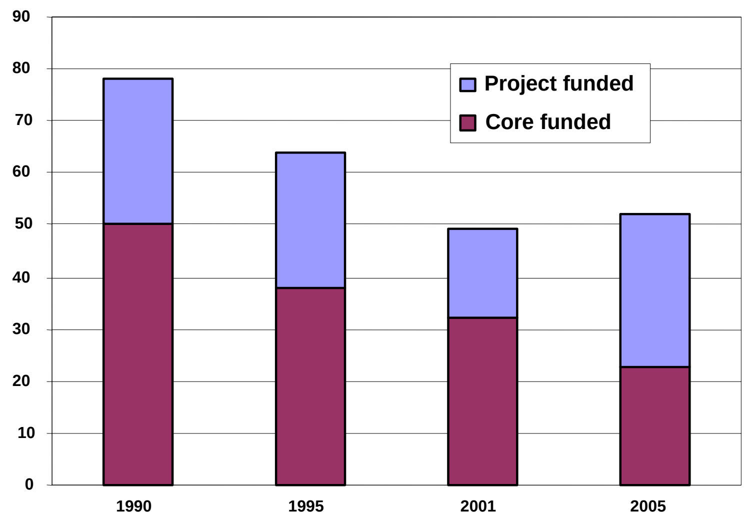

Figure 2. The number of international research staff employed at CIP, 1990-2005

A second important trend in overall staff allocation at CIP is a shift from regional-based staff to headquarters-based staff. In 1990, 57 percent of the IRS employed at CIP was stationed in regional offices and 43 percent at the Center's headquarters in Peru. By 2005, the share of headquarters-based staff had grown to 62 percent (Figure 3). The concentration of CIP research staff at headquarters is partly due to the greater reliance on project funding. CIP has been more successful in obtaining support for headquarters-based projects than regionally-based projects. However, the regional share of core-supported staff has also fallen: between 1990 and 2005 the share of core-supported IRS assigned to regions fell from 45 percent to 32 percent.

The increasing reliance on project-based funding limits the flexibility of the Center to reallocate research expenditures, at least in the short-run. In the medium and long term, however, the Center can influence the allocation of project-based funding through management decisions made at the research proposal stage and through interchange with the Center's stakeholders about what kinds of projects are likely to achieve the highest returns to poverty reduction and other objectives.

Figure 3. The number of international research staff assigned to headquarters and regions

4.1.2. Allocation of research resources by activity in 2005

In November 2005 all CIP research staff at the M.S.-level and above was surveyed on the allocation of their time during the previous year. In the survey, staff was asked to assign 100 percent of their time among 34 topical areas (14 for potato, 12 for sweetpotato, and 8 others). These topical areas include all of the major research (outputs) listed in CIP's research portfolio as indicated by the 2005-2007 Medium Term Plan, as well as categories for "other," "information and communication," and "administrative duties" unrelated to the specific listed research activities. In a separate question, staff assigned 100 percent of their time according to the region where they expected the impact of their work to occur. A category was included for "global" impact if their research had application in multiple regions. See Fuglie (2006a) for a more complete description of the survey and results.

Altogether 116 persons completed the survey – 61 at the PhD level and 55 at the M.S. level (Table 3). For the purposes of aggregation and cost estimation, various weighting procedures were examined for different staff types. Research responsibilities and costs of PhD-level scientists are generally quantitatively and qualitatively different from M.S.-level positions. To account for these differences, PhD positions in non-social science disciplines were given a weight of 1.00 and M.S. positions in these disciplines were given a weight of 0.67. Social science staff-years were weighted at 0.67 and 0.45 for PhD and M.S. levels, respectively. Then, the annual research expenditure per activity was estimated by assigning CIP's annual budget of US$ 20 million across each activity in proportion to its share of (weighted) research staff-years. Note that CIP's actual budget varies from year to year but that US$ 20 million is about average.

Table 3. Number of CIP research staff in 2005 (M.S. and above)

	IRS Persons	NRS Persons	Total Persons	FTE
PhD	54	7	61	54.84
M.S.	7	48	55	53.58
Total	61	55	116	108.42

IRS = internationally-recruited staff
NRS = nationally-recruited staff
FTE=full-time equivalents (weighted)

Regionally, 41 percent of CIP's research resources were allocated to addressing the problems of Latin American countries (Table 4), and nearly all of this to the four countries of the Andean zone (Bolivia, Colombia, Ecuador and Peru). About 20 percent was allocated to various parts of Asia and 17 percent to Sub-Saharan Africa. Twenty percent of the work by CIP scientists was for technologies designed for global impacts affecting more than one region, according to the responses to the survey.

Table 4. Allocation of CIP science resource by impact region in 2005

Region	Research expenditure ($1000)	% of research expenditure
ESEAP-NEA	1,099	5
ESEAP-SEA	1,285	6
LAC	8,106	41
SSA	3,398	17
SWCA	2,025	10
Global impacts	4,087	20
Total	20,000	100

The estimates of expenditures by research area of research endeavor are shown in Table 5. Altogether, nearly half of CIP's scientific resources were allocated to potato research and 19 percent to sweetpotato research in 2005. The other 31 percent was allocated among a range of research areas, including other Andean root and tuber crops, natural resources management, urban agriculture, communication and administrative duties. For potato research, control of late blight disease through improved crop management and breeding resistant varieties receiving the single largest investment with 9.5 percent of all potato research. For sweetpotato research, the topics receiving the most research resources included breeding and disseminating new varieties high in beta carotene (for Vitamin A) and improving animal feed utilization of the crop.

Table 5. Estimated research expenditures by research endeavor in 2005

Research Area/Endeavor	Expenditure (1000 US$)	% of Total
POTATO R & D		
genetic resources	838	4.2
late blight	1,893	9.5
seed systems and viruses	920	4.6
bacterial wilt management	470	2.3
breeding for virus resistance	1,029	5.1
TPS	421	2.1
processing	219	1.1
IPM	853	4.3
market chain enhancement	577	2.9
drought management	397	2.0
soil fertility and conservation management	322	1.6
storage	165	0.8
integrated management and innovation systems	1,003	5.0
Other research and development	817	4.1
TOTAL POTATO R&D	9,925	49.6
SWEETPOTATO R & D		
genetic resources	390	2.0
enhanced Vitamin A	865	4.3
increased dry matter/starch/flour yield	464	2.3
planting material and virus control	406	2.0
IPM	124	0.6
utilization for animal feed	617	3.1
market chain enhancement	126	0.6
drought management	195	1.0
soil fertility and conservation management	73	0.4
storage	15	0.1
integrated management and innovation systems	270	1.3
Other research and development	315	1.6
TOTAL SWEETPOTATO R&D	3,860	19.3
OTHER R & D (unrelated to potato and sweetpotato)		
Native Andean crops	364	1.8
Natural resources management	1,065	5.3
Urban and peri-urban agriculture	1,146	5.7
Agricultural innovation systems	426	2.1
Information and communication	896	4.5
Management and Administrative duties	1,596	8.0
Other research and development activity	721	3.6
TOTAL OTHER R&D	6,215	31.1
GRAND TOTAL	20,000	100%

We do not have comparable data on staff time allocation by research endeavor or by impact area for years other than 2005. However, in 1990, the 78 IRS employed at CIP were allocated almost entirely to either potato or sweetpotato research as CIP had not yet established research programs on natural resource management, Andean root and tuber crops, or urban agriculture. By 2005, about 70 percent of total research staff time were devoted to these crops and the Center had lost about one-third of its IRS research positions since 1990. Thus, in 2005 the commodity programs were probably no more than half their size in 1990 in terms of science-person-years allocated to them.

4.2. RESULTS OF THE NEEDS & OPPORTUNITIES ASSESSMENTS

Table 6 provides a summary of the results of the technology assessments and benefits estimation for nine potato and six sweetpotato research endeavors. The anticipated research investment in each area over the next five years is given in the first column of numbers and the likelihood this research will successfully result in improved technology is given in the second column. Probabilities of research success varied from 50 percent (improvements in potato and sweetpotato marketing systems) to 90 percent for well-adapted sweetpotato varieties high in beta carotene (for Vitamin A).

Total crop areas affected by the productivity constraints and anticipated or possible adoption areas by 2020 are given in the next three columns. These crop area estimates only area in the countries included the assessment (see Figure 1 and Annex 2) and do not include possible spillovers to other developing or developed countries. Likely adoption areas after 10 years of technology dissemination to farmers (assuming the technologies are successfully developed) are considerably below the estimates of total affected areas in all of the cases. The large gap between likely and potential adoption area primarily reflects institutional weaknesses of national agricultural research and extension systems for these countries for these crops. A second adoption scenario ("Possible adoption area by 2020" in the table), reflects the judgments of the assessment teams of what could realistically be achieved if new partnerships and donor-funded projects could be developed in these countries specifically to disseminate the new technologies.

The average benefits per hectare of adoption are derived by summing up the economic benefits from higher yield and value and subtracting any change in production cost, and dividing by the number of hectares of adoption (7th column of Table 6). Adopters do not necessarily realize all of these benefits, however, because this figure does not include the effect of downward pressure on market prices from technology adoption which passes on some benefits to consumers. Further, non-adopters share benefits of technologies that increase market demand, since this affects the price received for the crop. A number of features stand out from the estimates of benefits per hectare. First, benefits per hectare from production technologies are well within the range of recent experience as reflected in *ex post* case studies of successful CIP-related technologies (Walker and Crissman, 1996; Walker and Fuglie, 2001).[11] In the assessments given in Table 6, these ranged from $227/ha for high dry matter sweetpotato to $889/ha for virus-resistant potato. Second, potato technologies generally registered higher gains per hectare than sweetpotato due to the higher unit value of this crop. Third, post-harvest marketing and utilization technologies, designed to add value to the market chain, gave higher net benefits per hectare of adoption than production technologies. Estimates of these benefits ranged from $567/ha for improved utilization of sweetpotato as animal feed to $2,085/ha for improved potato marketing and utilization using Participatory Market Chain Analysis (PMCA). Overall impact of post-harvest technologies were generally less than production technologies, however, because expected adoption rates were generally much smaller. The assessment teams anticipated greater constraints to scaling up dissemination of the post-harvest technologies. Moreover, these estimates assume the research is successful. But given the uncertainty in research outcomes, some of these endeavors will in all likelihood fail.

Columns 8 and 9 of Table 6 give the estimated annual aggregate economic benefits and income benefits accruing to poor rural households once the technologies have reached their likely adoption ceilings. In the case of post-harvest technologies, benefits going to poor producers were higher than aggregate benefits because of the welfare-transferring effect of higher commodity prices. By raising market utilization and demand for farm commodities, these technologies shifted income from (primarily urban) consumers to rural producers. Thus, the welfare impact on rural poor appears large even though the net effect on aggregate economic surplus may be small. For production technologies, the "poverty content" of improvements to sweetpotato was higher than those for potato. About 80-90 percent of aggregate economic surplus of sweetpotato went to poor households while for potato, the poverty content of technology adoption ranged from 40-60 percent. This is a consequence of (i) sweetpotato being more important in poorer areas, especially in Sub-Saharan Africa, and (ii) most sweetpotato is used on the farm where it is grown so that a smaller share of aggregate benefits is transferred to consumers through market price effects, and (iii) in Sub-Saharan Africa, consumer benefits from lower prices were included in the estimation of benefits going to rural poor since most of the market purchases are by rural, food-deficit households.

[11] Net benefits per hectare measured in CIP's *ex post* case studies varied from about $100 for IPM practices in the control of sweetpotato weevil in the Dominican Republic to $1,350 for an improved seed system with late-blight-resistant varieties in Vietnam (Walker and Crissman, 1996).

Qualitative assessments of health, environmental and employment effects of the new technologies generated surprising little useful information for the priority assessment exercise. Nearly all technologies were ranked as having positive contributions to these factors. The quantitative exercise for evaluating the health impact of biofortified sweetpotato provided a more useable result. Assuming a value per DALY saved of $1,000 gave an estimated economic worth of this health intervention of $21 million/year once adoption on 140,000 hectares was achieved in the target countries. This is in addition to the economic surplus and income benefits estimated for this technology, which are based on an expected yield improvement from the new varieties.

Finally, for at least three of the fifteen technologies listed in Table 6, there are likely to be alternative sources of technology either from developed country NARS, the private sector, or strong NARS in developing countries. Improvements in potato seed production, mainly for formal, regulated systems, are likely to be forthcoming from both the public and private sectors in developed countries. However, for many low-income countries where the great majority of potato growers rely on the informal seed systems, the usefulness of these improvements may be quite limited. Another technology where there will likely be important sources of alternative technology is potato varieties for processing. While the market for processing varieties (for chips and fries, especially) in developing countries is still relatively small, this is expected to grow rapidly in the next few decades. Most of the varieties currently grown for potato processing in developing countries originated in developed countries and CIP varieties selected for processing quality will likely face strong competition from them. The principal advantage of CIP potato processing varieties is likely to be added resistant to biotic stresses, especially against late blight and viruses. The third technology with alternative sources is likely to be sweetpotato product development; the private sector, particularly in China, is working to expand product utilization for sweetpotato starch-based products and snack foods.

Table 6. Results of the technology needs and opportunity assessments

Column:	2	3	4	5	6	7	8	9	10	11	12	13
Technology	CIP research investment 2006-2010	Probability of research success by 2010	Area affected by constraint	Likely adoption area by 2020	Possible adoption area by 2020	Average benefits per hectare of adoption	Aggregate economic surplus	Economic benefits to poor	Health Benefits	Environ-mental benefits	Employ-ment benefits	Alternative source of technology
	mil. $	%	000 ha	000 ha	000 ha	$/ha	mil $/year	mil $/year	Score*	Score*	Score*	Score*
Potato late blight control (breeding and management)	10.1	73%	5,652	693	1,577	777	319.4	175.4	1	1	1	0
Potato seed systems improvement (formal & informal)	4.8	58%	5,651	654	1,556	762	257.0	151.7	0	1	1	-1
Potato breeding for virus resistance	6.1	71%	3,152	220	539	889	119.2	65.2	1	1	1	0
Potato breeding for processing utilization	1.1	75%	532	155	452	1,452	2.3	120.9	1	1	1	-1
Potato IPM (tuber moths, leaf miner fly, Andean weevil, Colorado beetle)	4.6	64%	797	129	245	392	28.4	12.4	2	2	1	0
Potato bacterial wilt control (cultural practices & diagnostics)	2.5	60%	637	101	238	253	24.5	14.2	0	1	1	0
True Potato Seed (TPS) progenies & seed systems	2.3	54%	97	44	44	729	11.8	6.1	0	1	1	0
Cropping system improvement in potato-cereal systems in Indo-Gangetic Plain	0.4	55%	40	40	40	293	6.6	2.8	1	1	1	0
Potato marketing & utilization improvement through PMCA	3.2	52%	96	17	27	2,085	3.8	9.0	1	1	1	0
Sweetpotato improved supply & quality of planting material	2.2	75%	4,924	908	2,240	246	284.2	252.6	0	1	1	0
Sweetpotato breeding for high dry matter yield	2.5	75%	6,720	315	1,283	260	91.6	80.1	0	1	1	0
Sweetpotato breeding for high Vitamin A content	4.4	90%	4,503	140	619	227	28.9	23.0	21.0^	1	1	0
Sweetpotato IPM (weevils)	0.6	61%	1,146	197	505	265	38.5	31.5	2	1	1	0
Sweetpotato utilization for animal feed	2.9	85%	2,219	62	361	567	30.4	30.4	0	1	1	0
Sweetpotato small-enterprise, marketing systems & new product development	0.6	50%	492	77	155	1,533	0.1	10.5	0	0	1	-1

Probability of research success and adopter benefits per hectare varied by location – the table reports an average value across countries.
* Impact of technology adoption on human health, environmental quality and employment were scored qualitative (-1 = negative impact, 0 = no appreciable change, +1 = positive impact, +2=very positive impact), except for health impact of high Vitamin-A sweetpotato, which is annual value of DALY saved in mil. $/year. If similar adapted technology is likely to be available from developed country or strong NARS, "Source of alternative technology" was scored as -1. ^The impact of biofortified sweetpotato on reducing the health burden of Vitamin A deficiency was valued at $21 million/year (see text).

4.3. Benefit-cost analysis of CIP's commodity research

Table 7 summarizes the benefit-cost analysis of the *ex ante* returns to CIP research on potato and sweetpotato improvement. Two scenarios are considered based on different assumption of technology adoption: (i) the "status quo" scenario assumes current funding and institutional structure of CIP and its partner organizations (Table 7.1),and (ii) the "enhanced" scenario assumes that efforts to attract more funding and build stronger partnerships with local research and development organizations are successful and thus lead to greater dissemination of technologies (Table 7.2).

The primary usefulness of the results in Table 7 is they balance the size of potential benefits with their research and dissemination cost. In other words, even though some technologies may have greater potential impact, the marginal value of investing more research in their development may be less than investing in other technologies that can yield greater impact per additional dollar of investment. A key indicator is the Internal Rate of Return (IRR). Strategic research planning should give priority to strengthening research on technologies yielding the highest IRR to poverty reduction and shifting resources away from research with relative low IRR. he Net Present Value (NPV) of research is an indicator of the total size of the impact and is closely related to adoption area and benefits per hectare from adoption.

Referring to Table 7.1, four potato technologies stand out both in terms of the size of their impact (NPR) on poverty and the high returns per dollar of investment (IRR). These are:

1. Potato late blight resistance breeding and management
2. Potato clean seed (which includes rapid multiplication, formal and informal seed systems management, and farmer seed management)
3. Potato virus resistance breeding, and
4. Potato breeding for processing utilization.

Each of these investments yields an IRR on poverty reduction of at least 18 percent, and as high as 33 percent in the case of breeding for processing utilization. Note that the impact of breeding for processing utilization is low in aggregate impact but high in terms of poverty impact, which runs counter to most other technologies. The reason is that the main way this technology translates into poverty impact is by raising market demand (and therefore price) for the crop commodity. Higher prices result in higher incomes to producers. In terms of aggregate impacts, however, the benefit of higher prices to producers is offset by the cost of higher prices to consumers. The impact on poverty, however, focuses on the impacts on poor households, which in this case are primarily producers of the crop rather than the consumers of the marketed products.

Compared with the results of the 1996 priority setting exercise, the potential returns to research on breeding resistance to potato viruses appears to be much higher in the 2005 assessment. The principal reason is that the 2005 exercise gave much higher attention to impact in northern China, especially provinces in China's north central and western areas where potato production expanded very substantially during the 1990s while poverty remained stubbornly high.

Overall, sweetpotato research yielded even higher IRR to poverty reduction than potato research. This reflects both the higher concentration of poor households relying on sweetpotato, and the relatively low level of present investment in sweetpotato research. Overall, sweetpotato research gave a 30 percent IRR to poverty reduction compared with 19 percent IRR for potato research (Table 1). The specific sweetpotato technologies showing the highest returns to poverty reduction are:

1. Sweetpotato planting material improvement and virus control,
2. Sweetpotato breeding for high Vitamin A (beta carotene) yield,
3. Sweetpotato breeding for high dry matter yield, and
4. Integrated management of the sweetpotato weevil.

The importance of looking beyond a purely economic valuation and quantitatively assessing impacts on human health are revealed by the high returns to poverty reduction indicated to breeding for Vitamin A-rich sweetpotato. Without including health benefits in the estimation, this research investment would not rank among the priorities.

Research on post-harvest utilization of sweetpotato gave lower but still respectable returns to poverty reduction (13-14 percent IRR in Table 7.1). While research on sweetpotato processing by small enterprises and new product development gave low aggregate impacts (and a negative NPV), its impact on poverty reduction was nevertheless reasonably good. The reason is similar to the case of breeding for potato processing – adoption of these technologies provides higher prices and incomes to poor producers (and therefore results in poverty reduction), but these benefits are offset in terms of higher prices paid by consumers (who are substantially less poor in most of the regions where this technology is being developed).

The results in Table 7.2 give similar overall rankings among the technologies. One main value of these scenarios is that they highlight technologies facing particularly strong constraints to dissemination. This appears to be the case for research on sweetpotato utilization as animal feed.

It's IRR to poverty reduction increases relative to other technologies under the scenarios that relax the constraints to dissemination.

4.4. Technology-specific issues

1. Potato late blight resistance and disease management

This priority-setting exercise again confirms the importance of late blight in CIP's research portfolio, although it dropped from first to second place in terms of expected impact on poverty reduction (behind sweetpotato viruses & planting material). More than 5 million hectares of potato were judged to be affected by late blight in the targeted countries. CIP's breeding program has made significant strides in developing durable resistance in potato germplasm and the assessment team was optimistic about prospects for adoption. The expected benefits from improved late blight control are widely distributed across many countries in Asia, Latin America, and Sub-Saharan Africa. Improved technology may allow area expansion of the potato crop into seasons of heavy disease infestation, a benefit not considered in these estimates.

2. Potato seed quality and seed systems

Poor quality seed reduces yield on more than 5 million hectares of potato in target countries. Institutional considerations play an important role in determining the success of potato seed systems. In the 1996 assessment, somewhat pessimistic prospects for research to solve institutional weaknesses led to a low ranking for this project. In the 2005 assessment, this project received a much higher ranking due to large benefits projected for Sichuan, Yunnan and Guizhou provinces, a hugely important potato growing area in southwestern China.

3. Potato virus resistance

More than three million hectares in target countries could potential benefit from potato varieties resistant to viruses. There is a degree of substitutability or overlap between breeding for virus resistance and improving seed quality (which includes elimination of viruses). Recent advances in identifying available sources of resistance to the two main potato viruses limiting yield in developing countries (PVY and PLRV) raise the prospects for this project. So far, CIP's virus-resistant potato populations have been developed almost exclusively for application in North China, were viruses are endemic. However, the technology assessment projected adoption on only 7 percent of the potato crop area affected by viruses in the target countries. Given the global significance of virus constraints to potato yield and institutional constraints to potato seed systems, this research would seem to have promising applications in other regions.

4. Potato breeding for processing utilization

Demand for potato processed products is rising rapidly with urbanization and income growth in developing countries. Local varieties, however, are often not suitable for industry and processing firms rely on imports. Local farmers stand to gain significantly if they can produce varieties suitable for these new markets. Moreover, gains are likely to be shared broadly since diverting production to processing will raise potato prices in the fresh market as well (however, consumers of fresh table potatoes will have to pay more). CIP breeding costs for processing are relatively low since it is evaluated as a secondary trait in the late blight and virus breeding projects. These factors lead to a high ranking for poverty impact of this research endeavor. However, CIP is not likely to be the only source of new processing varieties for these countries, which could limit the impact of CIP's investment.

5. Bacterial wilt management in potato

Despite success in developing better diagnostic methods for bacterial wilt, the prospects for improving management through use of this technology remain quite uncertain. The economic importance of this project depends heavily on outcomes in Sichuan and Yunnan (China), which contribute about 70 percent of the global benefits from this technology. The heavy geographic concentration of benefits implies more risk than in the other disease management projects on potatoes. However, recent advances in identifying potential sources of genetic resistance may provide a new option for controlling this disease. Prospects for incorporating this resistance into varieties were considered too exploratory for formal socio-economic assessment.

6. True Potato Seed (TPS)

TPS was one of the most highly ranked CIP projects in the 1996 priority assessment exercise, but optimism about the prospects for this technology has waned considerable over the past 10 years. One reason is that improvements in clonal seed supply have advanced more rapidly than previously anticipated. It is now recognized that the niche for TPS is restricted to isolated areas with limited access to clonal seed or in areas that have suffered natural disasters and seed stocks have been lost or depleted. Estimated returns from CIP's investment in TPS are relatively low.

7. Potato insect integrated pest management (IPM)

Most of the expected economic impacts of potato IPM are from reduced pesticide application rather than higher crop yield. Some gains are also achieved through reduced storage losses. The health and environmental benefits were scored qualitatively and not included in the benefit-cost assessment. Further, most insect pests considered in this assessment were of regional importance, limiting the potential for region-to-region research spillovers. These factors led to relatively small estimates of economic or income benefits. CIP's investment in potato IPM needs to rely for justification on the health and environmental benefits not included in the benefit-cost assessment.

8. Potato marketing systems improvement through Participatory Market Chain Approach (PMCA)

A relatively new endeavor by CIP, PMCA involves improving the quality and reliability of production by resource-poor farmers and building trust among actors in the marketing chain in order to improve access of poor farmers to value-adding markets. While per hectare benefits are anticipated to be relatively large, the expected impact of PMCA is constrained by a relatively small adoption area. Scaling up this technology to achieve larger impact is likely to be difficult due to higher transactions cost faced by processors of sourcing supply from resource-poor farmers.

9. Potato-cereal cropping systems in the Indo-Gangetic Plain

Expected adoption of this technology is restricted to about 40,000 hectares in West Bengal (India) and Bangladesh. The technology assessment appears to establish a minimal goal for the project to be viable. Due to the limited geographic coverage of this research it is not included in Tables 9-12 which show the regional breakdown of expected adoption and benefits.

10. Sweetpotato planting material quality and supply (including virus control)

CIP's strategy for reducing yield losses from viruses is closely linked to propagation methods for disease-free planting material. To date, this has been by far CIP's most successful technology, although successful adaptation and adoption has been confined to three provinces in China. China still accounts for about 70 percent of the expected economic benefits, but in terms of poverty impact, the focus switches to Sub-Saharan Africa. Expectations on adoption of this technology may be overly optimistic given institutional weaknesses in producing quality planting material for vegetatively-propagated crops.

11. Sweetpotato biofortification for Vitamin A

Human populations with significant dietary deficiencies in Vitamin A inhabit areas where around 4.5 million hectares of sweetpotato are grown. The technology assessment expected new varieties rich in beta carotene to be adopted on about 140,000 hectares, about 90 percent of which was in Sub-Saharan Africa. Roughly 60 percent of the quantified benefits are from higher yield and 40 percent from improved health. The heavy concentration of impact on Sub-Saharan Africa gives this research endeavor a high impact on poverty relative to adoption area.

12. Sweetpotato dry matter yield and adaptation

Low dry matter-yielding varieties constrained sweetpotato production on 6.9 million hectares of cropland in the target countries, and adoption of high yielding varieties was expected on over 300,000 hectares. In the 1996 assessment, large impacts were anticipated in China, and success hinged on exploiting increased genetic variability from CIP as narrow genetic variability reportedly constrained progress in China's sweetpotato crop improvement program. In the 2005 assessment, most adoption was still expected to occur in China (especially Sichuan) although most impact on poverty reduction was now anticipated in Sub-Saharan Africa. Increased availability of food energy in very poor households may produce long-term benefits to health especially in malnourished children, a benefit not included in the analysis.

13. Sweetpotato weevil integrated pest management (IPM)

The high IRR to this project reflects the low level of investment in sweetpotato IPM at present. While clearly an important pest of sweetpotato in Sub-Saharan Africa, previous attempts to manage the pest in this region through IPM practices have not been successful. This is one constraint where genetically modified varieties may be required to obtain sufficiently high levels of damage control.

14. Sweetpotato utilization for animal feed

In much of Asia sweetpotato has evolved from a food crop to a feed crop, especially in "back-yard" pig production. Given the very large numbers of rural households engaged in this activity, the potential of improved feed utilization efficiency is large. Moreover, the likelihood of research success was judged to be relatively high. However, adoption was expected to occur on less than 3 percent of affected area due to institutional weaknesses in agricultural extension for this production system. If CIP's internal assessment is correct, this probably represents one of the most underexploited opportunities available for "research for development" globally.

15. Sweetpotato marketing, small-enterprises and product development

Although it has similar objectives as PMCA, this endeavor builds on CIP's long history of collaborative work on sweetpotato post-harvest development with the Sichuan Academy of Agricultural Sciences, China. It includes small-enterprise and new product development, especially for starch-based noodles and snack foods, as well as research on institutional arrangements for linking small farms to large processing companies. By expanding utilization for sweetpotato, most of the impact occurs through higher prices. The likelihood of success is considered to be rather low (50 percent) due to (i) CIP's disinvestment of technical capacity in post-harvest utilization and (ii) demand constraints for sweetpotato-based products. The assessment envisioned adaptations and adoption in Southeast Asia and East Africa. About half of new adoption is still expected to occur in Sichuan, although most of the Impact on poverty reduction is expected in East Africa. The private sector is recognized as an alternative source of similar technology.

16. Other CIP research endeavors not formally assessed

There are several other components of CIP's research program that were not formally addressed in the 2005 assessment. Three important ones are (i) natural resource management (NRM) in tropical mountains, (ii) improvement of other native Andean root and tuber crops (ARCT), and (iii) urban and peri-urban agriculture. The NRM and ARCT projects were, however, assessed in the 1996 exercise, and it does not appear that the prospects for these initiatives have changed appreciable in the past decade. The 1996 exercise anticipated relatively small benefits from the NRM and ARTC projects but noted that for the NRM project, synergies with other projects and spillovers to other regions through the Global Mountain Initiative could multiply benefits. In 1996 it was concluded that significant investment in ARTC was hard to justify on economic grounds, and recommended a "more limited and focused effort" to capture potential gains from enhancing biodiversity. CIP's urban/peri-urban agriculture project was begun in 2000 and has evolved to include a diverse set of activities in three or four urban areas. It would be worthwhile to undertake an impact assessment exercise of this project in the near future.

4.5 Further results: Expected benefits by technology and region

Given the central role of regional strategies in the current strategic plan, we have included several tables that disaggregate global impacts by region and country (all based on the "status quo" scenario). Table 8.1 shows aggregate impacts by region and breaks down these impacts by technology. Table 8.2 shows the same regional disaggregation of the impacts on poverty.

Further results by country are presented in Annex 3. These tables are based on the "status quo" adoption scenario. The tables show both aggregate impacts and the impacts on poverty. For some countries or provinces listed in the tables no impacts are indicated under this scenario. These are cases where there is potential impact but where CIP is not currently engaged with local partners to adapt and disseminate these technologies. These impacts appear in other scenarios that relax the adoption constraint.

Table 7. Benefit-cost analysis of CIP potato and sweetpotato research

Table 7.1.	**Scenario: Status Quo Adoption Ceiling**								
Technology	Adoption ceiling ha	Aggregate Benefits ($1000)				Benefits to Rural Poor ($1000)			
		Rapid (2020)		Slow (2030)		Rapid (2020)		Slow (2030)	
		NPV	IRR	NPV	IRR	NPV	IRR	NPV	IRR
Potato Late Blight (breeding and management)	693,212	2,820,479	57%	1,787,739	39%	361,555	24%	209,688	16%
Potato Clean Seed	653,990	1,589,567	59%	1,007,713	41%	195,045	25%	112,758	16%
Potato Breeding for virus resistance	220,450	1,061,525	52%	676,228	38%	120,108	23%	72,060	16%
Potato Utilization (breeding for processing)	154,890	4,281	9%	1,304	5%	82,726	37%	51,648	26%
Potato Bacterial Wilt management	100,690	210,291	38%	131,032	26%	19,144	13%	8,361	7%
Potato TPS	44,063	100,756	32%	62,550	23%	15,657	14%	7,936	9%
Potato IPM of insect pests	129,244	217,442	31%	133,612	22%	8,710	7%	(345)	3%
Potato Utilization (market chain improvement)	33,421	26,501	16%	14,157	10%	6,915	8%	616	3%
Potato Cropping Systems - South Asia	40,271	56,339	42%	34,987	28%	4,522	12%	1,733	6%
Total Potato	2,070,232	**6,087,181**	**49%**	**3,849,323**	**35%**	**814,383**	**22%**	**464,454**	**14%**
Sweetpotato Planting material & virus control	907,577	2,525,088	82%	1,607,917	56%	635,338	47%	393,915	30%
Sweetpotato Breeding for high Vitamin A	139,626	433,768	41%	272,599	29%	200,820	30%	122,950	21%
Sweetpotato Breeding for high Dry Matter	314,791	212,222	38%	100,824	25%	81,672	27%	100,824	25%
Sweetpotato IPM (weevil)	197,332	333,900	58%	209,629	37%	162,587	42%	99,575	26%
Sweetpotato Utilization for animal feed	62,088	265,368	41%	167,153	29%	35,817	18%	19,686	12%
Sweetpotato Utilization - small enterprises & new products	77,258	(5,670)	< 0%	(5,759)	< 0%	9,910	14%	4,249	8%
Total Sweetpotato	**1,698,672**	**3,764,677**	**56%**	**2,352,364**	**39%**	**1,126,143**	**35%**	**741,199**	**23%**

Costs for this scenario include CIP and NARS current research expenditures in each technology plus extension expenditures proportional to adoption area (see text).

Rapid adoption: reach ceiling by 2020. Slow adoption: reach ceiling by 2030. Net Present Value (NPV) calculated using a 3% annual real discount rate.

Aggregate Benefits include quantifiable economic and health benefits, discounted in cases where there are alternative supplies of similar technology.

Table 7.2	Scenario: Enhanced Adoption Ceiling								
Technology	Adoption ceiling ha	Aggregate Benefits ($1000)				Benefits to Rural Poor ($1000)			
		Rapid (2020)		Slow (2030)		Rapid (2020)		Slow (2030)	
		NPV	IRR	NPV	IRR	NPV	IRR	NPV	IRR
Potato Late Blight (breeding and management)	1,576,638	6,039,816	57%	3,827,144	40%	863,911	26%	505,430	17%
Potato Clean Seed	1,556,011	3,384,165	59%	2,143,498	41%	451,496	25%	261,414	16%
Potato Breeding for virus resistance	538,909	2,633,378	56%	1,679,523	40%	332,300	27%	202,772	19%
Potato Utilization (breeding for processing)	451,867	60,767	23%	35,469	16%	231,240	41%	144,873	28%
Potato Bacterial Wilt management	237,586	421,285	37%	261,695	26%	40,119	12%	17,076	7%
Potato TPS	245,029	412,068	31%	252,886	21%	13,378	6%	(2,979)	2%
Potato IPM of insect pests	44,268	97,755	24%	59,133	17%	11,598	9%	3,840	5%
Potato Utilization (market chain improvement)	51,608	37,839	13%	17,549	8%	8,218	6%	(2,028)	2%
Potato Cropping Systems - South Asia	40,271	55,621	35%	34,269	23%	3,803	9%	1,014	5%
Total Potato	4,742,187	**13,142,693**	**51%**	**8,311,165**	**35%**	**1,956,064**	**23%**	**1,131,412**	**15%**
Sweetpotato Planting material & virus control	2,239,934	5,835,848	84%	3,714,560	57%	1,658,730	50%	1,031,120	31%
Sweetpotato Breeding for high Vitamin A	618,874	1,900,869	51%	1,201,350	36%	867,869	38%	537,736	26%
Sweetpotato Breeding for high Dry Matter	1,282,958	1,111,656	53%	612,492	36%	475,619	39%	281,040	26%
Sweetpotato IPM (weevil)	505,197	852,109	61%	535,162	38%	419,343	44%	257,147	27%
Sweetpotato Utilization for animal feed	361,490	1,588,395	56%	1,008,397	40%	231,106	26%	136,455	17%
Sweetpotato Utilization - small enterprises & new products	154,515	(10,839)	< 0%	(11,197)	< 0%	19,990	14%	8,608	8%
Total Sweetpotato	**5,162,968**	**11,278,037**	**62%**	**7,060,765**	**43%**	**3,672,658**	**40%**	**2,252,106**	**26%**

For this scenario, annual research expenditures in each technology are doubled and extension expenditures increase in proportion to higher adoption area.

Rapid adoption: reach ceiling by 2020. Slow adoption: reach ceiling by 2030. Net Present Value (NPV) calculated using a 3 percent annual real discount rate.

Aggregate Benefits include quantifiable economic and health benefits, discounted in cases where there are alternative supplies of similar technology.

Table 8. Anticipated aggregate impacts of CIP research by region and technology
Scenario: Status quo adoption ceiling

All Potato and Sweetpotato Technologies ($1000/year after adoption ceiling reached))

Region/ Sub Region	Adoption area (ha)	Aggregate impact	Benefits to rural poor	% of global aggregate impact	% of global benefits to rural poor
ESEAP-NEA	1,966,092	723,380	109,020	63	41
ESEAP-SEA	102,332	28,499	2,725	2	1
LAC	211,753	68,403	10,624	6	4
SSA	982,877	194,116	118,006	17	44
SWCA	505,850	160,696	26,961	14	10
Global	2,070,232	1,146,594	267,336	100	100

Potato ($1000/year after adoption ceiling reached))

Region/ Sub Region	Late blight (breeding & mngt)	Viruses (breeding)	Clean Seed	Bacterial wilt management	IPM of insect pests	True Potato Seed (TPS)	Processing utilization (breeding)	Marketing & new products (PMCA)	Total Potato impact	Total Potato adoption area (ha)
ESEAP	178,218	104,210	152,201	17,616	132	0	642	0	453,020	1,242,1 31
LAC	37,428	0	3,795	342	14,968	129	121	3,699	60,483	173,249
SSA	20,515	0	10,294	591	0	0	9	119	31,528	183,140
SWCA	83,252	14,957	13,669	5,964	10,828	11,688	148	0	147,110	471,711
ESEAP-NEA	163,678	104,210	151,533	17,579	0	0	628	0	437,627	1,213,815
ESEAP-SEA	14,541	0	668	38	132	0	14	0	15,392	28,316
SWCA-SA	75,776	0	3,639	5,964	9,209	10,780	142	0	112,113	323,129
SWCA-CAC	7,476	14,957	10,030	0	1,619	908	6	0	34,996	148,582
Global	319,413	119,167	179,960	24,514	25,928	11,817	921	3,818	692,140	2,070,232

Sweetpotato ($1000/year after adoption ceiling reached))

Region/ Sub Region	Breeding high Vitamin A	SP planting material & virus mgmt	Utilization for-animal feed	Breeding high dry matter	IPM of sweetpotato weevil	Markets, small enterprises and new products	Total Sweetpotato impact	Total Sweetpotato adoption area (ha)*
ESEAP	2,746	204,559	30,404	32,004	628	19	270,360	826,293
LAC	858	2,402	0	2,639	2,020	0	7,920	38,503
SSA	39,849	74,117	0	14,601	34,011	9	162,588	799,737
SWCA	6,485	3,106	28	2,122	1,845	0	13,586	34,139
ESEAP-NEA	0	202,720	27,693	26,827	0	15	257,254	752,277
ESEAP-SEA	2,746	1,839	2,711	5,177	628	4	13,106	74,016
Global	49,938	284,184	30,432	51,367	38,505	28	454,454	1,698,672

Table 9. Anticipated benefits to rural poor of CIP research by region and technology
Scenario: status quo adoption ceiling

Potato ($1000/year after adoption ceiling reached))

Region/ Sub Region	Late blight (breeding & mngt)	Viruses (breeding)	Clean Seed	Bacterial wilt management	IPM of insect pests	True Potato Seed (TPS)	Processing utilization (breeding)	Marketing and new products (PMCA)	Total Potato impact	Total Potato adoption area (ha)
ESEAP	26,335	14,441	21,476	2,289	4	0	5,292	0	69,837	1,242,131
LAC	5,263	0	503	38	2,231	23	551	1,480	10,089	173,249
SSA	5,956	0	2,757	175	0	0	168	168	9,224	183,140
SWCA	12,591	420	1,003	852	1,894	2,376	3,602	0	23,600	471,711
ESEAP-NEA	24,676	14,441	21,435	2,287	0	0	5,200	0	68,038	1,213,815
ESEAP-SEA	1,659	0	42	2	4	0	92	0	1,799	28,316
SWCA-SA	12,415	0	547	852	1,860	2,364	3,561	0	22,461	323,129
SWCA-CAC	176	420	456	0	34	12	40	0	1,139	148,582
Global	50,145	14,861	25,739	3,354	4,129	2,400	9,612	1,648	112,750	2,070,232

Sweetpotato ($1000/year after adoption ceiling reached))

Region/ Sub Region	Breeding high Vitamin A	SP planting material & virus mgmt	Utilization for- animal feed	Breeding high dry matter	IPM of sweetpotato weevil	Markets, small enterprises & new products	Total Sweetpotato impact	Total Sweetpotato adoption area (ha)*
ESEAP	98	31,721	4,985	4,575	26	503	41,908	826,293
LAC	84	65	0	283	103	0	535	38,503
SSA	26,476	49,345	0	9,628	22,081	1,251	108,781	799,737
SWCA	1,423	833	14	573	518	0	3,361	34,139
ESEAP-NEA	0	31,633	4,728	4,186	0	434	40,981	752,277
ESEAP-SEA	98	89	257	389	26	68	927	74,016
Global	28,082	81,964	4,998	15,060	22,728	1,754	154,586	1,698,672

Table 10. Maximum potential aggregate impact of CIP research by region and technology (adoption occurs on all affected areas – no adoption constraint)

All Potato and Sweetpotato Technologies ($1000/year with no adoption constraint)

Region/ Sub Region	Total Adoption Area (ha)	Total Aggregate Impact	Total Poverty Impact	% of Global Aggregate Impact	% of Global Poverty Impact
ESEAP-NEA	19,524,631	6,700,496	1,191,919	70	43
ESEAP-SEA	2,523,025	459,527	32,750	5	1
LAC	2,211,597	551,284	110,842	6	4
SSA	10,202,703	1,930,722	1,264,910	20	46
SWCA	2,281,745	448,216	140,748	5	5
Global	16,740,365	9,630,718	2,741,169	100	100

Potato ($1000/year with no adoption constraint)

Region/ Sub Region	Late blight (breeding & mngt)	Viruses (breeding)	Clean Seed	Bacterial wilt management	IPM of insect pests	True Potato Seed (TPS)	Processing utilization (breeding)	Marketing & new products (PMCA)	Total Potato impact	Total Potato adoption area (ha)
ESEAP	178,218	1,647,584	1,391,608	61,073	4,317	24,637	7,206	0	3,314,644	11,109,351
LAC	59,397	131,372	136,907	4,825	143,515	257	287	20,183	496,744	1,912,032
SSA	20,515	0	82,818	11,847	5,174	7,465	137	1,229	129,185	1,808,698
SWCA	83,252	76,104	68,248	38,730	20,392	11,688	2,371	0	307,389	1,910,285
ESEAP-NEA	163,678	1,647,584	1,356,199	58,723	0	23,237	6,980	0	3,256,400	10,852,097
ESEAP-SEA	14,541	0	35,409	2,350	4,317	1,401	226	0	58,244	257,254
SWCA-SA	75,776	0	27,130	38,730	13,902	10,780	2,270	0	175,191	1,290,204
SWCA-CAC	7,476	76,104	41,118	0	6,490	908	101	0	132,198	620,081
Global	341,382	1,855,061	1,679,581	116,476	173,399	44,048	10,001	21,412	4,247,963	16,740,365

Sweetpotato ($1000/year with no adoption constraint)

Region/ Sub Region	Breeding high Vitamin A	SP planting material & virus mgmt	Utilization for- animal feed	Breeding high dry matter	IPM of sweetpotato weevil	Markets, small enterprises & new products	Total Sweetpotato impact	Total Sweetpotato adoption area (ha)*
ESEAP	814,559	808,190	1,120,347	636,020	6,269	467	3,385,852	10,938,304
LAC	18,405	12,366	0	16,952	6,816	0	54,540	299,566
SSA	837,290	434,028	0	354,327	175,791	101	1,801,537	8,394,005
SWCA	52,691	32,129	282	43,477	12,248	0	140,827	371,460
ESEAP-NEA	668,643	693,432	1,076,597	545,502	0	396	2,984,569	8,672,533
ESEAP-SEA	145,916	114,758	43,750	90,518	6,269	71	401,282	2,265,771
Global	1,722,945	1,286,712	1,120,629	1,050,776	201,125	568	5,382,755	20,003,335

Table 11. Maximum potential benefits to rural poor of CIP research by region and technology (adoption occurs on all affected areas – no adoption constraint)

Potato ($1000/year with no adoption constraint)

Region/ Sub Region	Late blight (breeding and mngt)	Viruses (breeding)	Clean Seed	Bacterial wilt management	IPM of insect pests	True Potato Seed (TPS)	Processing utilization (breeding)	Marketing & new products (PMCA)	Total Potato impact	Total Potato adoption area (ha)
ESEAP	267,602	233,326	196,249	7,699	142	4,000	18,548	0	727,566	11,109,351
LAC	41,355	16,681	17,669	577	19,544	47	1,423	7,699	104,995	1,912,032
SSA	61,830	0	23,216	3,515	748	3,189	696	1,697	94,889	1,808,698
SWCA	69,394	2,138	6,394	5,357	3,157	2,376	14,907	0	104,586	1,910,285
ESEAP-NEA	262,216	233,326	195,303	7,640	0	3,979	18,168	0	720,632	10,852,097
ESEAP-SEA	5,386	0	946	59	142	21	380	0	6,934	257,254
SWCA-SA	68,679	0	4,525	5,357	3,019	2,364	14,739	0	99,547	1,290,204
SWCA-CAC	716	2,138	1,869	0	137	12	167	0	5,040	620,081
Global	440,181	252,145	243,528	17,147	23,590	9,612	35,573	9,396	1,032,036	16,740,365

Sweetpotato ($1000/year with no adoption constraint)

Region/ Sub Region	Breeding high Vitamin A	SP planting material & virus mgmt	Utilization for- animal feed	Breeding high dry matter	IPM of sweetpotato weevil	Markets, small enterprises & new products	Total Sweetpotato impact	Total Sweetpotato adoption area (ha)*
ESEAP	106,668	115,415	182,130	88,548	260	4,082	497,104	10,938,304
LAC	3,382	335	0	1,785	346	0	5,848	299,566
SSA	530,056	287,373	0	232,412	115,955	4,223	1,170,020	8,394,005
SWCA	12,205	8,613	135	11,670	3,538	0	36,162	371,460
ESEAP-NEA	97,537	108,204	179,182	82,713	0	3,652	471,287	8,672,533
ESEAP-SEA	9,132	7,212	2,948	5,835	260	429	25,816	2,265,771
Global	652,312	411,736	182,265	334,416	120,099	8,305	1,709,133	20,003,335

V. COMPARING CIP AND NARS RESEARCH PRIORITY ASSESSMENTS

The research priority assessments described earlier in this paper are drawn primarily from CIP's current research portfolio. While this portfolio has developed over the 35 years of CIP's existence in contact and collaboration with CIP's partners, it raises the question whether the priorities identified by CIP would be the same priorities of scientists from developing countries. Over time, new productivity constraints may emerge and old constraints lose their prominence and research centers may be slow to respond to such changes due to institutional inertia and lack of timely information.

As a complement to CIP's internal research priority assessment, we elicited the opinions of leading scientists from National Agricultural Research Systems (NARS) in developing countries on their priorities for potato and sweetpotato research. In late 2005, two email surveys, one on potato research priorities and one on sweetpotato research priorities, were sent to 156 research staff from agricultural research institutes, universities, non-government organizations and the private sector in developing countries. Persons receiving the survey were identified by CIP staff. Respondents were also encouraged to forward the questionnaire to other knowledgeable persons in their countries. The questionnaire included sections for describing priority needs for crop improvement (breeding), vegetative propagation (seed), crop management (including pests, disease, soil and water), germplasm conservation, post-harvest utilization and marketing, impact assessment, and information technology. The survey questions referred to constraints to both farm productivity and crop value, as well as needs of the local potato research community (such as for improved access to potato germplasm and scientific information). Respondents were asked to rank needs using a score of 1 (not important) to 4 (very important). To increase response rates, the questionnaires were translated into English, Spanish, Chinese and Russian. In total, 91 responses (55 on potato and 36 on sweetpotato) were received from 34 developing countries. A complete description of the surveys and results can be found in Fuglie (2006c, 2006d).

To give emphasis to research priorities for poverty reduction, NARS survey rankings and CIP assessments were both weighted by commodity area and poverty indicators. NARS survey responses from each country were weighted by the crop area in potato or sweetpotato and proportion of the national population subsisting on less than $1/day. CIP's benefit assessment was also weighted by poverty impact according to the procedures described above. While we would expect to see substantial convergence between the priorities identified by CIP and NARS, departures between the two sets of priorities in some case may be justified. For example, some research needs may be significant but nevertheless offer low returns due to lack of good technological opportunities to address them. In other cases, CIP may have determined that it did not have a strong comparative advantage vis-à-vis the private sector or other sources of innovation for a particular research need even though NARS expressed strong preferences for technologies to address it. Nevertheless, the NARS survey responses provide an important "check" for CIP's internal assessment process, and CIP departures from the expressed priorities of NARS should be carefully examined and justified.

Table 12 compares the priority rankings for potato research of CIP's internal assessment and the survey of NARS scientists, each weighted by poverty indicators. In the table we combined some of the NARS needs to make the categories more compatible with how CIP research themes are defined. Overall, there appears to be a strong convergence between the top-ranked research needs expressed by NARS and the research priorities identified in CIP's assessment. All of the NARS issues receiving a mean score above 3.4 are included in the CIP research portfolio except two: research on ware potato storage and research on soil fertility. For ware potato storage, CIP disinvested in research on rustic potato systems when field testing showed there were few good prospects for technology development (Fuglie *et al.*, 2000), while technologies for advanced storage systems are readily available from the private sector. For soil fertility constraints, CIP needs to identify where its comparative advantage may lie. Much of this need is for location-specific information or technology. One potato research investment by CIP, however, stands out as receiving low scores by both NARS and CIP's internal assessment but still remains a part of CIP's research portfolio: breeding and propagation systems for True Potato Seed (TPS). This was a technology that was ranked high in CIP's previous internal assessment in 1996 but which subsequent field evaluations showed was overly optimistic (Chilver *et al.*, 1999). Given that both NARS and CIP's 2005 reassessment rank this as a low need and low-payoff area, it becomes increasingly difficult for CIP to justify continued investment in this technology.

For sweetpotato research, there appears to be substantially less convergence between the priority needs expressed by NARS and the research priorities established by CIP (**Table 13**). Both NARS and CIP ranked virus elimination from planting material and the closely related topic of improved systems for seed supply as the number one need of sweetpotato in developing countries. However, other highly-ranked needs of NARS were either scored low by CIP (post-harvest improvement through improved marketing, new food products and/or small-enterprise development) or do not appear in CIP's research portfolio at all (earliness, virus resistance in new varieties and research to support policy reform). On the other hand, several of the high-payoff sweetpotato research priorities identified by CIP (new varieties fortified with beta-carotene, new varieties high in dry matter for starch and other processing uses, and weevil management) were among the second class of priorities by NARS. One explanation for this divergence is that in developing countries, sweetpotato production is concentrated in two major production areas – China and Sub-Saharan Africa – each with different sets of needs. NARS respondents from China expressed a strong need for varieties and technologies for industrial utilization of the crop, while in Sub-Saharan Africa the sweetpotato weevil poses a major threat to crop production and Vitamin A deficiency is a serious problem. Viruses, however, were indicated as a leading constraint in both of these production regions. Another explanation is the relatively small investment in sweetpotato research by CIP as a whole. In 2005, less than 20 percent of CIP research staff were working on sweetpotato, a substantial reduction in share compared with the 1990s. There appear to be a number of research needs that should be strong candidates for expanding CIP's sweetpotato research program, such as for early-bulking and virus-resistant varieties, ware storage, and policy research.

Table 12. Comparison of CIP and NARS priority assessment for potato research

NARS research need	NARS score	NARS priority class	CIP research portfolio	NPV benefits to poor (mil. $)	CIP priority class
Late blight management & resistant varieties	3.97	1	Late blight breeding and management	219.7	1
Varieties with stable and high yield, consumer acceptance	3.90	1	Yes		
Seed systems & virus management	3.81	1	Potato clean seed	112.8	2
Bacterial resistant varieties	3.70	1	Yes		
Genetic resource characterization	3.65	1	Yes		
Economic & poverty impact of research	3.63	1	Yes		
Virus resistant varieties	3.61	1	Potato breeding for virus resistance	72.1	2
Processing quality in varieties	3.60	1	Potato breeding for processing quality	51.6	2
Insect management	3.57	1	Potato IPM of insect pests	(0.3)	3
Prebreeding	3.53	1	Yes		
Ware storage	**3.50**	**1**	**No**		
Cropping systems management	3.48	1	Yes		
Marketing systems improvement	3.48	1	Potato market chain improvement	0.6	3
Soil fertility management	**3.44**	**1**	**No**		
Bacterial disease management	3.43	1	Potato bacterial wilt management	8.4	3
Insect resistant varieties	3.38	2	Yes		
Ex situ conservation of genetic resources	3.38	2	Yes		
Drought management & tolerant varieties	3.38	2	Yes		
Seed storage	3.35	2	No		
Intellectual Property Rights management	3.34	2	No		
Capacities in information & communication	3.31	2	No		
Health and environmental risk of pesticides	3.26	2	No		
Communicating to target audiences	3.26	2	No		
Earliness in varieties	3.26	2	No		
Reforming food & agricultural policy	3.19	2	No		
Internet-based learning modules	3.18	2	No		
Water management	3.18	2	No		
Management of other fungal diseases	3.13	2	No		
Seed dormancy	3.08	2	No		
Soil erosion control	3.05	2	No		
New product development	3.03	2	No		
High starch or flour yielding varieties	2.99	3	No		
TPS propagation systems and progenies	**2.92**	**3**	**Potato TPS**	**7.9**	3
Heat tolerant varieties	2.92	3	No		
Harvesting methods	2.49	3	No		
Marginal soil tolerant varieties	2.31	3	No		
Long day adaptation in varieties	2.29	3	No		
Nematode resistant varieties	2.29	3	No		
Nematode management	2.28	3	No		
Cold tolerant varieties	2.17	3	No		
Soil acidity management	2.16	3	No		

In some cases, the research need scored in the NARS survey is included in CIP's research portfolio although did not undergo a formal assessment, so no Net Present Value (NPV) is available. Most of these can be classified as "service functions," such as genetic resource conversion, impact assessment, and training in information technologies, and do not lend themselves to benefit-cost analysis. In other cases CIP research was consider too exploratory for formal benefit-costs assessment (e.g., drought tolerance, bacterial wilt resistance) or the topic was incorporated in CIP's breeding objectives (e.g., potato breeding for stable and high yield) and therefore no separate evaluation was done.
Source: NARS survey responses are from Fuglie (2006c). Respondents scored each topic on scale of 1 (not important) to 4 (very important). Table reports mean scores weighted by the poverty head count index of the country where the survey respondent was working. CIP research portfolio derived from the CIP 2005-2007 Medium Term Plan and net present value of benefits to persons in poverty from

Table 13. Comparison of CIP and NARS priority assessment for sweetpotato research

NARS research need	NARS score	NARS priority class	CIP research portfolio	NPV benefits to poor (mil. $)	CIP priori ty class
Virus management, seed quality & supply systems	3.70	1	Sweetpotato planting material and virus control	393.9	1
Small enterprise processing, marketing systems, new food products	3.65	1	Sweetpotato utilization - small enterprises & new products	4.2	3
Varieties with stable, high yield & consumer acceptance	3.55	1	Yes		
Drought management & tolerant varieties	3.53	1	Yes		
Early varieties	**3.52**	**1**	**No**		
Virus resistant varieties	**3.49**	**1**	**No**		
Genetic resource characterization	3.49	1	Yes		
Ex situ conservation of genetic resources	3.46	1	Yes		
Policy reform	**3.45**	**1**	**No**		
Ware storage	**3.42**	**1**	**No**		
Insect resistant varieties	3.39	2	Yes		
Cropping systems management	3.31	2	No		
Communicating to target audiences	3.31	2	No		
Seed storage	3.31	2	No		
Prebreeding	3.28	2	Yes		
High root & vine yield for animal feed	3.27	2	Yes		
Capacities in information & communication	3.26	2	No		
Soil fertility management	3.25	2	No		
Harvesting methods	3.19	2	No		
Marginal soil tolerant varieties	3.18	2	No		
Insect management	3.17	2	Sweetpotato IPM (weevil)	99.6	2
Improved nutrition in varieties	3.16	2	Sweetpotato breeding for Vitamin A	123.0	2
Nematode resistant varieties	3.13	2	No		
Varieties high in dry matter/starch/flour	3.05	2	Sweetpotato breeding for dry matter	100.8	2
Animal feed utilization	3.03	2	Sweetpotato utilization for animal feed	19.7	2
Economic & poverty impact of research	3.00	2	No		
Water management	2.92	3	No		
Fungal disease management	2.80	3	No		
Shade tolerant varieties	2.74	3	No		
Intellectual Property Rights management	2.69	3	No		
Health and environmental risk of pesticides	2.67	3	No		
Nematode management	2.66	3	No		
Internet-based learning modules	2.61	3	No		
In situ conservation of genetic resources	2.59	3	No		
Bacterial disease management	2.50	3	No		
Soil acidity management	2.31	3	No		
Soil salinity management	2.14	3	No		
Cold tolerant varieties	1.58	3	No		

In some cases, the research need scored in the NARS survey is included in CIP's research portfolio although did not undergo a formal assessment, so no Net Present Value (NPV) is available. Most of these can be classified as "service functions," such as genetic resource conversion, impact assessment, and training in information technologies, and do not lend themselves readily to benefit-cost analysis. In other cases CIP research was consider too exploratory for formal benefit-costs assessment (e.g., drought tolerance) or the topic was incorporated in CIP's breeding objectives (e.g., breeding for stable and high yield) and therefore no separate evaluation was done.
Source: NARS survey responses are from Fuglie (2006d). Respondents scored each topic on scale of 1 (not important) to 4 (very important). Table reports mean scores weighted by the poverty head count index of the country where the survey respondent was working. CIP research portfolio derived from the CIP 2005-2007 Medium Term Plan and net present value of benefits to persons in poverty from

VI. CONCLUSIONS AND IMPLICATIONS

The research priority assessment CIP undertook in 2005 developed a number of impact criteria. In addition to traditional economic surplus measures of the benefit of research, the impact assessment models evaluated likely impacts on poverty reduction, human health, rural employment and environmental sustainability. Both quantitative and qualitative indicators were used to identify and measure impacts, but the quantitative indicators were far more revealing on how to allocate CIP research in order to enhance impact on poverty reduction.

Table 14 summarizes the main quantitative indicators of impact by research endeavor. Fifteen technologies (nine potato and six sweetpotato) were included in the assessment. Ten of these focused on removing significant constraints to crop yield, and five dealt with adding value to commodity production through new varietal traits or improved post-harvest utilization. The first column of figures is the size of the 5-year research investment (by CIP plus complementary investments by NARS) to develop the technology to the point where it would be ready for release to farmers or other users. The second column of figures restates the adoption ceiling thought likely to be reached 10 years after its release. The rest of the table reports quantified impact indicators for (i) aggregate economic surplus, (ii) economic benefits accruing to poor rural households, (iii) the net number of persons lifted over a $1/day/capita poverty line, (iv) the increase in rural employment, and (iv) the improvement to human health measured in terms of the number of Disability Adjusted Life-Years (DALY) saved.

While the indicators in Table 14 give a broader range of impact indicators than estimates of aggregate economic surplus alone, probably the most relevant measure for assessing the relative impact on poverty is the estimate of the economic benefit accruing to poor rural households. Conceptually, this is an improvement over the estimate of the "poverty content" of research benefits developed by Walker and Collion (1997) in CIP's last priority assessment exercise because it explicitly takes into account market price effects of technological change and the diminutive effect this may have on farm income. But from a practical standpoint it requires much more information to derive and is only as good as the accuracy of the parameters used to estimate it. The estimate of the number of person lifted out of poverty, while intuitively appealing, is *not* an appropriate guide for how to choose among research investments to maximize impact on poverty. It is limited by the arbitrariness of the poverty line itself. It will be biased toward technologies that are adopted in locations where there are large numbers of persons with incomes just below the poverty line, since a small increment in income will be sufficient to push a large number above the line. It may show small impacts for technologies that help improve the livelihoods of significant numbers of very poor people who, though substantially better off than before, may still be defined as in poverty. Nevertheless, it is probably a valuable indicator for communicating the value of the institution to stakeholders given its intuitive clarity.

The employment impact indicator would be more relevant for a research portfolio that included both labor-saving and labor-using technologies. In CIP's case, none of the production-oriented technologies had any obvious negative implications for rural employment. Probably of more interest is whether research to expand post-harvest utilization might have a significant effect on rural non-farm labor. But at the time of this writing we did not have sufficient information to assess the employment impacts of these technologies, so this assessment remains incomplete.

Table 14. Quantified impact indicators of CIP potato and sweetpotato research

Technology	CIP & NARS research investment 2006-2010	Adoption area by 2020	Aggregate economic surplus by 2020	Economic benefits to rural poor by 2020	Number of persons out of poverty by 2020	Rural employmen t impact by 2020	Human health impact by 2020
	mil. $	000 ha	mil $/year	mil $/year	000	000 work-years	DALY saved/year
Potato late blight management	20.3	693	319	175	1,302	72	
Potato seed systems improvement	9.6	654	257	152	857	77	
Potato breeding for virus resistance	12.3	220	119	65	526	35	
Potato breeding for processing	2.3	155	2	121	278	n.a.	
Potato insect IPM	9.2	129	28	12	76	5	
Potato bacterial wilt management	5.0	101	25	14	110	8	
Potato TPS	4.5	44	12	6	45	5	
Potato-cereal systems improvement	0.8	40	7	3	25	2	
Potato marketing & utilization improvement (PMCA)	6.4	17	4	9	31	2	
All Potato	70.3	2,054	773	558	3,250	206	
Sweetpotato seed quality & supply	4.3	908	284	253	1,526	42	
Sweetpotato breeding for high dry matter	4.9	315	92	80	293	16	
Sweetpotato breeding for high Vitamin A	8.9	140	29	23	181	4	21,048
Sweetpotato weevil IPM	1.3	197	39	31	161	7	
Sweetpotato utilization for animal feed	5.9	62	30	30	178	n.a.	
Sweetpotato small-enterprises, marketing systems & new product development	1.1	77	0	10	30	n.a.	
All Sweetpotato	26.4	1,699	474	428	2,369	69	21,048
All CIP Commodity Research	96.7	3,753	1,247	986	5,620	275	21,048

n.a. – not available.

Quantifying the human health impact of food crop biofortification provided a means for aggregating this impact together with the income effects to provide a more complete assessment of this research endeavor. Other technologies in CIP's research portfolio, especially technologies that are likely to reduce pesticide use and exposure, are also likely to have positive health impacts but could not be similarly quantified for this exercise. The qualitative assessments indicated that these health impacts were likely to be of most significance for integrated pest management (IPM) of potato insect pests. This would be a good candidate to focus future work to try to quantify these health impacts in a similar manner.

Ultimately, research priority assessment is about providing information on how to enhance the impact of the research investment. In CIP's case, the primary objective is to reduce the extent and depth of poverty in developing countries. Table 15 presents some indicators of the impact on poverty of the evaluated research endeavors relative to their research cost. While all but one or two meet or exceed normal project evaluation criterion for funding (and therefore warrant continued or increased support), these indicators point to ways CIP could increase its impact with its existing research resources, provided there was flexibility to reallocate these resources.

The first two columns of figures in Table 15 are evaluation criterion commonly used to assess project investments: the Net Present Value (NPV) and the Internal Rate of Return (IRR). We have only included the benefits accruing to rural poor on the benefit-side of these calculations to emphasis the returns to poverty reduction. The third column relates the annual benefits to poor once the adoption ceiling is reached to the size of the initial research investment (but it is not actually a benefit-cost ratio since it does not report this ratio in terms of present values). The column of figures shows the research expenditure required to lift one person out of poverty. With a few exceptions, these indicators generally show high returns to CIP's potato and sweetpotato research endeavors. In particular, the per capita "cost" of poverty reduction is quite low, averaging only $17/capita for CIP's commodity research programs as a whole. By way of comparison, Thirtle *et al.* (2003) estimated from historical evidence that the average per capita cost of reducing poverty through agricultural research was $144 in Africa, $180 in Asia, and $11,000 in Latin America (it should be noted, however, that *ex ante* estimates of returns to research are almost always higher than *ex post* estimates of returns).

In the final column, we indicate which of the research investments appear to be deserving of more support and where this increased support could be drawn from (i.e., those with relative over-investment). Sweetpotato appears to be significantly underfunded relative to potato. The higher returns to poverty reduction from sweetpotato research stems from both from the significance of this crop in very poor countries and the low current investment in sweetpotato research at CIP. Improving the quality and supply of sweetpotato planting material was judged to have the largest single potential to alleviate poverty and at the least cost per capita of poverty reduction. Other research endeavors that yielded a present value of at least $100 million in net benefits to rural poor were sweetpotato breeding for high dry matter and beta carotene (for Vitamin A), sweetpotato weevil management, and for potato, late blight control and improved seed quality and supply. Research endeavors with low impact on poverty per dollar of research expenditure included efforts to improve potato and sweetpotato marketing and utilization, True Potato Seed (TPS) and potato insect IPM. Potato IPM delivered virtually no income benefits to the poor over and above the cost of the research investment, and requires assertion of substantial environmental or health benefits to be justified.

Table 15. Returns to poverty reduction of CIP research endeavors

Technology	NPV of benefits to rural poor	IRR of benefits to rural poor	Annual benefits to poor per $1 of research	Per capita "cost" of poverty reduction	Under/over-investment to enhance poverty impact
	million $	%	$/year	$/person	
Potato late blight control	210	16	8.66	15.56	About right
Potato seed systems improvement	113	16	15.75	11.24	UNDER
Potato virus resistance	72	16	5.32	23.30	About right
Potato breeding for processing	52	26	53.52	8.11	UNDER
Potato insect IPM	(0)	3	1.36	121.40	OVER
Potato bacterial wilt management	8	7	2.84	45.41	OVER
Potato TPS	8	9	1.34	100.35	OVER
Potato-cereal systems improvement	2	6	3.63	31.99	OVER
Potato marketing & utilization improvement (PMCA)	1	3	1.42	206.04	OVER
All Potato	464	14	7.94	21.63	OVER
Sweetpotato seed quality & supply	394	30	58.47	2.83	UNDER
Sweetpotato breeding for high dry matter	101	25	16.26	16.83	UNDER
Sweetpotato breeding for high Vitamin A	123	21	2.60	48.92	About right
Sweetpotato weevil IPM	100	26	24.97	7.82	UNDER
Sweetpotato utilization for animal feed	20	12	5.19	32.97	About right
Sweetpotato small-enterprises, marketing systems & new product development	4	8	9.26	37.43	OVER
All Sweetpotato	741	23	16.24	11.13	UNDER
All CIP Commodity Research	1,206		10.20	17.20	

Significant opportunities exist for improving the poverty impact of CIP research by reallocating resources not only among technologies but among regions as well. Table 16 presents comparative impact per dollar of research investment for different regions of the developing world included in the assessment. The figures for research investment by region are based on self-reporting by research staff on the region of impact of the work they were doing in 2005 (which is not necessary the region in which they were physically located). The allocation by region includes CIP's entire research program, which includes research on natural resource management, urban and peri-urban agriculture, and native Andean crops in addition to potato and sweetpotato research (see Table 5), as we are unable to break out the allocation of commodity research alone by region. Commodity research at CIP is probably less heavily concentrated on Latin America than CIP's entire research portfolio, but not appreciably so. The estimates of the cost of poverty reduction indicate rather sharply that by focusing fewer resources on impact for Latin America and more resources on impact in Asia and Africa would markedly strengthen CIP's relevance for poverty alleviation.

Table 16. Regional allocation of CIP research resources relative to impact

Region	CIP research expenditures 2006-2010		Likely adoption area	Benefits to rural poor	No. of persons out of poverty	Per capita "cost" of poverty reduction	Under or over-investment in research for maximizing poverty impact
	mil. $	mil. $	1000 ha	mil $/year	000	$/person	
Northeast Asia	4.4	15.3	1,966	109	3,753	4.08	UNDER
Southeast Asia	6.9	7.4	102	3	160	46.33	OVER
South Asia	6.8	8.8	357	26	558	15.71	About right
Central Asia & Caucasus	2.8	3.6	149	1	178	20.33	OVER
Sub-Saharan Africa	17.4	22.8	983	118	810	28.17	UNDER
Latin America & Caribbean	40.9	42.1	212	11	161	261.75	OVER
Global	20.9						UNDER
Total	100.0	100.0	3,769	267	5,620	17.79	

CIP research expenditures by region are based on self-reporting by staff on the likely impact of their work in 2005. About 21 percent of CIP research staff time was devoted to issues with impact potential in all regions which is shown in the Table as "global." To derive the per capita cost of poverty reduction by region, "global" expenditures were allocated across regions in proportion to their likely adoption area (shown in the second column of figures).

The ability of CIP to take adjust to new situations and take advantages of new opportunities to reduce poverty hinges on having flexibility to move resources from one endeavor to another. However, the trend toward increased reliance on restricted project funding by donors has limited this flexibility at CIP as with the CGIAR system as a whole. At the time of CIP's 1996 priority assessment exercise, about one-third of CIP's budget was committed to restricted or ear-marked projects. The other two-thirds of CIP's budget came in the form of block grants, or unrestricted funds, where the institution has a degree of flexibility in resource allocation. By 2005, the share of restricted or ear-marked funds had risen to about 60 percent of CIP's total budget, while in real terms annual expenditures had actually declined. The imbalances among commodities, regions and research endeavors that are sources of inefficiency in poverty reduction are likely to remain unless more flexibility is restored to the institution or unless donors chose to fund projects more in balance with where the greatest opportunities exist for using agricultural science to reduce poverty.

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VIII. ANNEXES

ANNEX 1. TECHNOLOGIES NEEDS AND OPPORTUNITIES EVALUATED

Potato

1. Late blight disease management (including resistant varieties)
2. Bacterial wilt disease management (does not include resistant varieties)
3. Breeding for resistance to virus disease (PVY and PVLR)
4. Insect pest management (IPM) of the following potato pests: Potato tuber moths, leaf miner fly, Andean potato weevil, Colorado potato beetle (including GMO and non-GMO resistant varieties)
5. Potato seed improvement (including disease detection and elimination, rapid multiplication technology, management of formal and informal seed distribution systems, and farmer seed management)
6. Breeding for processing quality (especially for chipping quality)
7. Marketing chain improvement (enabling farmers to meet quality standards, linking small farmers to processors and new markets, new product development)
8. Breeding and propagation systems for True Potato Seed (TPS)
9. Potato-cereal cropping systems management in the Indo-Gangetic Plain

Sweetpotato

10. Breeding for high dry matter yield (for starch and flour utilization)
11. Breeding for high beta carotene (for Vitamin A)
12. Improving quality and supply of planting material, including virus control
13. Insect pest management (IPM) of the sweetpotato weevil (does not include resistant varieties)
14. Improving utilization of sweetpotato for animal feed
15. Improving utilization of sweetpotato for starch-based products (small enterprise development, linking small farmers to large processors, new product development)

Other technologies thought to be globally important but about which we did not have sufficient knowledge at present for impact assessment (work is underway to obtain this information).

1. Potato and sweetpotato drought tolerance (breeding and crop management)
2. Potato biofortification (breeding higher content of protein, Vitamin C, iron and/or zinc)
3. Sweetpotato biofortification for traits other than Vitamin A (especially, anthocyanin)

Others constraints primarily of local but not global importance (not formally evaluated)

1. Nematode pests of potato and sweetpotato
2. Crop production on problem soils (saline, acid, water logged, others)
3. Environmental tolerances in potato and sweetpotato (to shade, cold, and heat)
4. Other diseases of potato (early blight, erwinia, fusarium, others)
5. Other disease of sweetpotato (scab, others)
6. Other insect pests of potato and sweetpotato
7. Seed and ware storage of potato and sweetpotato

ANNEX 2. LIST OF AGRO-ECOLOGIES AND COUNTRIES/PROVINCES

(51 potato, 40 sweetpotato, 68 total)

No.	Agroecology-potato	Agroecology-sweetpotato	Country	Region
1		Sub-tropical	China (Anhui)	ESEAP-NEA
2	Temperate-Continental		China (Gansu)	ESEAP-NEA
3		Sub-tropical	China (Guangxi)	ESEAP-NEA
4	Sub-tropical	Sub-tropical	China (Guizhou)	ESEAP-NEA
5	Temperate-Coastal		China (Hebei)	ESEAP-NEA
6	Temperate-Coastal		China (Heilongjiang)	ESEAP-NEA
7		Sub-tropical	China (Henan)	ESEAP-NEA
8		Sub-tropical	China (Hubei)	ESEAP-NEA
9		Sub-tropical	China (Hunan)	ESEAP-NEA
10		Sub-tropical	China (Jiangxi)	ESEAP-NEA
11	Temperate-Coastal		China (Jilin)	ESEAP-NEA
12	Temperate-Continental		China (Nei Mongol)	ESEAP-NEA
13	Temperate-Continental		China (Ningxia)	ESEAP-NEA
14	Temperate-Continental		China (Qinghai)	ESEAP-NEA
15	Temperate-Continental		China (Shaanxi)	ESEAP-NEA
16	Temperate-Continental		China (Shanxi)	ESEAP-NEA
17	Sub-tropical	Sub-tropical	China (Sichuan+Chongqing)	ESEAP-NEA
18	Sub-tropical		China (Yunnan)	ESEAP-NEA
19	Temperate-Coastal	Temperate	Korea, DPRK	ESEAP-NEA
20	Tropical highlands	Humid tropics	Indonesia	ESEAP-SEA
21		Tropical highlands	Indonesia (Papua)	ESEAP-SEA
22		Sub-tropical	Laos	ESEAP-SEA
23	Sub-tropical		Myanmar	ESEAP-SEA
24		Tropical highlands	Papua New Guinea	ESEAP-SEA
25	Tropical highlands	Humid tropics	Philippines	ESEAP-SEA
26		Semi-arid tropics	Timor Leste	ESEAP-SEA
27	Sub-tropical	Sub-tropical	Vietnam	ESEAP-SEA
28	Tropical highlands		Bolivia	LAC
29	Tropical highlands		Colombia	LAC
30		Sub-tropical	Cuba	LAC
31	Tropical highlands		Ecuador	LAC
32		Sub-tropical	Haiti	LAC
33	Tropical highlands	Sub-tropical	Peru	LAC

(Agro-ecologies and countries continued)

No.	Agroecology-potato	Agroecology-sweetpotato	Country	Region
34	Tropical highlands	Tropical highlands	Burundi	SSA-E
35	Tropical highlands	Humid tropics	Congo, DRC	SSA-E
36	Tropical highlands	Tropical highlands	Ethiopia	SSA-E
37	Tropical highlands	Tropical highlands	Kenya	SSA-E
38	Tropical highlands	Tropical highlands	Rwanda	SSA-E
39	Tropical highlands	Tropical highlands	Tanzania	SSA-E
40	Tropical highlands	Tropical highlands	Uganda	SSA-E
41	Tropical highlands	Humid tropics	Angola	SSA-S
42	Tropical highlands	Tropical highlands	Madagascar	SSA-S
43	Tropical highlands	Sub-tropical	Malawi	SSA-S
44	Tropical highlands	Sub-tropical	Mozambique	SSA-S
45		Sub-tropical	Zambia	SSA-S
46		Semi-arid tropics	Burkina Faso	SSA-W
47	Tropical highlands	Humid tropics	Cameroon	SSA-W
48		Humid tropics	Ghana	SSA-W
49		Semi-arid tropics	Niger	SSA-W
50	Tropical highlands	Humid tropics	Nigeria	SSA-W
51	Temperate-Continental		Armenia	SWCA-CAC
52	Temperate-Continental		Azerbaijan	SWCA-CAC
53	Temperate-Continental		Georgia	SWCA-CAC
54	Temperate-Continental		Kazakhstan	SWCA-CAC
55	Temperate-Continental		Kyrgyzstan	SWCA-CAC
56	Temperate-Continental		Tajikistan	SWCA-CAC
57	Temperate-Continental		Turkmenistan	SWCA-CAC
58	Temperate-Continental		Uzbekistan	SWCA-CAC
59	Sub-tropical		Afghanistan	SWCA-SA
60	Sub-tropical	Sub-tropical	Bangladesh	SWCA-SA
61	Sub-tropical		Bhutan	SWCA-SA
62	Sub-tropical		India (Bihar)	SWCA-SA
63	Sub-tropical	Sub-tropical	India (NEH)	SWCA-SA
64		Sub-tropical	India (Orissa)	SWCA-SA
65	Sub-tropical	Sub-tropical	India (Uttar Pradesh)	SWCA-SA
66	Sub-tropical		India (West Bengal)	SWCA-SA
67	Sub-tropical		Nepal	SWCA-SA
68	Sub-tropical		Pakistan	SWCA-SA

ESEAP-NEA = Northeast Asia
ESEAP-SEA = Southeast Asia and the Pacific
LAC = Latin America and the Caribbean
SSA-E = Sub-Saharan Africa (East)
SSA-S = Sub-Saharan Africa (South)
SSA-W = Sub-Saharan Africa (West)
SWCA-SA = South Asia
SWCA-CAC = Central Asia and the Caucasus

ANNEX 3. MODELS FOR IMPACT EVALUATION

When a farmer adopts a new agricultural technology, she adds to the quality of her stock of "capital" from which she derives the various goods and services needed for the livelihood of her family. Household capital comes in various forms, and new agricultural technology can contribute to more than one kind of capital. The Sustainable Livelihood Systems framework counts five principal types of household capital: financial (money and credit), physical (buildings and equipment, livestock, seed and food stocks), natural resources (land and water), human (labor, health, knowledge and ability) and social (connections, access to services, political voice). These capitals represent the total assets or "wealth" of the household and the annual returns to these assets represent the "income" available to meet the needs for livelihood and for reinvesting to grow or at least maintain the household's capital stock. Poor households may not have enough income to meet their basic needs for subsistence much less to invest to maintain or grow their capital and thus maintain or grow their future income. They are thus caught in a poverty trap. New technology raises the quality of household capital by increasing the productivity of land, human and other household capitals. With more productive capital, the household enjoys a stream of higher annual incomes. If the higher income stream is sufficiently large so that the household can meet both its subsistence needs and allow for new capital investment, it can allow the family to break out of the poverty trap and enjoy a progressive improvement to its livelihood.[12] Sometimes adoption of a single agricultural technology may have such a large impact on productivity it will be sufficient to break the poverty trap. It is also possible that the training and knowledge a farmer receives could improve decision making for other aspects of farm management. In most cases a series of improved technologies will likely be required over time to break the rural poverty trap, especially when subsistence needs increase with population growth.

Our models for impact evaluation focus on measuring the increase in the annual income stream that results directly from adoption of a new technology. This "income" includes not only monetary or in-kind income earned from market transactions but also the value of home-produced goods that are consumed by the farm household. We also include in "income" a valuation of improved health resulting from less malnutrition. But we do not include the potential to further grow household capital by reinvesting part of the higher income from technology adoption. This and other "multiplier effects" are likely to be large but beyond the scope of this exercise to examine formally.[13] Nevertheless, we include in our poverty impact

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[12] An introduction to the Sustainable Livelihoods Framework for assessing poverty can be found in Scoones (1998) and Adato and Meinzen-Dick (2002). A good description of how capital accumulation by households breaks the poverty trap is given in an insightful new book, The End of Poverty, by Jeffery Sachs (2005, pp. 244-50).

[13] Haggblade and Hazell (1989) provide a good analytical review of multiplier effects of agricultural technology adoption on economic growth. There is also a long history of research that has shown that in very low-income countries where most of the population is engaged in semi-subsistence farming, agricultural growth is usually a perquisite for general

assessment whether the improvements in potato and sweetpotato productivity envisioned by CIP scientists are likely to raise the income stream of poor farm households above a $1/capita/day poverty threshold (in purchasing power parity dollars). Below this threshold households cannot meet their subsistence needs, so raising income levels above this level is essential for enabling families to break out of the poverty trap.

Our framework for assessing income and poverty impacts is to measure changes in producer and consumer welfare resulting from adoption of productivity-enhancing technologies. Specific models are described in this section for assessing welfare impacts of new technologies that (i) increase farm-level productivity, (ii) add value to the market chain, (iii) improve human health and (iv) enhance agricultural sustainability. We also present methods for extending these models to assess impacts on employment and poverty reduction. However, as noted in the previous section, not all of these quantitative assessments were completed within the time frame for CIP's priority assessment exercise. Environmental impacts, for example, were assessed only qualitatively. Indicators of poverty impact were only partially completed.

A3.1. Assessing impact of research to increase crop productivity

The framework for assessing the economic impact of adoption of new farm technology is shown in Figure 4. Adoption of technology reducing the marginal cost of production and shifts the supply function downward (shown by the arrow in Figure 4. Total output increases from Q_0 to Q_1. Depending on market demand conditions, this will put downward pressure on the market price (shown in Figure 4 to fall from P_0 to P_1). The change in total economic surplus (the social value of all welfare gains from technology adoption) is indicated by the shaded regions. These benefits are shared by farm households who produce the commodity and by non-farm households who can consume more food available at a lower price. Producers of the commodity who do not adopt the new technology may suffer a net income loss because they face the lower market price but do not achieve lower unit costs afforded by the new technology.

The framework described in Figure 4 provides a more rigorous approach than Eq 1 for assessing impact of agricultural technology adoption on poverty. The estimate of total economic surplus in Figure 4 is similar to the total expected benefits given in Eq 1,[14] but the added-value of the figure

economic and industrial growth, which results from the increased investment and resource transfer afforded by higher agricultural productivity (Johnson and Mellor, 1961; Hayami and Ruttan, 1985; Timmer, 2002).

[14] Eq 1 is equivalent to the changes in total economic surplus shown in Figure 4 in the special case where the supply elasticity is 1 and the demand elasticity is 0 (a supply elasticity of 1 assures that percentage changes in yield are equivalent to percentage changes in the marginal cost of production, and a demand elasticity of 0 will leave the market price unchanged even as market supply is increased).

is that one can extract from this total the share of benefits going to farm adopters and the share of benefits going to non-farm consumers. Most of the households in extreme poverty in developing countries live in rural areas and depend on agriculture for their livelihood. Thus, by focusing on how technology adoption affects the welfare of farm households, we get a clearer picture of the potential of agricultural research to reduce poverty.

In semi-subsistence agriculture, farm households may sell only a portion of their production and keep a significant part for home use either as food or animal feed. On-farm utilization of the commodity isolates it from the negative price effects described above. Thus, in semi-subsistence agriculture farm households are likely to capture a larger share of the welfare gains of productivity improvement in food crops than in fully commercial agriculture (Herdt and Hayami, 1977). We modify the model to account for the extent to which potato and sweetpotato are used on-farm in various countries and regions of the world. The modified model is illustrated in Figure and quantified in the equations that follow. In Figure 5, separate demand functions are specified for home food consumption, home feed utilization, and market demand for the commodity. Aggregate demand for the commodity is the horizontal summation of these use-specific demand functions and the elasticity of the aggregate demand function is the weighted average of the use-specific demand elasticities. An account is also made for a portion of the harvest to be retained as seed. Most econometrically-estimated demand elasticities are based on how market prices respond to the marketed surplus only and ignore options by the farm household to increase own utilization if the market price falls. Thus, these elasticities may significantly overstate the price effect of technology-induced supply changes. In terms of the welfare effects of this technological change, the farm household captures not only the gains in "producer surplus" from lower-cost production, but also the consumption benefits of farm and feed utilization (shown by the shaded regions in Figure 5).

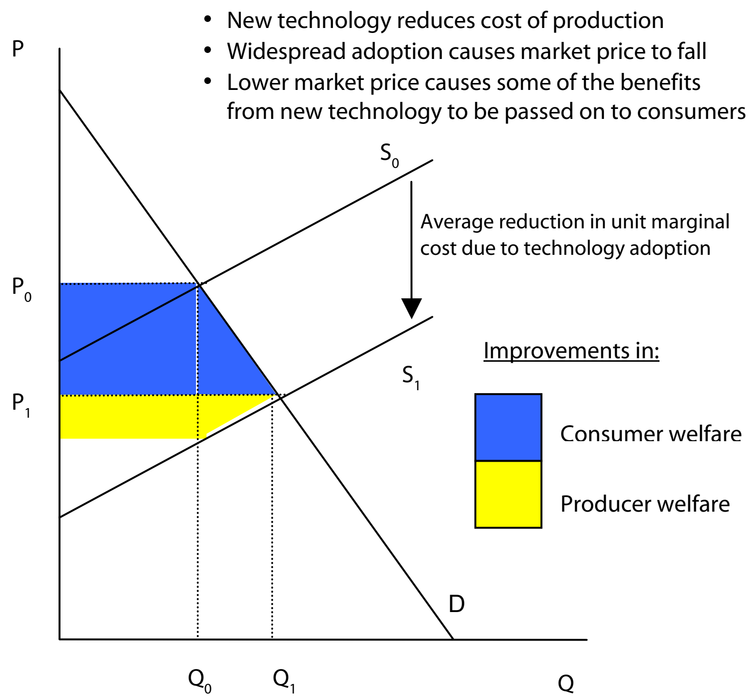


Figure 4. Economic impact of a yield-enhancing production technology

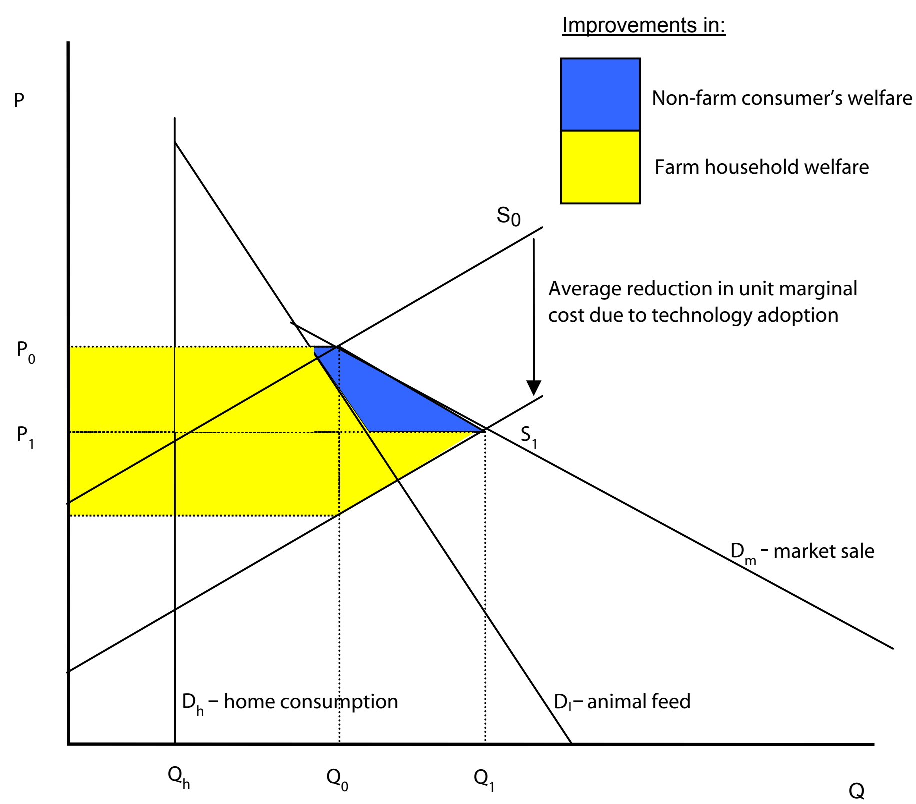


Figure 5. Distribution of economic benefits from technological change in semi-subsistence agriculture

The steps for estimating the economic impacts from productivity improvement in crop production are as follows: First, from the technology assessments made by scientists we determined the shift in commodity supply (the arrow in Figure 4) that is expected to result from technology adoption. We estimate this separately for each technology in each country where adoption is expected to occur. Let:

1. P_0 = initial market price of the commodity (US$/ton);
2. Q_0 = initial aggregate supply of the commodity (metric tons);
3. A_0 = initial area harvested (hectares)
4. Y_0 = initial average yield ($Y_0 = Q_0/A_0$ by definition)
5. Pr = probability that the technology is successfully developed;
6. ΔY = change in yield from technology adoption (% of Y_0);
7. ΔC = change in production cost from technology adoption (US$/ha);
8. A_T = expected adoption ceiling (% of current area);
9. ε = price elasticity of supply of the commodity (% increase in production for every 1% increase in market price);
10. U_m, U_f, U_l, and U_s = shares of crop production sold to market, consumed as food by the farm household, fed to on-farm animals, and used for seed or waste, respectively ($U_m+U_f+U_l+U_s = 1$ by definition);
11. η_m = price elasticity of demand for marketed surplus of a commodity;
12. η_f = price elasticity of demand for home food consumption;
13. η_l = price elasticity of demand for farm use as animal feed;
14. η_a = price elasticity of demand (in absolute value) averaged across all uses of the commodity (weighted by utilization share).

We express the shift in the commodity supply function resulting from adoption of the new technology by a parameter K, where K is the percent reduction in the marginal cost of production (relative to initial price P_0):

$$\textbf{Eq 2} \quad K = \Pr * A_T * \left(\frac{\Delta Y}{\varepsilon} + \frac{\Delta C}{P_0 Y_0} \right)$$

The part of **Eq 2** in the parenthesis measures the percent reduction in the unit cost of production on a representative farm that adopts the new technology. Multiplying by the fraction of the proportion of crop area where adoption occurs, A_T, converts this into the percent cost reduction of the aggregate supply function (i.e., the average of the unit production cost of adopters and non-adopters). Additionally, multiplying this by the probability of success translates the estimate of K into an expected value.

Once the shift in the supply function has been estimated (K in **Eq 2**), the second step is to determine its effect on market price. A reduction in the average unit cost of production can be expected to increase total supply and marketed surplus as farmers reap higher yields and adjust their crop acreage. This will put downward pressure on market price. The anticipated price effect is given by:

Eq 3 $$Z = \frac{K^* \varepsilon}{\eta_a + \varepsilon}.$$

Z is measured as a percent change in initial price P_0 (i.e., $Z = (P_0 - P_1)/P_0$) and takes a positive value when price falls. The reduction in market price will offset some of the incentive to increase production from the lower costs afforded by technology adoption. However, the net effect will be larger output and lower prices. Crop acreage could increase, stay the same, or even decline depending on market conditions. In the case of a subsistence crop for which there is not much market demand, higher yield may cause farmers to plant less of it (getting more production from fewer hectares), thereby freeing up farm land and labor for other crops.

The estimates of the supply shift K and the price effect Z provide the basis for disaggregating total welfare effects among producers and consumers. Changes in total economic surplus (ΔTS), the welfare of consumers who purchase the commodity at lower prices (ΔCS), and in the welfare of producing households (who may consume part of the crop), are given by[15]:

Eq 4 $$\Delta TS = P_0\, Q_0\, (1 - U_s)\, K \left(1 + \tfrac{1}{2} Z \eta_a\right)$$

Eq 5 $$\Delta CS = P_0\, Q_0\, (1 - U_s)\, Z \left(1 + \tfrac{1}{2} Z \eta_a\right)$$

Eq 6 $$\Delta PS = \Delta TS - \Delta CS.$$

where U_s is the share of production lost to waste or used for seed, so that Q_0 $(1-U_s)$ is net usable production. To help motivate these equations, note that a good approximation of the changes in total economic surplus from technological adoption is simply $P_0 Q_0 (1-U_s) * K$. K is a measure of the expected cost savings, as a percent of the total value or cost of current production, resulting from the higher yields or lower input use resulting from technology adoption. If ε=1 and η_a=0, then the total expected benefits measured by **Eq 1** in Section III exactly equals $P_0 Q_0 (1-U_s) * K$.[16] This is the economics benefits measure used by Walker and Collion (1996) in CIP's previous priority assessment exercise.

[15] See Alston, Pardey and Norton (1995), *Science Under Scarcity*, p. 211.

[16] When ε=1 and η_a=0, the total economic surplus given in Eq 4 is equivalent to the measure of total benefits used by Walker and Collion (1997) shown in Eq 1. See footnote 10.

A3.2. Assessing impact of research to enhance crop utilization and market systems

Research to improve marketing or expand utilization of crop commodities can affect the welfare of producers and consumers differently than research to expand crop production. Income benefits from post-harvest technologies will also be affected by whether the utilization takes place on the farm (such as though improvements to farm crop storage, animal feed utilization or small-scale processing) or off the farm (such as industrial processing of feed or food products). Our assessments included technologies of both types. Technologies expected to increase industrial demand for the commodities include crop varieties suitable for processing and methods to link small-scale farmer groups to new markets such as "participatory market-chain approach," or PMCA.[17] Technologies to improve on-farm utilization included improved utilization of sweetpotato for animal feed and methods to link farm-level primary starch processing with large-scale starch refining industries.

When new commodity utilization occurs primarily off the farm, the main way it affects farm household welfare is through higher prices for the marketed surplus. Higher market prices will affect not only the part of the crop that is sold to processors, but also the crop sold to consumers though the fresh market. This will likely be true even if the varieties are distinct for each market. The reason being is that as more farm resources are devoted to supplying processors, fewer resources are available to supply the fresh market, thus reducing net supply to the fresh market and causing prices to rise in this market as well. In some cases we observe higher prices being paid for processing varieties than for varieties sold to the fresh market; but this may reflect differences in the cost of production (with higher prices being paid to compensate for higher costs of production) or a premium processors are prepared to pay for regularity of supply and quality. It is unlikely that large price differences would persist between two market segments, other things being equal, as producers for the low-price market would have a strong incentive to switch to the high-price market and processors would have a strong incentive to switch to lower-cost farm suppliers. Farm-processor supply & procurement contracts may preserve price differentials for a while, but the party paying (receiving) the higher (lower) price would have an incentive to discontinue or renege upon the contract.

[17] See Bernet, T., A. Devaux, Ortiz, O. and Thiele, G.. (2005). Participatory Market Chain Approach. Participatory Research and Development for Sustainable Agriculture and Natural Resource Management: A Sourcebook. J. Gonsalves, T. Becker, A. Braunet al. Laguna, Philippines, CIP-UPWARD, IDRC, IFAD. **1**.

Figure 6 illustrates how increases in market utilization affect the welfare of producers and consumers. Suppose new products expand demand for a farm commodity by ΔM percent of initial production. This shifts the demand function outward (shown by the arrow in Figure 6), causing the market price to rise from P_0 to P_1. The total quantity supplied increases by less than ΔM percent, however: only some of the supply going to processors comes from new production. Some is supplied out of current production that is sold to the fresh market (thus reducing supply and raising the price in this market as well). Thus all farmers (adopters and non-adopters) who sell at least some of their crop production will benefit from this type of new technology. But consumers of the fresh product will lose welfare due to the higher price they must now pay. In Figure 6, the shaded areas indicate the welfare gain to producers. The increase in total economic surplus is given only area shaded in blue, however, as yellow-shaded area is an income transfer from consumers of the fresh product to producers. Not shown in Figure 6 are welfare effects on consumers of the processed product, who gain from expansion of supply of this type of product. But we have ignored these effects in our impact assessment, since we assume that the consumers of processed food products will be primarily non-poor and urban.

The assessment of the adoption ceiling was the likely level of market utilization that new products processed from these varieties would reach within 10 years after the new technology became available, which we define as ΔM (measured as a percent of current output). The effect on market price (denoted by Z_D to distinguish it from the price effect given in Eq 3) is:

Eq 7 $$Z_D = \Pr * A_T * \left(- \frac{\Delta M}{\eta_a + \varepsilon} \right).$$

Z_D is still defined as the expected change in $(P_0\text{-}P_1)/P_0$ at full adoption, but in this case has a negative value due to the rise in market price ($P_1>P_0$). Note that we include probability of success (Pr) and adoption ceiling in estimating Z_D (these are also included in the estimation of Z in Eq 3 since they are part of K).

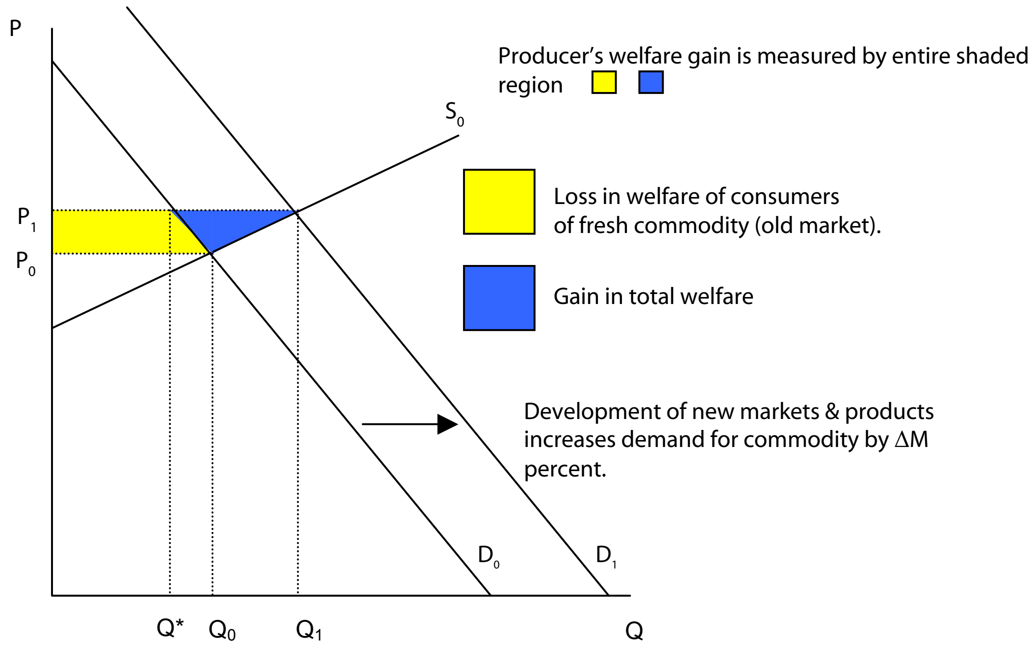


Figure 6. Economic impact of a new technology that expands market demand for an agricultural commodity

The effects on total, consumer and producer surplus resulting from the increase in commodity demand are given by:

Eq 8 $$\Delta TS = P_0\, Q_0\, (1-U_s)\, Z_D^2 \left(\frac{\eta_a + \varepsilon}{2}\right)$$

Eq 9 $$\Delta PS = P_0\, Q_0\, (1-U_s)(-Z_D)\left(1 - \tfrac{1}{2} Z_D \varepsilon\right)$$

Eq 10 $$\Delta CS = \Delta TS - \Delta PS = P_0\, Q_0\, (1-U_s)\, Z_D \left(1 + \tfrac{1}{2} Z_D \eta_a\right)$$

Note that since Z_D is negative (price rises) the change in consumer surplus is negative while the changes in total surplus and producer surplus are positive.

Technologies that improve the means of crop utilization by farmers themselves (such as small-scale processing or animal feed efficiency) will provide additional benefits to the farm household. Not only will producing the crop be more profitable (due to the rise in commodity price), but the farm family will also earn value-added from selling the processed product or meat. Figure 7 illustrates these gains. Here, the demand curve represents a "derived demand" for the crop, where the main market demand is for the processed product or meat. Improving the technology for on-farm processing shifts this derived demand curve outward. This increase in demand causes the price to rise from P_0 to P_1.[18] But in addition to producing a more valuable crop, farm households produce more of the transformed product more efficiently. The shaded region between P* and P_1 represents the increase in farm income due to higher profits from the farm processing or livestock enterprise.

Figure 7 presents a case where the entire crop is transformed into another product for market sale. If part of the crop is sold to the fresh market and part used for processing or feed, then the welfare implications are slightly more complex. All producers who sell part of the crop to the market, whether they process it or not, will gain from higher market prices for the crop, while consumers of the marketed surplus of the fresh crop will lose welfare from the higher market price. Suppose a new processing technology increases the efficiency of on-farm transformation of the crop by a technology shift parameter ΔL, where ΔL measures the change in unit processing cost as a percent of the initial crop price P_0. Let U_L be the share of the crop used for processing on-farm and U_m the share of the crop sold to the fresh market (with the associated demand elasticities η_l and η_m, and a weighted average demand elasticity of η_a). Then the changes in farm household welfare and consumer welfare can be estimated from the following relations:

Eq 11 $$Z_D = \Pr * A_T * \left(- \frac{\Delta L \, \eta_a}{(1 + \Delta L)(\eta_a + \varepsilon)} \right).$$

Eq 12 $$\Delta PS = P_0 \, Q_0 \, (U_L) \left(\frac{- Z_D (\eta_l + \varepsilon)}{\eta_l + Z_D (\eta_l + \varepsilon)} \right) \left(1 - \tfrac{1}{2} Z_D \varepsilon \right)$$

Eq 13 $$\Delta CS = P_0 \, Q_0 \, (U_m) \, Z_D \left(1 + \tfrac{1}{2} Z_D \eta_m \right).$$

Total welfare change is the sum of the changes to producer and consumer surplus. Again, Z_D takes a negative value (since prices rise). Therefore, ΔPS will be positive and ΔCS will be negative.

[18] In a situation where all of commodity production is used on-farm, then the price represents the shadow-value or opportunity cost of the commodity rather than its market price. The shadow-value is based on the factor shares of the processing or livestock operation.

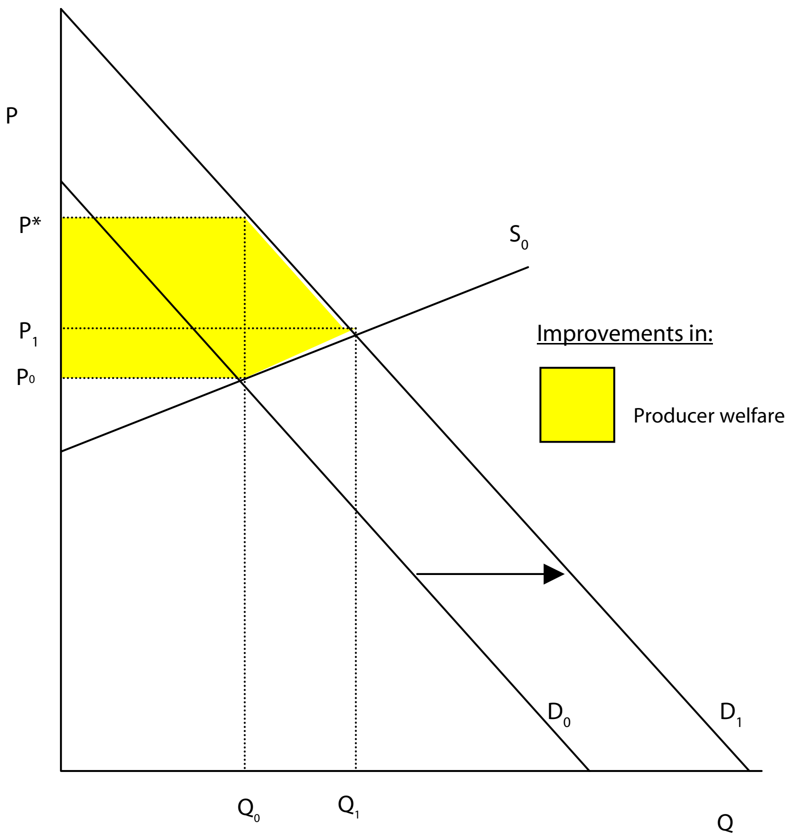


Figure 7. Economic impact of technology that improves on-farm transformation of commodity into higher-valued product

A3.3. Assessing impact of crop biofortification on human health

Exploiting the potential for improved technology for staple food production to alleviate malnutrition has been a driving force of the CGIAR system since its inception. One way this comes about is that it allows poor households to afford more food: poor producers who adopt new technology achieve higher incomes from farming and poor consumers gain in real income through the lower market price of food. There is ample evidence that among very poor households, higher income is associated with higher levels of macro-nutrient consumption.[19] It may also come about by enabling poor farm families to produce higher quality food to directly address micro-nutrient malnutrition. Both macro- and micro-nutrient deficiencies can lead to permanent disabilities or death, especially in young children. The potential impact of new agricultural technology on malnutrition is probably not fully measured by the economic surplus measures described in the previous section. Here, we describe an alternative approach for

[19] There is little question that among very poor households, an increase in real income leads to higher food consumption, both in terms of quantity and quality, and significantly reduces malnutrition. However, there is considerable debate on the size of these effects. Most studies suggest that among poor households every 1 percent increase in household expenditure increases per capita caloric intake by about 0.3 to 0.4 percent, although some studies have found significantly lower expenditure-calorie elasticities. Much of this debate arises from the difficulty in accurately measuring household income and food consumption. There is also the important issue of gender and age bias in intrahousehold resource allocation such that this elasticity may differ by source of income and across members of the households (see Deaton, 1997, p. 204-270, for a review and discussion of these issues).

quantifying potential impact of agricultural technology adoption on human health. This approach captures the potential life-long benefits of improving the nutrition. We apply the approach to the specific case of Vitamin A deficiency (VAD) and how improved varieties of sweetpotato rich in beta carotene may reduce the incidence and health cost of VAD.

Our approach to quantifying the potential human health impact of new agricultural technology is the Disability-Adjusted Life-Years (DALY) method. DALY measures the number of life-years (number of lives times the number of years an individual is affected by a health condition) lost or diminished due to illness or death. New technology that improves health reduces the number of DALY lost, which can then be translated into an economic measure for comparative purposes. This approach has been developed by the impact assessment team of the *HarvestPlus* Challenge Program (Stein *et al*,. 2005), although we have modified their method because of our concerns that their method may exaggerate the potential health impact of food crop biofortification (see Fuglie and Yanggen, 2006, for a complete description of our method and a comparison with the *HarvestPlus* approach). In principal the DALY approach could also be used to determine the potential human health benefits of reducing stunting in young children or exposure to pesticides by farm workers as well, although for this exercise we did not have sufficient information to evaluate these cases using this method.[20]

The DALY model includes the effects of morbidity and well as mortality related to a particular condition such as VAD, and expresses the resulting burden of disease in a single DALY index. DALY lost is the sum of 'years of life lost" due to cause-specific mortality and the sum of "years lives with a disability" due to a cause-specific morbidity (disease). The severity and the duration of the disability are taken into account. The disability is given a weight between 0 and 1 based on its severity (0 being equivalent to normal health and 1 with death). The estimate of the number of DALY lost annually (in present-value terms) is given by:

Eq 14 $$DALY_{lost} = \sum_j \left(\frac{1 - e^{-rL_j}}{r} \right) T_j\ M_j + \sum_i \sum_j \left(\frac{1 - e^{-rd_{ij}}}{r} \right) T_j\ I_{ij}\ D_{ij}$$

[20] An alternative economic evaluation method for assessing long-term health impacts is to estimate the present value of the loss in life-time earnings resulting from a death or disability. Selowsky and Taylor (1973) used this approach to estimate the economic cost of severe malnutrition in young children, which led to permanent reduction in mental function, lower schooling achievement, and lower life-time earnings. The DALY method uses "disability weights" ranging between 0 (for normal health) and 1 (death) to assess long-term impacts of a health condition. The disability weights are analogous to the downward shift in the life-time earnings profile of the alternative approach described by Selowsky and Taylor (1973).

T_j = total number of people in target group j
M_j = mortality rate associated with the deficiency in target group j
L_j = average remaining life expectancy for a person in target group j
I_{ij} = incidences rate of disease i in target group j
D_{ij} = disability weight for disease in target group j
d_{ij} = duration of the disease i in target group j
R = discount rate for future life-years.

The first term of **Eq 14** gives the present-value number of life-years lost due to VAD causes. The second term measures the morbidity effects of VAD: namely, on clinical VAD (blindness, night blindness, Bilots' spot, and cornea scaring) and measles. The target populations are children under 5 years of age, pregnant women, and lactating mothers. This approach gives greater weight to the effects on children relative to adults since the death or disability of a child may entail more 'life-years' lost. It also applies time discounting to life-year's lost, meaning that living in the present is given greater weight than living in the future. Finally, to derive an economic value to 'life-years saved' from an intervention such as adoption of a more nutritious diet, some economic value is applied. All of these points – on weighting of children versus adults, weighting the severity of disability versus death, discounting future life-years, and economic valuation of life, have been subject to considerable debate and discussion. Our approach is to follow the recommendations of the *HarvestPlus* impact assessment team in addressing these issues (Stein *et al*., 2005). See Table 17 for the disease components, disability weights and data sources used to estimate the health cost of VAD in terms of DALY.

Table 17. Elements and assumptions in estimating the health cost of Vitamin A deficiency

Disease	Disability weight *	Duration * (years)	Target population (UNICEF, 2005)	Source of statistics	Disease share attributed to VAD *
Clinical VAD	0.10	0.80	Preg. & Lact. Women	West *et al.* (2005)	100%
Clinical VAD	0.05	1.00	Children < 6	West *et al.* (2005)	100%
Measles	0.35	0.027	Children < 6	WHO (2006)	10%
Mortality	1.00	Life time	Children < 6	UNICEF (2005)	3%

VAD = Vitamin A deficiency; DALY = disability-adjusted life-year; N.A. = data not available.
* Disability weights, disease duration, and attribution to VAD are from Stein *et al.* (2005).

Once the current health cost of VAD is determined, the next step in the model is to determine how many DALY could be saved through adoption of biofortified sweetpotato. We use assumptions in Low *et al.* (2001) to determine the contribution of biofortified sweetpotato to Vitamin A intake, which holds average sweetpotato consumption constant but allows for replacement of varieties without beta carotene to be replaced by orange-fleshed varieties rich in this nutrient. We then determine how the incidence of VAD in a target population would change. For this, we first derive an estimate of the current mean intake of Vitamin A in a population that is consistent with the estimation of Vitamin A deficiency in that population. Assuming that current VA intake (CIVA) is normally distributed in the target population with mean μ and variance σ^2, then prevalence of VAD in that population is given by

$\Phi\left(\frac{CIVA-\mu}{\sigma} \leq \frac{RDA-\mu}{\sigma}\right) = VAD^O$, where Φ is the cumulative distribution function for the standard normal distribution.[21] Knowing VAD^o and σ we can therefore derive an estimate of μ, the current mean intake of Vitamin A in the target population. Although we do not have estimates for σ for all countries, we will assume a constant relationship of σ=1/3μ. This value is close to sample survey estimates of blood sample retinol levels given by West (2002) for Ecuador (μ=0.97 and σ=0.32 μmol/L) and Low *et al.* (2005) for Mozambique (μ=0.61 and σ=0.23 μmol/L). It also results in a very low proportion of below-zero values for Vitamin A intake (less than 1.3 percent). Then, the estimate of the mean current intake of Vitamin A among a target population is:

$$\textbf{Eq 15} \quad \mu = \frac{3\,RDA}{3+\Phi^{-1}\left(VAD^o\right)}.$$

We then determine how substituting OFSP for current varieties of sweetpotato would shift the VA distribution and derive a new estimate of VAD with biofortification. The shift in Vitamin A consumption in a population due to biofortification is illustrated in Figure 8 In the figure, the solid and dashed lines show the cumulative share of the population consuming at least an amount of Vitamin A given along the X-axis. The share of the population consuming less than the Recommended Daily Allowance of Vitamin A is considered to be deficient in this micro-nutrient. Assuming everyone in the population group adopts OFSP by about the same amount in their daily consumption shifts the VA distribution curve to the right, resulting in the dashed line. This reduces the proportion of the population suffering from VAD as shown by the arrow in the figure.

To account for seasonal availability of sweetpotato, it is useful to distinguish between the *prevalence* of a disease or health condition and its *incidence* in a population. Prevalence is a stock concept, giving the average proportion of a population suffering from the condition at a single point in time, while incidence is a flow concept, indicated the proportion of the population that will suffer the condition at some point in a year or in their lifetime. The two concepts are related by the average duration of the condition, with prevalence = incidence * duration. Adopting OFSP

[21] This is actually how the prevalence of VAD is determined from sample surveys of blood retinol levels in individuals. Using the mean and standard deviation of the sample and assuming normality, VAD prevalence is estimated as the area under the left-hand tail of the probability density function for vitamin intake below an RDA standard. The estimate is then adjusted by a weighting factor based on how representative the sample is judged to be of country-wide conditions (West, 2002).

during the months of the year when sweetpotato is available will reduce the average prevalence of VAD by reducing its duration.

Let λ be the increase in each person's Vitamin A consumption in a target population if OFSP is adopted. Then the mean intake of Vitamin A when sweetpotato is in season will be μ+λ and the seasonal prevalence of VAD will fall to:

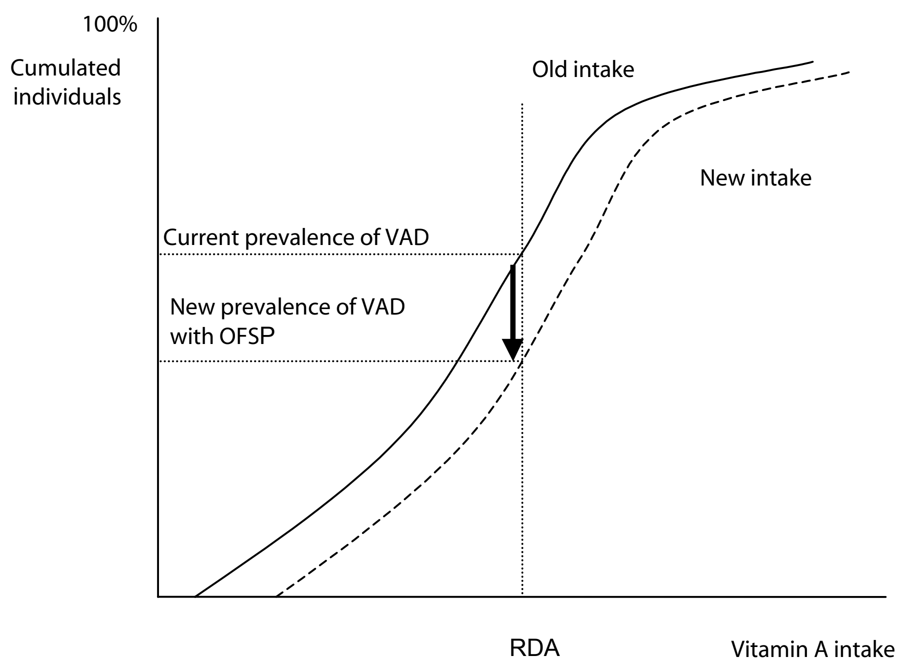
Eq 16 $$VAD^{*} = \Phi\left(\frac{RDA-(\mu+\lambda)}{\sigma}\right).$$

Let *M* be the number of months in a year when sweetpotato is in season. Then the new average prevalence of VAD in the population is:

Eq 17 $$VAD^{N} = VAD^{o}\left(\frac{M}{12}\right) + VAD^{*}\left(1-\frac{M}{12}\right).$$

To determine the efficacy of biofortification, we simply take the proportional reduction in average VAD prevalence, or $E=\left(VAD^{O}-VAD^{N}\right)/VAD^{O}$. With an estimate of the efficacy of OFSP consumption on VAD-related health outcomes, we then estimate a new value of the number DALY lost from VAD. The reduction in DALY lost (i.e., the number of DALY saved) due to adoption of OFSP gives an estimate of the potential impact of biofortification on human health. Applying a value to a DALY translates this into an economic value for benefit-cost analysis. Stein *et al*. (2005) suggest \$500 or \$1000 per DALY saved as we follow their recommendation. These values of the number of DALY saved and their economic worth are estimates of the maximum potential impact achievable through biofortification of sweetpotato in a country given current sweetpotato consumption, assuming everyone in the affected population consumes the biofortified varieties. The anticipated impacts used in this assessment are substantially lower than this potential, however. Anticipated impacts are based on the assessment of the likely adoption ceiling that would be reached 10 years after the new varieties were first released.

To implement this approach requires an estimate of λ, or per capita intake of Vitamin A from adoption of OFSP. We derive this using the approach suggested by Low, Walker and Hijmans (2001). We assume no change in current (average) per capita sweetpotato consumption in a country and then derive the Vitamin A content if this consumption consistent of OFSP varieties high in beta carotene. This method determined that after allowing for 35 percent losses during food handling, 100 grams of OFSP would provide 228 retinol activity equivalents (RAE), or 51 percent of the RDA of Vitamin A.[22] Assuming OFSP is available *M* months of the year, the average per capita intake of Vitamin A from OFSP, as a proportion of RDA, will be equal to $\left(\frac{x/365}{M/12}\right)*5.1$ where x = kilograms of sweetpotato/capita/year. For children under 5 years of age, we assume an average annual sweetpotato consumption of half the national average. For the rest of the year we assume Vitamin A intake is unchanged. We restrict the seasonal availability of sweetpotato to 5 months of the year for all of the countries in our study. This is the figure used by Low, Walker and Hijmans (2001) for Sub-Saharan Africa, and we suspect it applies reasonably well to most of Asia (Woolfe, 1992). Most of the consumption data are from FAOSTAT (see Fuglie and Yanggen, 2006, for the complete list of sources).



OFSP = orange-fleshed sweetpotato
VAD = Vitamin A deficiency
RDA = Recommended Daily Allowance

Figure 8. Impact of adoption of orange-fleshed sweetpotato on Vitamin A deficiency

[22] Using RDA as a cut-off level for measuring potential improvements from food-based nutritional interventions is again a necessary but undesirable simplification. Vitamin A requirements vary by individual and will be higher for persons that are sick. By definition, the RDA is simply the level at which the greatest majority of people is not at risk.

A3.4. Assessing impact of research on agricultural sustainability

Potato and sweetpotato are sometimes grown in fragile and marginal environments. Inappropriate land use management can result in declining productivity and increase vulnerability to climatic or other 'shocks' that disrupt production patterns. The long-term nature of these consequences necessitates a different approach for assessing the value of research to address them. First, improvements in the long-run productivity of agricultural land resources are measured using changes in the present value of net output. Second, improvements in the resilience of a system are measured by the degree to which the risk of negative production shocks is reduced, assuming that farm households exhibit a preference for stable income. These impacts on agricultural sustainability are illustrated in Figure 9 In the Figure, the long-run performance of the current production system is given by Y_0 and its performance under improved NRM is shown by Y_1. Adoption of NRM arrests the long-run decline in system production and also reduces variability in output.

To quantify the value of agricultural production systems with greater long-run productivity, we use an infinite time horizon model to measure the net present value of improvements to sustainability. For the purpose of economic valuation we assume that under improved natural resource management (NRM) practices, productivity of a production system will increase by λ percent each year over what would occur under present NRM practices (e.g., adoption arrests a yield decline of π percent per year). Thus, with adoption at time t=0 when yield is at Y_0, the yield improvement over what would have occurred without adoption is given by:

Eq 18 $$\Delta Y_t = Y_o \left(1 - e^{-\pi t}\right)$$

Further, we assume that adoption of improved NRM involves a one-time per hectare investment cost S_0 and a recurring maintenance cost of s each year. With an infinite time horizon, the present value of benefits per hectare of adoption of improved NRM at time t=0 can be expressed as:

Eq 19 $$PV_{NRM} = \int_0^{\infty} e^{-rt} \left[P_0 Y_0 \left(1 - e^{-rt}\right) - s\right] dt - S_0$$

where r is the discount rate applied to long-run sustainability valuation. This valuation simplifies to:

Eq 20 $$PV_{NRM} = P_0 Y_0 \frac{\pi}{r(r + \pi)} - \frac{s}{r} - S_0$$

For improvements in system resilience, we estimate the premium that risk-averse individuals would be willing to pay for more stable production systems. We estimate the welfare value of reducing risk following the mean-variance approach developed by Newbery and Stiglitz (1981). The value to farmers of reducing risk depends on (i) their preferences for risk-taking, (ii) how adoption of a new technology would lessen yield risk and (iii) the ability of farmers to adjust to income risk through transactions in credit and asset markets or changes in storage position. Assuming that farmers are risk averse and that their means of adjusting to income risk are small, we can expect they would benefit positively from adoption of new technologies that improve crop yield stability. To simplify the problem we further assume that price and yield risk are independent. Let σ_0 be the coefficient of variation of yield of the current system. Suppose this is reduced to σ_1 with adoption of new technology (i.e., $\sigma_1 < \sigma_0$). Letting farmers' average preference for risk be given by the relative risk aversion coefficient R, the annual benefit of improved stability (B_s) expressed as a percentage of current mean crop income (P_0Y_0) for greater yield stability is given by:

Eq 21 $$\frac{B_s}{P_0 Y_0} = \frac{1}{2} R \left(\sigma_0^2 - \sigma_1^2\right).$$

To illustrate, suppose presently the coefficient of yield variation in a drought-prone environment is 30 percent and breeders' estimate that drought tolerant varieties could be developed that would reduce yield variation to 20 percent with no change in average yield. Newbery and Stiglitz (1981) suggest a value of R=1 to represent risk-aversion attitudes of low-income farmers in developing countries. Then, according to **Eq 21**, the value to farmers of adopting these drought-tolerant varieties would be equal to five percent of the average value of crop production (or, equivalently, with the value of adopting a variety that increased yield by five percent).

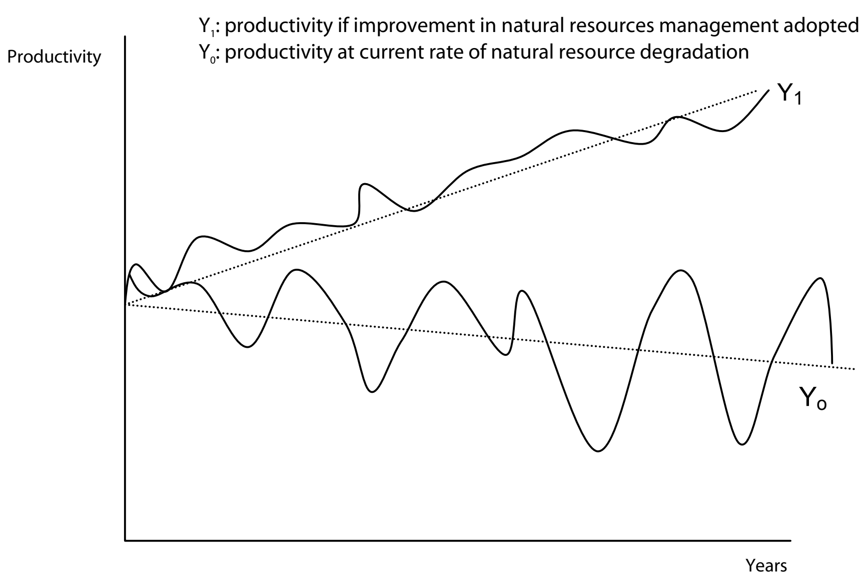


Figure 9. Impact of improved natural resource management on agricultural sustainability

A3.5. Assessing prospects for technology dissemination

To obtain the stream of benefits over time requires we first estimate a diffusion profile, for which we use a logistic curve. The logistic diffusion curve displays the typical S-shaped diffusion sequence in which adoption is at first slow but then picks up rapidly as the majority of potential adopters take up the new technology, finally slowing again as the aggregate adoption rate approaches the adoption ceiling. The logistic diffusion curve consists of three parameters: α, which measures the rate of adoption in the initial year of adoption, β which measures the speed of diffusion amongst the general farm population, and γ which measures the adoption ceiling. Given γ and with modest assumptions on α (i.e., assume only a small percent of farmers adopt the technology in its first year of use), then various values of β can be used to generate alternative diffusion profiles. We will select a low value of β to portray a slow rate of diffusion and a higher rate of β to portray a more rapid rate of uptake of the new technology. In either case, adoption approaches but does not exceed the adoption ceiling. The percentage of area or farms in a country having adopted the new technology in year t is then given by:

Eq 22 $$\theta^t = \frac{\gamma}{1 + e^{-(\alpha+\beta t)}}.$$

Some examples of diffusion curves are shown in Figure 10. In one case, the adoption ceiling is assumed to be 50 percent, and in another case the adoption ceiling is 30 percent. By selecting appropriate values of β, the more rapid diffusion curve shows the ceiling being reached in about 10 years for its introduction, while the more gradual diffusion curve shows the ceiling being reached in about 15 years.

For benefit cost analysis, the present value of CIP and NARS annual investment in research (R_t) and dissemination (D_t) for a specific technology is given by:

Eq 23 $$PV(Cost) = \sum_{t=0}^{T} e^{-rt} (R_t + D_t)$$

where r is the real discount rate.

The present expected value of aggregate economic benefits from this investment is given by

Eq 24 $$PV(Total\ Benefit) = \sum_{t=0}^{T} e^{-rt}\ \theta^t\ (\Delta TS).$$

The net present value is simply given by $PV(Total\ Benefit) - PV(Cost)$. The internal rate of return is given by solving for the discount rate *r* that equates the present values of benefits and costs. Similarly, we can consider only the benefits that are likely to accrue to farming households. These are given by:

Eq 25 $$PV(\text{Producer Benefit}) = \sum_{t=0}^{T} e^{-rt}\, \theta^{t}\, (\Delta PS).$$

For the benefit-cost analysis, we use a planning horizon of 30 years and assume a discount rate of 3 percent for determining net present value (NPV). Research costs are assumed to occur in the first 5 years of the planning horizon and extension to last over 10 years beginning in year 6. Adoption starts on year 6 and reaches an adoption ceiling after 10 or 20 years, depending on the diffusion scenarios for "rapid" and "slow" adoption, respectively. Once the adoption ceiling is reached, benefits are assumed to continue at this level until the end of the planning horizon. Benefits from adoption are estimated for each country where adoption is expected to occur and aggregated across countries to get an estimate of global expected benefits for each technology.

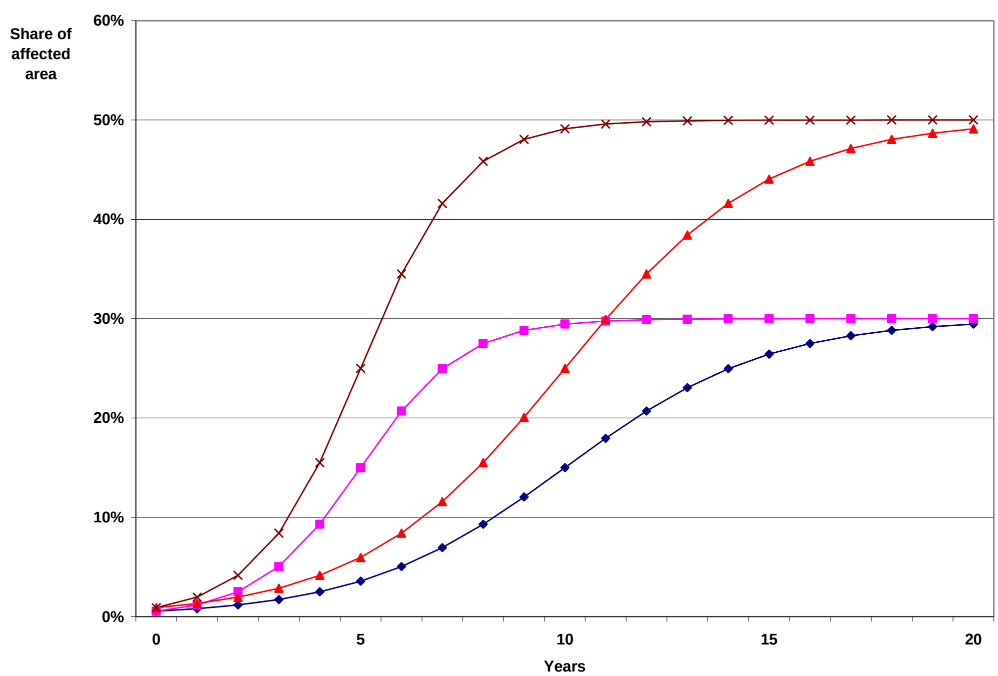


Figure 10. Diffusion of agricultural technology (logistic curve) over affected crop area

Adoption is given as the percentage of crop area in a country affected by a particular productivity constraint (see text). These logistic curves model four possible diffusion paths for new technology: two reach ceilings of 50% and 30% of affected crop area, respectively, in 10 years, and two reach the same ceiling after 20 years.

A3.6. Impact indicators of CIP's contribution to the MDG's

So far we have only developed a comparative assessment of expected economic net benefits from investing in various types of technologies and deploying them in various countries. To be more explicit about the contribution this would make to the MDG requires further information on how these benefits are distributed, especially the share of the benefits that are capture by poor households and how this affects their overall income. Further, new technology affects other dimensions of poverty, such as human health and natural resource sustainability.

First, consider impact on poverty reduction. To determine whether certain technologies may be more "pro-poor" than others, we weight the producer benefits derived above by the share of national population living below a poverty line ($1/capita/day). This is similar to the approach used by Walker and Collion (1997) to derive the "poverty content" of CIP's agricultural research endeavors, except that we have extracted out the likely benefits to farm producers from the estimate of total economic benefits used by Walker and Collion. The only exceptions are for countries in which either potato or sweetpotato is a major staple food of poor, non-farm consumers.[23] In these cases we include both consumer and producer benefits, weighted by the poverty index, to derive a rate of return to poverty benefits from an investment in research.

Another impact index that is often asked by research managers and donors is an estimate of the number of persons likely to be brought out of poverty as a result of CIP's research. This is a considerably more difficult task. Below, we illustrate a way to derive such an estimate, but note that to implement this procedure requires either considerable data or generous use of assumptions.

We estimate the likely impact of CIP's research program on the number of persons living in poverty not to compare various potato and sweetpotato research alternatives but rather to assess the expected impact of donor investment in CIP as a whole. The principal value of this measure, presumably, would be to compare with other donor investments in poverty reduction. To derive this measure in the absence of detailed household survey data linking household income and crop area, we need to employ a number of simplifying assumptions on crop area per poor

[23] In our exercise the cases where CIP commodities are considered to be major staples of non-farm poor include potato in the Andes countries and sweetpotato in Sub-Saharan Africa.

household and on the distribution of income among the poor. First, we obtain or derive country-specific estimates for the following variables:

1. θ*A = adoption ceiling of a technology, in hectares (is from the technology assessments and A is the total crop area in a country);
2. θ_P = share of adoption area by poor households.
3. A_h = average area planted to sweetpotato or potato per poor household per year;
4. N_h = average number of persons per farm household;
5. ω = the share of the population living below a poverty line (e.g., $1/day/capita);
6. φ = the poverty gap of the population below this poverty line (e.g., the average shortfall in income below the poverty line of the poor population expressed as a percentage of the poverty line; in other words, ω-φ is the average income of those in poverty);

We assume that all adopting households get the same benefit per hectare of adoption. If a farm household adopts a new technology, therefore, the benefit per hectare of adoption is given by $\Delta PS/(\theta * A)$, where ΔPS is the expected value of producer benefits once the adoption ceiling for this technology is reached and (θ*A) is the adoption ceiling expressed in number of hectares. The impact on daily per capita income for poor adopters can be estimated as:

$$\textbf{Eq 26} \quad \textit{Poverty Benefit per Capita} \equiv PC = \frac{A_h\left(\dfrac{\Delta PS}{\theta * A}\right)}{365 * N_h}$$

To derive the number of poor beneficiaries from adoption requires an estimate of θ_P, the share of total adoption area by poor households (equivalently, θ_P equals the share of total producer benefits going to poor producers). Country-specific estimates of θ_P are rarely available, and the usual procedure is to assume $\theta_P = \omega$, or the national poverty index. In countries where farm size (or at least potato or sweetpotato area) is fairly uniform and where poverty rates are very high, then this is probably a fair approximation. But in countries were there is substantial inequity in land ownership, poor farm families may have substantially less land in potato or sweetpotato than the average, and θ_P might be significantly smaller than ω. θ_P could also be larger than ω if poor households were more likely to be producers of the crop than a farm family with higher income. With some estimate of θ_P, the number of poor households adopting the technologies in a country can be estimated as:

$$\textbf{Eq 27} \quad \textit{Number of poor beneficiaries} \equiv PB = N_h * \frac{\theta_p(\theta * A)}{A_n}$$

An approximation of the effect of technology adoption on the number of persons living in poverty is to assume that each person living in a farm household that adopts the new technologies increases his or her daily income by the amount given in **Eq 26**. If we knew the income distribution of adopters we could derive an estimate of the number whose income would rise above the poverty line following technology adoption. Suppose that the income distribution of those living below $1/day is approximately uniform[24] with mean daily income of this group equal to $1 minus the poverty gap (i.e., 1-φ). Then the share of poor adopters who are lifted above the poverty line after adopting the new technology is PC/2φ (see Figure 11). The number of poor beneficiaries lifted out of poverty is thus equal to:

$$\textbf{Eq 28} \quad \textit{Number of poor out of poverty} = \frac{PC}{2\varphi} * PB = \frac{\theta_p * \Delta PS}{365 * 2\varphi}$$

According to Eq 28, the number of persons lifted out of poverty in a country through adoption of an agricultural technology is simply the total daily benefits going to all poor divided by twice the poverty gap. For other income distributions like the normal or lognormal distribution, the estimate of the poverty impact will likely be higher, since a larger share of the poor population will be concentrated near the poverty line. Thus, **Eq 28** will likely provide a lower-bound estimate of the poverty impact of technology adoption.

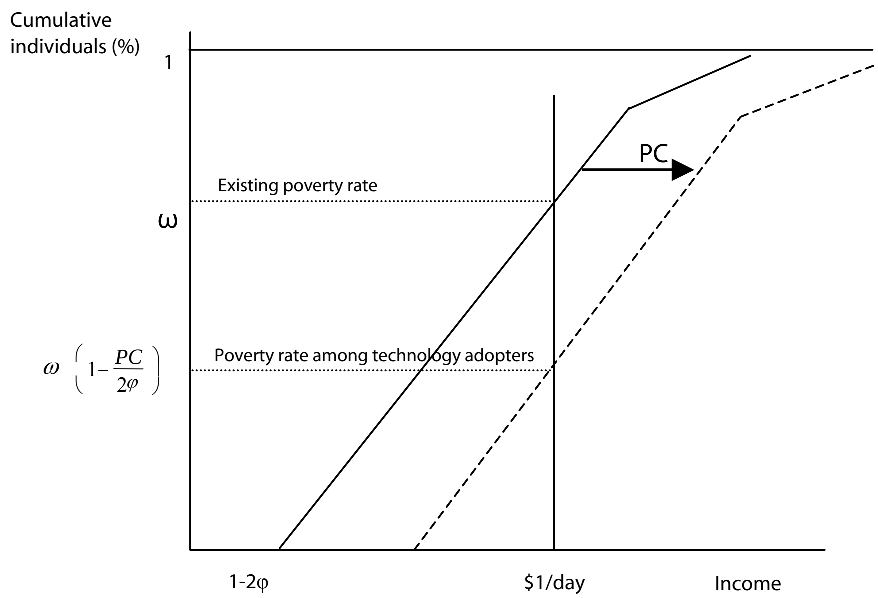


Figure 11. Effect of technology adoption on poverty.

[24] Usually, a lognormal function can be expected to provide a better fit to income distribution in a population. Here, I have assumed a uniform distribution because of its mathematical simplicity and also because it is less likely to exaggerate estimates of poverty reduction. Using a lognormal distribution would likely show larger impacts on poverty reduction because more of the poverty population will be concentrated near the poverty line. Formulas for assessing poverty reduction when incomes are distributed lognormally are given in Weisbrot *et al.* (2004).

In the figure, the income of persons living in poverty (below $1/capita/day) is assumed to be uniformly distributed among persons in the poverty group. The solid line shows the cumulative income distribution the poverty rate equal to ω and φ indicating the poverty gap. The minimum income of the population is therefore (1-2φ). With technology adoption, per capita income daily income of poor adopting households increases by PC. The new poverty rate among adopters is $\omega\left(1-PC/2\varphi\right)$.

One can do a similar exercise to determine the adverse effect of lower farmer prices on the welfare of non-adopters, which could push some of this group into poverty. Per capita effects are likely to be much smaller, however, especially in cases where poor households consume or use much of their crop on-farm, as well as the positive effects of lower prices on consumer welfare.

In addition to these indicators of income poverty impacts, we also report other impact indicators, such as on employment and health. Employment impacts are reported as the change in full-time equivalent workers employed annually (based on an annual work-year of 220 days). The health impacts are given both in terms of DALY and the number of lives saved and illnesses avoided annually. Most of the estimated DALY from sweetpotato biofortification results from lowering child mortality among the Vitamin A deficient group. In addition to the quantitative estimates, for some technologies we also report the qualitative scores for their anticipated health and environmental impacts. However, as previously mentioned, the qualitative indicators provide very little additional information for assessing the new technologies, since nearly all technologies were scored positively on these criteria.

ANNEX 4. RESULTS OF THE TECHNOLOGY ASSESSMENTS

A4.1 Potato

Technology	Agro-ecology	Potential Yield Increase	Potential production cost change ($/ha derived from % of actual cost)			Quality Improvement (price change)	Post-harv loss reduction (% actual losses)
			Seeds	Fungicide	Pesticide		
Control of Late Blight in potato	Highlands	40%		-$250/ha			5%
	Sub-tropical lowlands	20%		-$125/ha			10%
	Temperate	30% *(15%)*		-$125/ha			10%
	Probability of success	75%					
	Health Score	+1					
	Environment Score	+1					
	Alternative supplier	NO					
Control of Bacterial Wilt in potato	Highlands	10%	+$180/ha			50% (seed growers)	10%
	Sub-tropical lowlands	20%	+$180/ha			50% (seed growers)	60% (less rot)
	Temperate	0					
	Probability of success	60-65%					
	Health Score	0					
	Environment Score	+1					
	Alternative supplier	NO					

Technology	Agro-ecology	Potential Yield Increase	Potential production cost change ($/ha derived from % of actual cost)			Quality Improvement (price change)	Post-harv loss reduction (% actual losses)
			Seeds	Fungicide	Pesticide		
Propagation of Healthy Clonal Planting Materials for Potato	Highlands	30-40%					5
	Sub-tropical lowlands	40%					10
	Temperate	30%					5
	Probability of success	80%					
	Health Score	0					
	Environment Score	0					
	Alternative supplier	NO					
Potato viruses (Breeding)	Highlands	30%	-$120/ha		0	15%	5%
	Sub-tropical lowlands	40%	-$240/ha	0	-$40/ha	10%	5%
	Temperate	30%	-$180/ha	0	-$20/ha	10%	5%
	Probability of success	75%					
	Health Score	+1					
	Environment Score	+1					
	Alternative supplier	NO					

Technology Potato IPM of insect pests	Agro-ecology	Potential Yield Increase	Potential production cost change ($/ha derived from % of actual cost)			Quality Improvement (price change)	Post-harv loss reduction (% actual losses)
			Seeds	Fungicide	Pesticide		
PTM *(Tecia solanivora)*	Highlands (Columbia, Ecuador)	5% in field; 15% in store			-$200/ha		50-60% of losses; 15% store yld inc
PTM *(P. operculella* & *S. tangolias)*	Highlands (all Andes)	2% in field; 50% in store			-$100/ha		100% of losses; 50% store yld inc
PTM (*P. operculella*)	Highlands- ESEAP (Indo, Phil)	0% in field; 15% in store			-$100/ha		100% of losses; 15% store yld inc
PTM (*P. operculella*)	Highlands-SSA (Kenya, Ethiopia)	5% in field; 15% in store			-$100/ha		100% of losses; 15% store yld inc
PTM (*P. operculella*)	Highlands-SWCA (Nepal, India NEH, Bhutan)	0% in field; 15% in store			-$150/ha		100% of losses; 20% store yld inc
PTM (*P. operculella*)	Sub-tropical lowlands (Bangladesh)	0% in field; 20% in store			-$150/ha		100% of losses; 15% store yld inc
LMF	Highlands-ESEAP (Indo, Phil)	0% in field; 0% in store			-$400/ha		
LMF	Highlands-LAC (Peru coastal)	40% in field; 0% in store			-$400/ha		
CPB	Temperate	10% in field			-$100/ha		
APW	Highlands - LAC (all)	5% in field; 30% in store			-$200/ha		30% store yld inc
□		Prob. Of success		Health score	Envir. Score	Alt. Supplier	
PTM	- *P. operculella* & *S. tangolias*	80% (LAC & and others)		+2	+2	NO	
PTM	- *T. solanivora*	70% (LAC)		+2	+2	NO	
PTM	- Using GMOs	100 %		+2	+2	NO	
APW	- Using IPM	60% (LAC)		+2	+2	NO	
APW	- Using GMOs	60%		+2	+2	NO	
LMF	· Using IPM	70% (LAC & others)		+2	+2	NO	
CPB	· Using IPM	70% (CAC)		+2	+2	YES (USA public sector)	
CPB	Using GMOs	100%		+2	+2	YES (USA private sector)	

Technology TPS Breeding	Agro-ecology	Potential Yield Increase	Potential production cost change ($/ha derived from % of actual cost) Seeds	 Fungicide	 Pesticide	Quality Improvement (price change)	Post-harv loss reduction (% actual losses)
LAC	Highlands	40%	-$180/ha	-$250/ha	0	-10%	2%
ESEAP	Highlands	20%	-$180/ha	-$200/ha	0	-10%	4%
SWCA-Caucasus	Highlands	10%	0	0	0	0	4%
SWCA- Central Asia	Highlands	10%	0	0	0	0	4%
SWCA – Nepal	Highlands	18%	-$150/ha	0	0	0	0
SWCA – India NE	Highlands	42%	-$180/ha	0	0	0	0
SSA	Highlands	30%	-$240/ha	-$50/ha	0	-10%	2%
LAC	Sub-tropical lowlands	N/A	N/A	N/A	N/A	N/A	N/A
ESEAP	Sub-tropical lowlands	40%	-$180/ha	-30%	0	-10%	5%
SWCA - Bangladesh	Sub-tropical lowlands	15%	-$140/ha	0	0		
SSA	Sub-tropical lowlands	40%	-$240/ha	-20%	0	-10%	2%
SWCA-CAC	Temperate	5%	0	0	0	0	0
		Prob. of Success		Health score	Envir. Score	Alt. Supplier	
	LAC	60%		+1	+1	No	
	ESEAP	60%		+1	+1	No	
	SWCA-- Highlands Caucasus	5%		+1	+1	No	
	SWCA - Highlands Central Asia	10%		0	0	No	
	SWCA – Continental Central Asia	10%		0	0	No	
	SWCA – Nepal	70%					
	SWCA – India NEH States	60%					
	SWCA - Bangladesh	40%					
	SSA	60%					

Technology Potato	Agro-ecology	Potential Yield	Potential production cost change			Quality	Post-harv loss reduction
			($/ha derived from % of actual cost)			Improvement	
		Increase	Seeds	Fungicide	Pesticide	(price change)	(% actual losses)
Potato processing (breeding)	Highlands	10%	0	0	0	30%	10%
	Sub-tropical lowlands	20%	0	0	0	40%	15%
	Temperate	20%	0	0	0	50%	15%
	Probability of success	75%					
	Health Score	+1					
	Environment Score	+1					
	Alternative supplier	YES (private sector)					
Potato-cereal cropping systems							
SWCA - Bangladesh	Sub-tropical lowlands	7%					
SWCA - India	Sub-tropical lowlands	8%					
	Probability of success	50%					
	Health Score	0					
	Environment Score	0					
	Alternative supplier	NO					

A4.2 Sweetpotato

Technology Sweetpotato	Agro-ecology	Potential yield increase (%)	Potential production cost change ($/ha derived from % of actual cost)			Quality Improvement (price change)	Post-harv loss reduction (% actual losses)
			Seeds	Fertilizer	Pesticide		
Breeding for extractable dry matter = high starch low sugar sweetpotato	Humid tropics	3 - 20%	0	0	0	0%	5%
	Sub-tropical lowlands	4 - 20%	0	0	0	0%	5%
	Highlands	4 - 20%	0	0	0	0%	5%
	Probability of success	75%					
	Health Score	0					
	Environment Score	+1					
	Alternative supplier	YES (China NARS)					
Breeding for high food quality in storage roots and vines = high Beta Carotene, Fe, Zn and protein (plus acceptable dry matter)	Humid tropics	5 - 20%	0	0	0	0 - 5%	5%
	Sub-tropical lowlands	5 - 20%	0	0	0	0 - 5%	5%
	Highlands	8 - 20%	0	0	0	0 - 5%	5%
	Probability of success	90%					
	Health Score	+2					
	Environment Score	+1					
	Alternative supplier	NO					
Improved Planting Materials and Management Techniques for control of Viruses and other seed maladies	Humid tropics	50%	+5%	0	0	0%	0%
	Sub-tropical lowlands	50%	+5%	0	0	0%	0%
	Highlands	25%	+5%	0	0	0%	0%
	Probability of success	75%					
	Health Score	0					
	Environment Score	+1					
	Alternative supplier	NO					

Technology Sweetpotato utilization	Agro-ecology	Potential yield increase (%)	Potential production cost change ($/ha derived from % of actual cost)			Quality Improvement (price change)	Post-harv loss reduction (% actual losses)
			Seeds	Fertilizer	Pesticide		
New Utilization – animal feed (on-farm)	Humid tropics	Not applicable					
	Sub-tropical lowlands		0	+ $10/ha	0	30%	0%
	Highlands		0	+ $10/ha	0	10%	0%
	Probability of success	85%					
	Health Score	0					
	Environment Score	+1					
	Alternative supplier	NO					
New Utilization – market chain development	Humid tropics	0				10%	
	Sub-tropical lowlands	0				10%	
	Highlands	0				10%	
	Probability of success	50%					
	Health Score	0					
	Environment Score	0					
	Alternative supplier	YES (Private sector)					

Technology Sweetpotato IPM of insect pests (sweetpotato weevil species)	Agro-ecology	Potential yield increase (%)	Potential production cost change ($/ha derived from % of actual cost)			Quality Improvement (price change)	Post-harv loss reduction (% actual losses)
			Seeds	Fertilizer	Pesticide		
- C. brunneus & C. puncticolis	Highlands SSA (Lake Victoria, Ethiopia, Madagascar)	30%					
- C. brunneus & C. puncticolis	Humid tropics SSA (Nigeria, Cameroon, Ghana, Angola, Congo DR)	30%					
- C. formicarius	Sub tropical lowlands - LAC (Cuba)	20%	0	0	-$450/ha	0%	No data
- C. formicarius	Humid tropics - ESEAP (Indo, Phil)	10%					
- C. formicarius	Sub-tropical lowlands - SWCA (Orissa, Bihar, Bangladesh)	20%					
	Probability of success						
	- C. brunneus & C. puncticolis	60%					
	- C. formicarius	80%					
	- using GMO	50%					
	Health Score	+0					
	Environment Score	+1					
	Alternative supplier	NO					

ANNEX 5. FURTHER RESULTS OF PROJECTED IMPACTS BY COUNTRY

(Figures are in $1000/year after status quo adoption ceiling is research, except where otherwise indicated)

Table A5.1. Potato research aggregate impacts by country

Country / province	Region - Subregion	Late blight (breeding and mgmt)	Virus resistance (breeding)	Clean seed supply and management	Bacterial wilt management	IPM of insect pests	True Potato Seed (TPS)	Processing utilization (breeding)	Marketing and new products (PMCA)	Total impact	Total adoption area (ha)
Bolivia	LAC-Andes	2,405	0	479	139	824	0	4	861	4,712	32,910
Colombia	LAC-Andes	13,895	0	1,658	193	4,318	0	0	0	20,065	32,773
Ecuador	LAC-Andes	9,302	0	266	0	4,101	0	117	395	14,181	49,461
Peru	LAC-Andes	11,826	0	1,393	10	5,725	129	1	2,443	21,526	58,106
Total for region	LAC	37,428	0	3,795	342	14,968	129	121	3,699	60,483	173,249
Burundi	SSA-E	144	0	31	6	0	0	0	0	181	2,075
Congo, DRC	SSA-E	397	0	135	11	0	0	0	0	542	3,903
Ethiopia	SSA-E	4,483	0	2,874	83	0	0	0	0	7,440	39,285
Kenya	SSA-E	3,689	0	2,488	163	0	0	9	78	6,427	38,258
Rwanda	SSA-E	3,957	0	1,442	101	0	0	0	0	5,500	21,953
Tanzania	SSA-E	943	0	396	35	0	0	0	0	1,374	7,000
Uganda	SSA-E	2,086	0	1,328	90	0	0	0	40	3,544	20,419
Angola	SSA-S	45	0	19	0	0	0	0	0	64	833
Madagascar	SSA-S	1,201	0	473	50	0	0	0	0	1,724	10,059
Malawi	SSA-S	136	0	57	0	0	0	0	0	192	2,498
Mozambique	SSA-S	50	0	21	0	0	0	0	0	71	925
Cameroon	SSA-W	567	0	207	10	0	0	0	0	783	5,005
Nigeria	SSA-W	2,816	0	825	44	0	0	0	0	3,685	30,928
Total for Region	SSA	20,515	0	10,294	591	0	0	9	119	31,528	183,140

Country / province	Region - Subregion	Late blight (breeding and mgmt)	Virus resistance (breeding)	Clean seed supply and management	Bacterial wilt management	IPM of insect pests	True Potato Seed (TPS)	Processing utilization (breeding)	Marketing and new products (PMCA)	Total impact	Total adoption area (ha)
China (Gansu)	ESEAP-N	0	32,259	0	0	0	0	0	0	32,259	48,823
China (Guizhou)	ESEAP-N	50,870	0	50,007	0	0	0	0	0	100,877	281,737
China (Hebei)	ESEAP-N	0	0	0	0	0	0	69	0	69	15,804
China (Heilongjiang)	ESEAP-N	0	0	0	0	0	0	256	0	256	38,874
China (Jilin)	ESEAP-N	0	0	0	0	0	0	91	0	91	7,182
China (Nei Mongol)	ESEAP-N	0	33,649	0	0	0	0	212	0	33,861	105,811
China (Ningxia)	ESEAP-N	0	4,518	0	0	0	0	0	0	4,518	8,160
China (Qinghai)	ESEAP-N	0	5,341	0	0	0	0	0	0	5,341	6,110
China (Shaanxi)	ESEAP-N	0	0	0	0	0	0	0	0	0	0
China (Shanxi)	ESEAP-N	0	0	0	0	0	0	0	0	0	0
China (Sichuan)	ESEAP-N	66,528	0	65,444	10,287	0	0	0	0	142,259	370,784
China (Yunnan)	ESEAP-N	46,280	0	22,682	7,291	0	0	0	0	76,253	235,053
Korea, DPRK	ESEAP-N	0	28,443	13,400	0	0	0	0	0	41,842	95,478
Indonesia	ESEAP-S	4,276	0	0	0	132	0	14	0	4,422	8,514
Myanmar	ESEAP-S	7,036	0	0	0	0	0	0	0	7,036	10,089
Philippines	ESEAP-S	1,373	0	668	38	0	0	0	0	2,079	4,274
Vietnam	ESEAP-S	1,855	0	0	0	0	0	0	0	1,855	5,439
Total for Region	ESEAP	178,218	104,210	152,201	17,616	132	0	642	0	453,020	1,242,131
Afghanistan	SWCA-SA	570	0	1,754	0	0	0	0	0	2,324	2,975
Bangladesh	SWCA-SA	12,171	0	0	2,459	4,530	1,250	0	0	21,126	79,891
Bhutan	SWCA-SA	374	0	207	10	0	0	0	0	591	2,000
India (Bihar)	SWCA-SA	7,456	0	0	393	0	0	0	0	7,849	28,860
INDIA (NEH)	SWCA-SA	0	0	1,678	0	0	4,592	0	0	6,270	15,605
India (Uttar Pradesh)	SWCA-SA	0	0	0	0	0	0	142	0	142	20,250
India (West Bengal)	SWCA-SA	35,316	0	0	2,207	0	0	0	0	43,410	91,540
Nepal	SWCA-SA	15,564	0	0	213	4,678	4,938	0	0	25,393	70,720
Pakistan	SWCA-SA	4,324	0	0	683	0	0	0	0	5,007	11,288
Armenia	SWCA-CAC	2,001	1,986	1,595	0	111	0	0	0	5,693	22,449
Azerbaijan	SWCA-CAC	3,388	0	0	0	190	177	0	0	3,754	17,328
Georgia	SWCA-CAC	2,087	0	2,669	0	116	108	0	0	4,980	20,184
Kazakhstan	SWCA-CAC	0	8,584	0	0	591	0	0	0	9,175	41,083
Kyrgyzstan	SWCA-CAC	0	0	0	0	305	476	0	0	782	7,677
Tajikistan	SWCA-CAC	0	1,440	1,430	0	97	147	6	0	3,120	14,761
Turkmenistan	SWCA-CAC	0	0	0	0	11	0	0	0	11	300
Uzbekistan	SWCA-CAC	0	2,948	4,336	0	198	0	0	0	7,482	24,800
Total for Region	SWCA	83,252	14,957	13,669	5,964	10,828	11,688	148	0	147,110	471,711

Table A5.2. Potato research benefits to rural poor by country

Country / province	Region - Subregion	Late blight (breeding and mgmt)	Virus resistance (breeding)	Clean seed supply and management	Bacterial wilt management	IPM of insect pests	True Potato Seed (TPS)	Processing utilization (breeding)	Marketing and new products (PMCA)	Total impact	Total adoption area (ha)
Bolivia	LAC-Andes	346	0	69	20	118	0	74	308	935	32,910
Colombia	LAC-Andes	1,137	0	136	16	353	0	0	0	1,641	32,773
Ecuador	LAC-Andes	1,644	0	47	0	725	0	420	201	3,036	49,461
Peru	LAC-Andes	2,137	0	252	2	1,034	23	56	971	4,476	58,106
Total for region	LAC	5,263	0	503	38	2,231	23	551	1,480	10,089	173,249
Burundi	SSA-E	50	0	11	2	0	0	0	0	62	2,075
Congo, DRC	SSA-E	175	0	59	5	0	0	0	0	239	3,903
Ethiopia	SSA-E	649	0	416	12	0	0	0	0	1,076	39,285
Kenya	SSA-E	530	0	357	23	0	0	168	56	1,134	38,258
Rwanda	SSA-E	1,193	0	435	30	0	0	0	0	1,658	21,953
Tanzania	SSA-E	415	0	175	15	0	0	0	0	605	7,000
Uganda	SSA-E	1,115	0	710	48	0	0	0	112	1,985	20,419
Angola	SSA-S	14	0	6	0	0	0	0	0	20	833
Madagascar	SSA-S	462	0	182	19	0	0	0	0	662	10,059
Malawi	SSA-S	36	0	15	0	0	0	0	0	50	2,498
Mozambique	SSA-S	12	0	5	0	0	0	0	0	17	925
Cameroon	SSA-W	61	0	22	1	0	0	0	0	84	5,005
Nigeria	SSA-W	1,246	0	365	19	0	0	0	0	1,630	30,928
Total for Region	SSA	5,956	0	2,757	175	0	0	168	168	9,224	183,140

Country / province	Region - Subregion	Late blight (breeding and mgmt)	Virus resistance (breeding)	Clean seed supply and management	Bacterial wilt management	IPM of insect pests	True Potato Seed (TPS)	Processing utilization (breeding)	Marketing and new products (PMCA)	Total impact	Total adoption area (ha)
China (Gansu)	ESEAP-N	0	7,531	0	0	0	0	0	0	7,531	48,823
China (Guizhou)	ESEAP-N	10,036	0	9,866	0	0	0	0	0	19,902	281,737
China (Hebei)	ESEAP-N	0	0	0	0	0	0	974	0	974	15,804
China (Heilong.)	ESEAP-N	0	0	0	0	0	0	2,114	0	2,114	38,874
China (Jilin)	ESEAP-N	0	0	0	0	0	0	595	0	595	7,182
China (N. Mongol)	ESEAP-N	0	3,127	0	0	0	0	1,517	0	4,643	105,811
China (Ningxia)	ESEAP-N	0	603	0	0	0	0	0	0	603	8,160
China (Qinghai)	ESEAP-N	0	891	0	0	0	0	0	0	891	6,110
China (Shaanxi)	ESEAP-N	0	0	0	0	0	0	0	0	0	0
China (Shanxi)	ESEAP-N	0	0	0	0	0	0	0	0	0	0
China (Sichuan)	ESEAP-N	6,716	0	6,606	1,038	0	0	0	0	14,361	370,784
China (Yunnan)	ESEAP-N	7,924	0	3,884	1,248	0	0	0	0	13,056	235,053
Korea, DPRK	ESEAP-N	0	2,289	1,078	0	0	0	0	0	3,367	95,478
Indonesia	ESEAP-S	129	0	0	0	4	0	92	0	225	8,514
Myanmar	ESEAP-S	1,416	0	0	0	0	0	0	0	1,416	10,089
Philippines	ESEAP-S	86	0	42	2	0	0	0	0	129	4,274
Vietnam	ESEAP-S	28	0	0	0	0	0	0	0	28	5,439
Total for Region	ESEAP	26,335	14,441	21,476	2,289	4	0	5,292	0	69,837	1,242,131
Afghanistan	SWCA-SA	49	0	151	0	0	0	0	0	200	2,975
Bangladesh	SWCA-SA	1,890	0	0	382	703	194	0	0	3,280	79,891
Bhutan	SWCA-SA	88	0	48	2	0	0	0	0	138	2,000
India (Bihar)	SWCA-SA	1,786	0	0	94	0	0	0	0	1,880	28,860
INDIA (NEH)	SWCA-SA	0	0	347	0	0	950	0	0	1,297	15,605
India (Uttar Pradesh)	SWCA-SA	0	0	0	0	0	0	3,561	0	3,561	20,250
India (West Bengal)	SWCA-SA	4,507	0	0	282	0	0	0	0	5,540	91,540
Nepal	SWCA-SA	3,846	0	0	53	1,156	1,220	0	0	6,276	70,720
Pakistan	SWCA-SA	249	0	0	39	0	0	0	0	288	11,288
Armenia	SWCA-CAC	103	103	82	0	6	0	0	0	294	22,449
Azerbaijan	SWCA-CAC	50	0	0	0	3	3	0	0	55	17,328
Georgia	SWCA-CAC	23	0	29	0	1	1	0	0	54	20,184
Kazakhstan	SWCA-CAC	0	69	0	0	5	0	0	0	74	41,083
Kyrgyzstan	SWCA-CAC	0	0	0	0	2	4	0	0	6	7,677
Tajikistan	SWCA-CAC	0	43	43	0	3	4	40	0	133	14,761
Turkmenistan	SWCA-CAC	0	0	0	0	1	0	0	0	1	300
Uzbekistan	SWCA-CAC	0	205	302	0	14	0	0	0	521	24,800
Total for Region	SWCA	12,591	420	1,003	852	1,894	2,376	3,602	0	23,600	471,711

Table A5.3. Sweetpotato research aggregate impacts by country

Country / province	Region - Subregion	Breeding high Vitamin A	Planting material supply and virus mgmt	Utilization for animal feed	Breeding for high dry matter	IPM of sweetpotato weevil	Markets, small enterprises and new products	Total impact	Total adoption area (ha)*
Peru	LAC-Andes	858	0	0	1,468	0	0	2,326	5,776
Cuba	LAC-Carib	0	2,402	0	841	1,843	0	5,087	23,474
Haiti	LAC-Carib	0	0	0	330	177	0	507	9,253
Total for Region	LAC	858	2,402	0	2,639	2,020	0	7,920	38,503
Burundi	SSA-E	1,666	4,323	0	820	2,069	0	8,879	49,200
Congo, DRC	SSA-E	264	881	0	220	565	0	1,930	17,779
Etiopía	SSA-E	1,381	1,748	0	333	620	0	4,081	12,507
Kenya	SSA-E	1,868	2,836	0	540	1,345	1	6,590	26,161
Rwanda	SSA-E	2,168	5,838	0	1,106	2,802	0	11,915	71,364
Tanzania	SSA-E	6,597	21,637	0	4,112	10,289	4	42,639	218,196
Uganda	SSA-E	16,494	24,887	0	4,730	9,465	5	55,581	268,487
Angola	SSA-S	2,134	1,578	0	394	1,026	0	5,132	39,514
Madagascar	SSA-S	1,451	2,898	0	505	1,293	0	6,147	38,862
Malawi	SSA-S	3,103	6,891	0	1,720	4,236	0	15,949	51,514
Mozambique	SSA-S	2,110	379	0	67	167	0	2,723	4,320
Zambia	SSA-S	66	219	0	55	134	0	474	1,440
Burkina Faso	SSA-W	248	0	0	0	0	0	248	288
Cameroon	SSA-W	0	0	0	0	0	0	0	0
Ghana	SSA-W	0	0	0	0	0	0	0	0
Niger	SSA-W	299	0	0	0	0	0	299	104
Nigeria	SSA-W	0	0	0	0	0	0	0	0
Total for Region	SSA	39,849	74,117	0	14,601	34,011	9	162,588	799,737

Country / province	Region - Subregion	Breeding high Vitamin A	Planting material supply and virus mgmt	Utilization for animal feed	Breeding for high dry matter	IPM of sweetpotato weevil	Markets, small enterprises and new products	Total impact	Total adoption area (ha)*
CHINA (Anhui)	ESEAP-N	0	45,937	6,280	6,079	0	0	58,297	170,208
CHINA (Guangxi)	ESEAP-N	0	0	0	0	0	0	0	0
China (Guizhou)	ESEAP-N	0	0	0	0	0	0	0	0
CHINA (Henan)	ESEAP-N	0	0	0	0	0	0	0	0
CHINA (Hubei)	ESEAP-N	0	0	0	0	0	0	0	0
CHINA (Hunan)	ESEAP-N	0	0	0	0	0	0	0	0
CHINA (Jiangsu)	ESEAP-N	0	0	0	0	0	0	0	0
China (Sichuan)	ESEAP-N	0	156,783	21,412	20,748	0	15	198,958	582,069
Korea, DPRK	ESEAP-N	0	0	0	0	0	0	0	0
Indonesia	ESEAP-S	2,746	1,522	0	3,047	628	4	7,947	41,705
INDONESIA (Papua)	ESEAP-S	0	0	336	0	0	0	336	731
Laos	ESEAP-S	0	0	234	166	0	0	399	1,844
Papua New Guinea	ESEAP-S	0	0	478	0	0	0	478	2,053
Philippines	ESEAP-S	0	318	0	0	0	0	318	3,720
Timor Leste	ESEAP-S	0	0	7	300	0	0	308	4,067
Vietnam	ESEAP-S	0	0	1,656	1,664	0	0	3,321	19,896
Total for Region	ESEAP	2,746	204,559	30,404	32,004	628	19	270,360	826,293
Bangladesh	SWCA-SA	2,149	1,070	0	717	437	0	4,374	9,893
INDIA (NEH)	SWCA-SA	0	0	28	94	0	0	122	1,722
INDIA (Orissa)	SWCA-SA	2,799	1,264	0	847	778	0	5,688	15,235
India (Uttar Pradesh)	SWCA-SA	1,536	772	0	464	630	0	3,402	7,289
Total for Region	SWCA	6,485	3,106	28	2,122	1,845	0	13,586	34,139

* Countries or provinces having no adoption or impact are potential areas for impact but CIP is not currently engaged in these locations.

Table A5.4. Sweetpotato research benefits to rural poor by country

Country / province	Region - Subregion	Breeding high Vitamin A	Planting material supply and virus mgmt	Utilization for animal feed	Breeding for high dry matter	IPM of sweetpotato weevil	Markets, small enterprises and new products	Total impact	Total adoption area (ha)*
Peru	LAC-Andes	84	0	0	162	0	0	246	5,776
Cuba	LAC-Carib	0	65	0	23	50	0	138	23,474
Haiti	LAC-Carib	0	0	0	99	53	0	152	9,253
Total for Region	LAC	84	65	0	283	103	0	535	38,503
Burundi	SSA-E	909	2,359	0	447	1,129	0	4,844	49,200
Congo, DRC	SSA-E	185	617	0	154	395	0	1,351	17,779
Ethiopia	SSA-E	317	402	0	76	142	0	938	12,507
Kenya	SSA-E	426	647	0	123	307	22	1,525	26,161
Rwanda	SSA-E	1,120	3,016	0	572	1,448	0	6,155	71,364
Tanzania	SSA-E	4,618	15,146	0	2,879	7,202	511	30,356	218,196
Uganda	SSA-E	14,005	21,132	0	4,016	8,037	713	47,904	268,487
Angola	SSA-S	1,494	1,105	0	276	718	0	3,593	39,514
Madagascar	SSA-S	886	1,769	0	308	789	0	3,752	38,862
Malawi	SSA-S	1,293	2,871	0	717	1,765	0	6,644	51,514
Mozambique	SSA-S	799	143	0	25	63	4	1,035	4,320
Zambia	SSA-S	42	140	0	35	86	0	302	1,440
Burkina Faso	SSA-W	174	0	0	0	0	0	174	288
Cameroon	SSA-W	0	0	0	0	0	0	0	0
Ghana	SSA-W	0	0	0	0	0	0	0	0
Niger	SSA-W	209	0	0	0	0	0	209	104
Nigeria	SSA-W	0	0	0	0	0	0	0	0
Total for Region	SSA	26,476	49,345	0	9,628	22,081	1,251	108,781	799,737

Country / province	Region - Subregion	Breeding high Vitamin A	Planting material supply and virus mgmt	Utilization for animal feed	Breeding for high dry matter	IPM of sweetpotato weevil	Markets, small enterprises and new products	Total impact	Total adoption area (ha)*
CHINA (Anhui)	ESEAP-N	0	8,658	1,295	1,146	0	0	11,099	170,208
CHINA (Guangxi)	ESEAP-N	0	0	0	0	0	0	0	0
China (Guizhou)	ESEAP-N	0	0	0	0	0	0	0	0
CHINA (Henan)	ESEAP-N	0	0	0	0	0	0	0	0
CHINA (Hubei)	ESEAP-N	0	0	0	0	0	0	0	0
CHINA (Hunan)	ESEAP-N	0	0	0	0	0	0	0	0
CHINA (Jiangsu)	ESEAP-N	0	0	0	0	0	0	0	0
China (Sichuan)	ESEAP-N	0	22,975	3,433	3,040	0	434	29,882	582,069
Korea, DPRK	ESEAP-N	0	0	0	0	0	0	0	0
Indonesia	ESEAP-S	98	62	0	124	26	68	378	41,705
Indonesia (Papua)	ESEAP-S	0	0	61	0	0	0	61	731
Laos	ESEAP-S	0	0	61	40	0	0	101	1,844
Papua New Guinea	ESEAP-S	0	0	96	0	0	0	96	2,053
Philippines	ESEAP-S	0	27	0	0	0	0	27	3,720
Timor Leste	ESEAP-S	0	0	5	194	0	0	199	4,067
Vietnam	ESEAP-S	0	0	33	32	0	0	65	19,896
Total for Region	ESEAP	98	31,721	4,985	4,575	26	503	41,908	826,293
Bangladesh	SWCA	342	209	0	140	85	0	777	9,893
INDIA (NEH)	SWCA	0	0	14	32	0	0	46	1,722
INDIA (Orissa)	SWCA	718	381	0	255	234	0	1,589	15,235
India (Uttar Pradesh)	SWCA	362	243	0	146	199	0	950	7,289
Total for Region	SWCA	1,423	833	14	573	518	0	3,361	34,139

* Countries or provinces having no adoption or impact are potential areas for impact but CIP is not currently engaged in these locations.

CIP'S MISSION

The International Potato Center (CIP) seeks to reduce poverty and achieve food security on a sustained basis in developing countries through scientific research and related activities on potato, sweetpotato, and other root and tuber crops, and on the improved management of natural resources in potato and sweetpotato-based systems.

THE CIP VISION

The International Potato Center (CIP) will contribute to reducing poverty and hunger; improving human health; developing resilient, sustainable rural and urban livelihood systems; and improving access to the benefits of new and appropriate knowledge and technologies. CIP will address these challenges by convening and conducting research and supporting partnerships on root and tuber crops and on natural resources management in mountain systems and other less-favored areas where CIP can contribute to the achievement of healthy and sustainable human development.

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