Impact Assessment Analysis to Support International Agricultural Research Funding Decisions: Historical Overview, Methods and Applications at ICRISAT

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Abstract

This synthesis paper presents a historical evolution of the impact assessment analysis at ICRISAT to support its strategic research investment choices. It presents the methods and diverse applications with specific attention on methodologies and applications to improve the efficiency and reliability of the results from research priority setting processes. It documents the impact assessment tools adapted to support decision making and the types of decisions that were supported. A summary of the essential activities as well as the focus of the support and future directions are also covered. The important features of the economic framework are highlighted, particularly the multi-region traded good model and spillover estimation. While this overview illustrates the full range of parameters underlying the estimation of benefits from research investments, it draws attention to four recent interesting enhancements in the methodology and applications to support international agricultural research funding decisions.

The paper establishes clearly the factors which have influenced the Institute's concern with continuously strengthening its impact assessment and priority setting processes. At various stages, the set of criteria used for priority setting to reflect the overall goals of the CGIAR practically guided research priority setting. In particular, the CGIAR Independent Science and Partnership Council (ISPC, earlier Technical Advisory Council (TAC) and later the Science Council) identify the overall expanding research and development goals of the CGIAR. Through the ISPC, priority setting at the CGIAR system level is monitored centrally with the

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expectation that each Center's strategies should dovetail with system goals and priorities.

Another influencing factor is demonstrated through concrete evidence of the role of the almost 5 year cycles of External Program and Management Reviews which gave imperatives for developing more objective procedures to supporting research decision-making. Ultimately, the continuing implementation by the Institute to achieve more objective and evidence based decision making is demonstrated by its mainstreaming of the use of more systematic applied welfare economics framework approach in the context of the evolving development outcomes of the international agricultural research in the CGIAR. The priority-setting methodology developed was found to provide clear criteria for establishing choices among competing research activities across regions especially with consideration of spillover effects. It is more analytically rigorous, draws on scientists' empirical and intuitive knowledge base, and is transparent and interactive. ICRISAT continues to aspire to achieve specific development outcomes through research in the semi-arid tropics, and this intention is supported by an enhanced priority setting process with more detailed economic surplus quantification and increasingly more available reliable data.

Key Words: priority setting, agricultural research, impact assessment analysis, applied welfare economic framework, evidence based decision making

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1 Background and Introduction

From the early 90s to almost the end of the 2000s, ICRISAT continued to be confronted by the challenges of declining financial support for agricultural development. Increasingly, the major donors' imperative is to focus on countries with greatest need and sub-Saharan Africa (SSA) has been set as the targeted priority region. Priority for a larger emphasis on SSA dominated the CGIAR agenda in general and ICRISAT had to address this priority setting and resource allocation challenge across regions in particular. The fundamental question is to show evidence that the Institute can effectively and efficiently benefit less developed SAT regions in sub-Saharan Africa from its existing well established and advance research facilities based in Asia[7].

A key aspect of the whole priority setting and spillover context at ICRISAT is the Asia/Africa nexus. The debate about the relative resource allocation by ICRISAT on the two continents has featured strongly in Management decision making. Economists were challenged and explored the relevant methodologies to address the above persistent question. A review of literature and an inventory monograph containing the above research efforts on research spillover effects across regions were published in 2001 and 2004 respectively (Deb and Bantilan, 2001; Shiferaw et al., 2004). While two publications were released on the area of research spillovers, there remained a lack of actual objective estimates on the core parameter, namely, the likely research spillovers from Asia to Africa (or vice versa) for various types of potential research endeavors.

Continuing on the above effort, objective estimates using the economic surplus model was revitalized where global, regional and country level research benefits are estimated considering the applicability of research outputs beyond their targeted research domains. More recently, as disaggregated data to support this type of decision support has increasingly become accessible, a thorough analysis commenced at ICRISAT on estimating the likely spillovers among regions and continents. In this process, a core team of young scientists have been trained in this area as ICRISAT undertook significant assessment of ICRISAT's inter-regional research spillovers. This encompassed ICRISAT social scientists'

[7] In addressing this issue, reference to the estimates from priority setting efforts has been called for, particularly appealing to the substantial spillover benefits of both upstream crop improvement and natural resource management (NRM) research undertaken in SAT Asia to the African SAT zones. In particular, the global applicability of international public goods (IPGs) from research for desirable traits for yield, disease resistance, and end-use quality were notable as follows: 1. peanut varieties released in 17 SSA countries; 2. pearl millet varieties released in 4 SSA countries; 3. sorghum varieties and hybrids in 13 SSA countries; and 4. chickpea varieties in 4 SSA countries. Furthermore, screening methods for disease resistance developed at headquarters are used in the ESA and WCA programs, and simulation models were adapted and validated for ICRISAT's mandate crops under SAT conditions.

capacity in defining research domains in close interaction with bio-physical scientists. Economists and bio-physical scientists' teamwork have flourished through the above interactions. It is noted that the impact assessment culture and evident appreciation and positive outlook of bio-physical scientists at various levels in ICRISAT has contributed to successful R&D process documentation as well as objective data along with subjective estimates of the applicability of technologies across research across production environments. An integrated economic framework was used to estimate the overall economic benefits from ICRISAT research with the goal of providing information for identifying priorities and research resource allocation. Some of the methodological challenges faced by the team and results of these efforts to address the above concerns are highlighted in this overview paper.

Thus, as ICRISAT celebrated its 40th anniversary in 2012, it saw the continuous research and development efforts on five mandate dryland cereals and grain legumes grown especially in the semi-arid tropics regions. During this period 1972 to 2012, ICRISAT expanded its research agenda along the research, development and innovation pathway with research objectives broadening from increased food production to include sustainable resource management and environmental concerns, gender and equity, among others. Along with the expansion of the research agenda, there has been greater appreciation of the need for quantifying the economic returns to research investment, and other dimensions of impact - social, environmental and institutional. In line with these changes, priority setting at ICRISAT changed with the principal scope widening from yield and nutrition gains primarily to include achieving equity and environmental sustainability. This change is reflected not only in the evolving institutional vision and strategy but also in its research priorities with a pursuit of a well-balanced and focused portfolio. Stronger accountability mechanisms have been motivated to achieve an objective and transparent priority setting. In this context, the establishment of a transparent, consistent, objective, and participatory priority setting process became essential in supporting institutional decisions and research planning. The process slowly evolved an institutional impact culture with heightened awareness among agricultural scientists and research managers about the expected benefits and payoffs from research.

This synthesis paper documents the research priority setting methods used at ICRISAT. Research evaluation and priority setting have evolved to provide continuous cycles of learning to improve impacts. Prior to 1992, research priorities were established based on consultative meetings with ICRISAT and NARS scientists to identify key productivity constraints and propose research themes and approaches to address them. For its 1994-1998 Medium Term Planning (MTP) cycle, ICRISAT undertook a quantitative priority setting exercise using clear criteria for establishing choices among competing research activities. This drew on scientists' empirical and intuitive knowledge base. Research themes identified were impact oriented, projecting clear milestones against which progress can be measured and evaluated ex-post. This identification formed an integral part of the research evaluation process and facilitated revising priorities in the light of such experiences.

Following the quantitative priority setting exercise, ICRISAT pursued extensive discussions with partners in the MTP 1998-2000 cycle and broad targets were identified to capture the areas of research and nature of the benefits they intended to deliver. In this case, four targets were articulated by ICRISAT including prosperity, diversity, environment and inclusiveness. Due to time and costs, simple scoring methods were used to rank identified constraints through a broader consultation within ICRISAT and beyond with all partners in the research and development continuum. The target of inclusiveness appealed to participatory methods to support the priority setting and decision support tools that facilitate the participation of stakeholders and allow them to express their preferences. Scoring methods were used to rank priorities in the subsequent three-year MTP cycles. In addition, ICRISAT enhanced priority setting through institutionalization, building up a structured database serving as benchmark of reference for future research evaluation, including qualitative impact indicators, using the results from numerous diffusion, adoption and impact assessment studies in setting priorities and mainstreaming poverty considerations.

CGIAR priorities consistently provided guidelines in which to cast ICRISAT priorities. The last two to three years witnessed another round of structural change in the CGIAR system which stimulated rejuvenated interest on targeting and priority setting across the agricultural research portfolio globally across centers and global research programs. This came at a time when ICRISAT had just completed an extensive External Program and Management review which recommended revitalizing its application of formal research priority setting and impact assessment methodology to support research decision making. Particularly notable are three recommendations, that is:

- Use of geospatial analysis, ecosystem and crop modelling, and an appropriate socioeconomic framework to support priority setting
- Thorough analysis of past and likely future research spillovers between Africa and Asia to guide ICRISAT resource allocations between those two regions
- Development of hypotheses that determine the IPG potential of ICRISAT's downstream work on technology development, testing and adaptation within an institutional innovations framework.

In this process, ICRISAT seriously embarked on a renewed effort to specifically address these three concerns. The Institute revisited and scrutinised suitable methodologies and applied them to generate data and information to support priority setting across the three regions in sub-Saharan Africa and Asia.

Table 1 presents a summary timeline of the research priority setting activities to support decision-making at ICRISAT. It includes the time horizon from 1980s to the present when methods and tools were harnessed to strengthen research priority setting capacity to address the increasing demand to support research decision making. The current effort especially addresses one persistent question relating to research investments in Sub-Saharan Africa and Asia. More recently, the challenges increased to complement the trends and spatial analysis with the analysis of global research spillovers as the Institute, in partnership with 4 other CGIAR centers and partners globally, bid for leadership of two major CGIAR Research Programs.

Table 1: A Summary of Research Impact Assessment to Support Decision-Making at ICRISAT

Time Period	*Priority Setting*	*Return on Investment- ex post*	*Comment*
1980-1992	Consultative Judgements TAC/CGIAR		Subjective determination via consultation based on TAC Guidelines
1992-1998	Scoring Model – 'tandem matrix'	Started as part of REIA program activities	Driven by tight budgets included establishment of REIA program, as recommended by 1998 EPMR Considerable quantification as input to scoring.
1999-2007	Scoring Model - CG	Guided by Science Council/SPIA requirements	Driven by change in structure of CGIAR
2008-present	Formal Spillover modelling via ES methods	Driven by recommendation of the 2008 EPMR	Driven by need for accountability The estimation of spillovers was suggested by EPMR as a way of addressing issue of SSA and Asia.
	Spatial tools and trends analysis in enhancing global foresight analysis and estimates on research spillovers	Review facilitated by the new ISPC suggested serious effort in measuring global research spillovers during CRP proposal review process.	CGIAR reviewers "must have" requirements in identifying research priorities

In the rest of this paper we, first, in section 2 provide more details of the activities summarised above and in Table 1. Section 3 summarizes the basis for selecting the framework being used to quantify potential research spillovers and how this relates to ex post assessment activities and other modelling for priority setting in the CG System. Section 4 summarises some preliminary results. Section 5 details framework enhancement and presents the estimation of parameters and concluding remarks are presented in section 6.

2 Research priority setting at ICRISAT: evolution from the 1980s to the present

Research priority setting involves a process of explicitly or implicitly making choices over possible research activities. ICRISAT has conducted formal or informal priority setting exercises to help set the research agenda, guide allocation of research resources, and improve the quality and efficiency of research. The outcome of these exercises is a ranking of research programs, projects or research themes within a program or global theme. Research priorities are set across commodities, regions, disciplines, technology types and research problems. Priorities are set at different levels including the global, regional, national, research program, and project. Decisions about resource allocation also differ depending on the level at which priorities are set.

The priority-setting initiative at ICRISAT has been sustained by a determination to build an objective and transparent basis through its Medium Term Plans (MTPs). ICRISAT faced the challenge of a changing external environment where funds for research were declining, especially starting in the early 90s and pursuit of a focused research agenda became imperative.

2.1 Early priority setting approaches (1980s - 1992) – Consultative Judgments

During the late 1980s to the early 1990s, ICRISAT followed the CGIAR Technical Advisory Council's (CGIAR/TAC) guidelines which identified four basic factors for identifying agricultural research priorities. These factors included: 1) comparative advantage, (e.g., the advantage that ICRISAT has in undertaking projects where long-term, continuous effort is required), 2) internationality, (i.e., the existence of externalities and spillover effects), 3) partnership, (i.e., encouragement of inter-center and center-NARS (national agricultural research system) activities), and 4) efficiency and equity.

The fourth factor related to total potential benefits and high expected payoffs, with consideration to the distributive consequences of successful research. This distributional element meant identifying the area (ecological and geographical regions) and people affected, the benefits of research in relation to costs, feasibility of implementation and successful completion, and potential effects on the livelihoods of the poorer or marginalized sections.

Efforts to establish research priorities were based on consultative meetings with ICRISAT scientists and NARES partners to identify key productivity constraints, and propose research themes and approaches to address them. These exercises help to build consensus around important issues especially when ICRISAT resources were expanding. This approach did not provide information on trade-offs between various research undertakings.

2.2 Quantitative priority setting for the 1994-1998 MTP – Scoring Model

For its MTP cycle 1994-1998, ICRISAT undertook a more significant effort for research priority setting. It involved application of a participatory approach and it prioritised among numerous competing research possibilities to make optimum use of scarce research funds against the background of a strategic plan. ICRISAT used an ex-ante multi-objective framework, considering indicators for economic efficiency, equity, internationality and sustainability, for assessing research priorities. A supply-side methodological orientation was used to complement the (CGIAR/TAC) demand-side analysis. The distinct advantage of the quantitative framework that was established is that at a time of intense competition for scarce funds, it made explicit the benefits that would flow from additional investments to an institute as well as the opportunity costs corresponding to reductions.

The priority-setting methodology used by ICRISAT was found to provide clear criteria for establishing choices among competing research activities. It was more analytically rigorous, drew on scientists' empirical and intuitive knowledge base, and was transparent and interactive. Research themes were identified along with expected impacts, projecting clear milestones against which progress could be measured and evaluated. The assumptions about prospective yield increases, research lags, probabilities of success, and adoption lags and ceilings were tested against actual delivery of a new research-induced technology. This formed an integral part of the research evaluation process and facilitated revising priorities in the light of such experiences. This type of methodology was also later applied in other CGIAR centers (IRRI 1997, ILRI 1999). The seminal work of Kelley, Ryan and Patel in 1995 laid the groundwork for rigorous priority setting at the institute level. The methodology was used by ICRISAT to develop its MTP 1994-1998 and is described below.

2.3 Influence from CGIAR priority guidelines (1999-2007)-Scoring model

In the follow-up MTP cycle for 1998-2000, ICRISAT pursued extensive discussions with partners in which broad targets were identified that captured the areas of research and the nature of the benefits they intended to deliver through these partnerships during the MTP period. Four scoring criteria used by ICRISAT include the prosperity, diversity, environment and inclusiveness.

Prosperity. Poverty is a fundamental cause of hunger, disease, environmental degradation, and a host of other afflictions. Since the majority of the poor in the SAT are engaged in farming or other agriculturally related enterprises, the road to prosperity lies in the development of more productive and efficient agricultural systems.

Diversity. Poor farmers with small landholdings cannot afford the risk of being overly dependent on just a few crops or cropping systems. Diversity creates options; it spreads risk; it evens out peaks and valleys in labor use and income; and it enables the creation of added value by expanding the application of farmers' management skills to new enterprises. More diverse, complex cropping systems are usually more robust and stable, and sustainable over time.

Environment. Environmental resources are the fundamental inputs of agriculture. The conscious or unconscious abuse of these resources can throw entire societies into poverty. This target has particular relevance to the SAT where poverty is a driving force behind short term exploitation of the environment to satisfy pressing food needs.

Inclusiveness. Research products must be understood and valued by those who use them if they are to have impact. It is difficult to achieve this unless stakeholders are involved in the identification of relevant research priorities, and in the research process itself.

The target of inclusiveness appealed to participatory methods to support the priority-setting process and decision-support tools that facilitate the participation of stakeholders, allowing them to express their preferences.

Subsequent three-year MTP cycles followed, and the criteria used to rank priorities were more or less maintained across regions. The strategies and priority guidelines offered by the CGIAR TAC (later called Science Council) were influential in this evolution. The criteria were broadened to include equity, efficiency, internationality sustainability, new science opportunity, relevance to NARS priorities, and future trends (Deb and Bantilan, 2001). Notably, major efforts continue to be launched to consult NARS partners and other stakeholders in the setting of priorities. The approaches to strategic planning and priority setting in the CGIAR continued to advance in the last few years, where the basis of priority setting not only became more inclusive and participatory, but also increasingly appeals to process plans for strategic planning, impact pathways, situation and outlook analysis, periodic commodity and sector reviews, and more systematic understanding and foresight of the external environment and mega trends (See Box 1). These approaches shaped the ICRISAT research priority setting effort in the 2000s, and were found to be consistent with the concurrent CGIAR research priorities and regional research priority setting by regional bodies such CORAF/WECARD, ASARECA and SADC.

However, with increasing pressure resulting from dwindling core funding in the period from 1999-2002, time and costs involved in implementing the rigorous priority setting approach used in the 1994-1998 cycle were not available and hence a simpler scoring method was used. In this case, a range of constraints was first identified through a large consultation process with partners in the research and development (R&D) continuum through a survey of significant constraints and opportunities in the semi-arid tropics. The results were shared in a series of consultative meetings at the regional level in West and Central Africa, Southern and Eastern Africa, and Asia. During these meetings, constraints and opportunities were translated into research themes. Using a matrix format, a simple mean-scoring method was used to rank the relative importance of these research themes.

Box 1: ICRISAT - Understanding the External Environment - SAT Futures Approach

The agricultural environment in the semi-arid tropics is constantly changing, in terms of cropping patterns, income opportunities, trade regulations, and other factors. In order to remain relevant, ICRISAT monitors these changes and their implications for the priorities and its research agenda. This monitoring process was formalized as a global research theme in the early 2000s (one of six themes at ICRISAT at that time) titled SAT Futures and Development Pathways. This global theme has three broad objectives: 1) to track changes in the external environment, and better understand the factors driving these changes, 2) correspondingly, review (and adjust where needed) ICRISAT's research agenda, priorities, and funding allocations among alternative research areas, and 3) provide an analytic, objective basis for research management decisions, i.e. a decision support system for senior management.

The SAT Futures project includes strategic socio-economic research in specific areas: commodity trends and market outlooks; input supply and access constraints; patterns and determinants of technology adoption; institutional innovations; and dynamics and determinants of poverty. These studies identify technological, policy, and institutional alternatives and development pathways to enhance the livelihoods of smallholder farmers in the SAT. They also inform and direct ICRISAT's research investment towards the most crucial areas.

The project uses a participatory approach. ICRISAT organized a series of brainstorming meetings to discuss poverty-related problems and their implications for research priorities. Many key stakeholders are involved to ensure that the final outputs reflected the diversity of views and experiences. These include national and international institutes, development investors, universities, the private sector, extension, NGOs, and farmer organizations. The broad involvement also enables tapping of the large, multidisciplinary pool of expertise in policy and planning, sustainable development, rainfed agriculture, agricultural economics, farming systems research, germplasm enhancement, environmental conservation, etc. Simultaneously, focus group meetings were also conducted in each region (East Africa, West and Central Africa, Southern Africa, South Asia, Southeast Asia), involving scientists from ICRISAT and partner institutions.

The SAT Futures approach in strategic planning and priority setting follows a systematic procedure: literature survey, data analysis, stakeholder consultations, and synthesis of the major issues. It seeks to identify the unique features of the SAT, and understand the differences in agricultural trends between the SAT and other regions of the developing world. During ICRISAT's research priority setting and visioning exercise during this period (early 2000), the process was supported by a review of major trends in SAT agriculture using available long term time series data from the 60s. The review summarized the major constraints limiting income growth, poverty alleviation, food security and environmental sustainability now and towards 2020, the implications for future R&D strategies and priorities for the SAT, and the roles for ICRISAT, NARS, NGOs and the private sector in implementing these R&D strategies.

Box 1 contd..
In sum, these initiatives led to: 1) development of guidelines to enhance participation in research, 2) clear identification of key issues and external factors affecting SAT agriculture, emerging challenges and opportunities, and strengths as well as gaps in existing research systems, 3) documentation: synthesis report summarizing responses from the baseline survey, as well as collation of relevant literature from other sources (eg World Bank, FAO), 4) development of a framework that underpins the critical issues in SAT agriculture, linking productivity, food security and poverty reduction, 5) update and analysis of micro-level data and macro-level statistics (both demographic and agricultural) to support research decision making, and 6) design of research for development strategies for the SAT, 7)

Several important strategy documents have been published: 1) Future challenges and opportunities for agricultural R&D in the SAT, 2) Future of agriculture in the SAT of Africa: an issues paper, and 3) Vision on SAT agriculture for Asia.

The SAT Futures project, too, has evolved, in response to this consultative exercise. Research has been refocused on three areas: 1) Strategic assessments for agriculture and economic growth in the SAT of Asia and Africa and implications for agricultural research priorities, 2) Development pathways and policies for rural livelihoods, and 3) Synthesis studies: lessons learned from impact studies, institutional arrangements and implications for research spillovers across regions.

The key question is: “How can agricultural research improve the payoffs to diverse and changing investment opportunities?” The ultimate objective is to steer research direction and development towards a more sustainable pathway, which addresses poverty and environmental degradation.

2.4 An Overview of ICRISAT Priority Setting and Impact Assessment Support: 1982 to Present Experience

An overview of ICRISAT priority setting and impact assessment experience is presented in Table 2. As was noted above with the increasing pressure resulting from dwindling core funding in the period from the mid -90s to early 2000, the time and costs involved in implementing the rigorous priority setting approach used in the 1992 exercise were not available, so a simpler scoring method was used. This section highlights four important considerations mainstreamed in the priority setting exercises:

- Structured database
- Institutionalization
- Inclusion of qualitative impacts in priority setting
- Mainstream poverty considerations into priority setting

Table 2:Summary of ICRISAT Priority Setting and Impact Assessment Support 1982 to Present

Decision Support Activity	Time Period	Decision Support Focus	Methodology	Key Parameters Quantified	Key Parameters Qualitatively Assessed
Priority Setting					
Consultative Judgements TAC	1980-1992	Initial research directions	Consultation using TAC guidelines	Productivity Area	
Scoring Model – 'tandem matrix'	1992-1998	Revised research directions with significant budget tightening	Scoring model using quantification of some impacts for all possible research options	Net present value, adoption, Sympson's internationality index	Equity index, sustainability index
Scoring Model – CG	1999-2007	Changing structure due to CG wide changes	Scoring model (referred to update of 1992-98 dataset	Production, Area, and update of parameters used in 1992	Inclusiveness, Diversity, Environmental sustainability
Formal Spillover Quantification via Economic Surplus (ES) methods	2008-present	External Review request for greater focus on spillovers.	Multi-region, trade good model with research domains for spillover estimations.	Production, Consumption, Prices, Elasticities of demand/supply, Spillovers, Research Domains, Research Focus, Probability of Innovative & Adaptive Research Success, Adoption, discount rate	Poverty reduction, Food and nutrition security, gender empowerment
Ex Post Impact Assessment					
Original assessments under REIA program activities	1992-1998	Support scoring model assessments and validate judgements	Economic Surplus modelling	Producer's surplus, Consumer's surplus, Total economic surplus, Net present value, Internal rate of return Production, Consumption, Prices, Elasticities of demand and supply, Adoption, exchange rate, discount rate	Environmental effects
Additional Impact Assessment via CG SPIA requirements	1999-2007	Provide CG SPIA requirements	Economic Surplus modelling	Producer's surplus, Consumer's surplus, Total economic surplus, Net present value, Internal rate of return Production, Consumption, Prices, Elasticities of demand and supply, Adoption, exchange rate, discount rate	Environmental effects
Strengthening via 2009 External Review. Establish IA Unit in 2012	2008 to present	Greater accountability and more comprehensive	Economic Surplus modelling cross check with expected spillover estimates.	Producer's surplus, Consumer's surplus, Total economic surplus, Net present value, Internal rate of return Production, Consumption, Prices, Elasticities of demand and supply, Adoption, exchange rate, discount rate	Poverty reduction, Food and nutrition security, Women empowerment

2.4.1 Structured database

Systematic calculation of the measures of the various priority-setting criteria requires a structured database. The database developed from the research evaluation and impact assessment (REIA) project of ICRISAT contains comprehensive information on variables including research objectives, target research domains, estimated yield losses, expected yield gains, probability of success, adoption rates and ceiling levels, research and adoption lags, expected output and manpower and capital requirements. This database serves as a benchmark or reference for research evaluation of future projects. This database was continuously updated through impact monitoring but not systematically.

2.4.2 Institutionalization

ICRISAT research management instituted a continuous cycle of priority setting with a defined and regular interval to provide an avenue of feedback and timely redirection of research. Establishing such a mechanism has already been earlier identified (Joshi and Bantilan, 2001) to require the following essential steps: (a) adaptation of a uniform methodological framework to assure comparability and consistency of identified priorities; (b) regular annual database updates; (c) establishment of a monitoring process for performance, adoption and impact; and (d) training to develop the capacity of scientists associated with priority setting. Training is essential not only to undertake priority setting consistently and objectively, but also to achieve transparency and active participation within the organization. In fact, in order to facilitate organizational priority-setting processes, a Monitoring and Evaluation (M&E) scheme was institutionalized by ICRISAT Governing Board (2004), whereby M&E should be written into research proposals such that movement along the research evaluation and impact pathway continuum can be monitored, any necessary mid-course adjustments could be made and ex-post impact assessments properly done.

2.4.3 Inclusion of qualitative impacts in priority setting

Since research evaluation and priority setting involve the process of making choices in the context of scarcity, most of the earlier efforts have placed emphasis on the economic principles of efficiency and on costs and benefits that can be expressed in monetary values. The latter raised concerns about qualitative aspects associated with externalities (Bantilan and Davis, 1991; Brennan and Bantilan, 2003), gender and distributional effects, and longer-term impacts which tend to be neglected with such an emphasis.

For inclusion of qualitative impacts in priority setting, a systematic documentation of the impact pathways has been useful in identifying the sources of the qualitative effects of technology adoption (Bantilan et al, 2005). The pathway helps in clarifying the nature of impacts by considering whether or not the expected changes due to technology adoption can be valued using conventional markets, and therefore identifying variables that have market impacts and those that relate to non-market effects. A listing of the potential positive and negative effects aids in the analysis of the market and non-market impacts of alternative technology options. This analysis is particularly useful for assessing qualitative effects and relative preferences among alternatives. It records the market impacts reflecting yield gains or reduced yield losses and changes in unit cost. The measurement of environmental effects in monetary terms within the context of economic surplus draws from changes in the social marginal cost of production (i.e., product supply) and the demand for the marketed product. The inventory of non-market effects may be substantial, e.g., significant positive effects may result in longer-term yield stability, or increased resource availability in the future. A detailed account of the analysis of possible market and nonmarket impacts is presented in Bantilan et al. (2005). This study explains how conventional calculations that exclude environmental effects can skew measures of the full potential benefits from an improved technology.

2.4.4 Mainstream poverty considerations in priority setting

Mainstreaming poverty considerations is an important issue in ICRISAT priority setting (Bantilan and Keatinge, 2007) in the light of recent developments in the global research agendas of international organizations, which have identified poverty eradication as a common goal (UN 2002 and CGIAR 2005). Mainstreaming poverty recognizes that there are at least five ways by which agricultural research can benefit the poor: 1) increasing poor farmers' productivity, 2) greater agricultural employment opportunities for small farmers and landless workers, 3) higher wages and growth in adopting regions, 4) lowering food prices, and 5) greater access to nutritive crops.

Ryan (2004) identified the following considerations in relation to poverty-targeted agricultural research priority setting: 1). It is not necessarily given that research investments targeted at the locations of the poor will achieve maximum impact on the resident poor. Many factors mediate this relationship and make it difficult to argue that priorities at the macro level should be primarily based upon the location of the poor. These factors include price effects, migration and research spillovers in other regions. However, as Fan and Hazell (2000) have shown, the marginal returns to research are higher in less-favored environments and also the effect of this on poverty alleviation is greater. Therefore it is not clear that it is appropriate to neglect the less-favored areas and allow "trickle down" forces from more favoured areas to equilibrate the benefits. 2) Wage and employment effects of targeted research can be counterintuitive. In particular, if labor-intensive commodities have nonresponsive demands, then research on those commodities could lead to mechanization or to their substitution in production of less labor-intensive commodities. 3) Growth linkages between agricultural and nearby rural industry can generate significant multiplier effects, benefiting the poor most when agricultural income is a high proportion of total income.

By analyzing a typology of agricultural regions based upon agroecological zones and socioeconomic factors that condition the size and distribution of benefits from technological change, five broad areas of focus for a pro-poor research agenda have been identified (Haddad and Hazell 2001): 1) increasing productivity in less-favored lands, especially in heavily populated areas but also in high-potential lands constrained by poor infrastructure and market access, 2) increasing production of staple food in areas where food price effects are still important and/or in areas that have a comparative advantage in growing these crops, 3) helping smallholder farms to diversity into higher-value products, especially in areas where market prospects are good, 4) increasing employment and income-earning opportunities for landless and near-landless workers in labor-surplus regions, and 5) nutritional enhancement of diets by investing in agricultural technology that reduces the price of micronutrient-rich foods; increase in physical access in remote rural areas, or increase in the nutrient content of food staple crops via traditional or transgenic technologies.

2.4.5 Addressing CGIAR priorities and regional emphasis

The environment facing publicly funded international agricultural research centers such as ICRISAT has changed significantly over the past two decades (ICRISAT, 2002; Byerlee, 2000). One important dimension of the changing agricultural research environment is the increased emphasis that is now given to food security and poverty alleviation. The CGIAR explicitly recognizes that investments in international public goods research, such as in international agricultural research centers, must have poverty and impact foci (GFAR & ISC, 2002). ICRISAT has embraced this perspective and is renewing its research efforts to give greater priority to problem-based, impact-driven science and output delivery (ICRISAT, 2002).

This changing context of agricultural research also implies that approaches to setting research priorities at ICRISAT must adapt to these changes. The new ICRISAT Vision and Strategy internalizes these changes. Recent CGIAR emphasis on a regional approach to agricultural research in order to better address poverty, food security, and the environment in developing countries, is being assumed by ICRISAT through its regionalized research and its administrative empowerment of the regions.

The ICRISAT Vision and Strategy (ICRISAT, 2002) as well as the 2003-2005 MTP have adapted to the CGIAR's new vision and ICRISAT has initiated steps to institutionalize regional research planning and priority setting. ICRISAT's current research strategy is addressed in 4 global themes and implemented through regional projects that are based on strategic regional priorities. However, to implement regional consultative priority setting, exercises must be done systematically at a regional level to support planning and resource allocation decisions. At this point, the CGIAR system priorities provide a framework for 80% of ICRISAT's priorities. Precedence models are used to allocate resources. In effect, the level of funding in the previous year is the basis for the following year's allocation of resources to project themes and projects. Research resources are increased or decreased marginally depending on the overall funding situation. Changes in total resources available are usually allocated in equal proportion across research themes. This approach is simple and quick and has minimal data requirements. It can also provide long-term continuity in funding of research themes and projects. One disadvantage of this approach is that it can continue allocating resources to research areas that have reached the limits of their productivity and for which changing research environment mean that they are not even high priority activities anymore. Precedence models are also not forward looking since funding decisions are based on past levels of resource allocation rather than on research investments that are likely to give the greatest impact. It is therefore difficult to use this model for introduction of new research areas.

2.5 Using the results of impact assessment in priority setting - learning cycles and feedback process

Ex-post impact assessment has a particular role in demonstrating the cost effectiveness of past investment for generating outcomes of interest and validating the relevance and efficiency of overall strategies pursued – and can be important for priority setting, based on actual evidence of impact. The pioneering effort on ex-post impact assessment at ICRISAT began as it initiated the Research Evaluation and Impact Assessment (REIA) Program in 1992. Impact culture was nurtured through the participatory role of all disciplines in the implementation of interactive process documentation and implementation of impact assessments under the guidance of economists in the ICRISAT Economics Research Program (also known through the years as Socioeconomics and Policy Program, Global Theme on SAT Futures and Development Pathways Theme, Global Theme on Institutions, Markets, Policy and Impacts and Research Program on Markets, Institutions and Policy).
An independent Impact Assessment Office (IAO), earlier established in 2000, was re-established in January 2011 to manage all ex-post impact assessment studies of the Institute. The office is responsible for ensuring that all ICRISAT research projects have clear, concise and measurable output and outcomes, leading to demonstrable impacts. The IAO ensures that all commissioned impact studies are credible and of high quality, and that these are appropriately documented for specific targeted groups. It is important to note that some of the targeted audiences have limited time to read a highly technical report, and hence the IAO coordinates the reproduction of the impact results into impact briefs that are easy to read and would encourage communication of impact results across different practitioners.

Research Priority Setting and ICRISAT's Impact Assessment Agenda

Extensive monitoring and evaluation of research projects often leads favorable outcomes attributed to them in impact assessment. Figure 1 adapted from Walker et al (2008) shows the linkages among ex-ante impact assessment (priority setting), monitoring and evaluation, and ex-post impact assessment showing the forward and backward flows of information. According to the illustration in Figure 1 flow of information from ex-post impact assessment to priority setting is a weaker link. The reasons for this weaker linkage are; a) insufficient investments in ex-post impact assessment to inform priority setting, b) scientists being optimistic about their research success – with high probabilities of technological support, it is difficult to work with such results in priority setting, and c) time lags may render the value of information less pertinent to today's challenges.

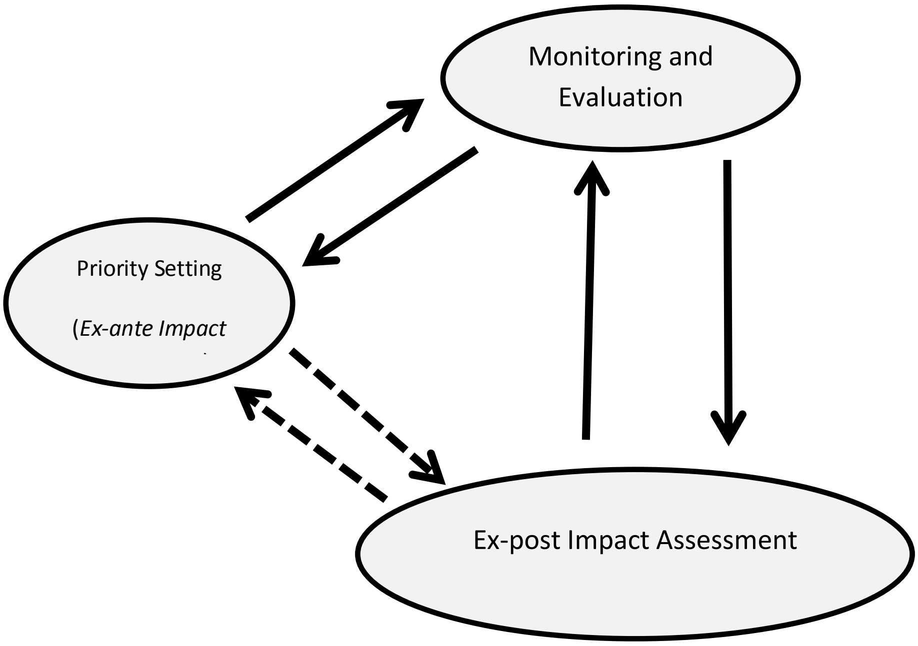


Figure 1. Linkages between priority setting and ex-post impact assessment (Walker et al 2008)

From the experience of ICRISAT, however, the linkages established were much stronger as the use of the results from "ex-post" impact assessment in "ex-ante" priority setting stimulated learning cycles and feedback processes. It has been demonstrated at ICRISAT that the process of assessing impact ex-post can generate insights that can help better inform ex-ante priority assessment and provide grounds for additional investment in the resultant research portfolio (Bantilan and Ryan 1996). More specifically, data from primary field studies provide a good basis for reasonable estimates of parameters, which are used in the priority-setting exercise, such as (i) levels and speed of adoption, and reasons for non-adoption of technology; (ii) farmers' perceptions of desirable traits or features of technology options; (iii) on-farm gains due to alleviation of biotic and abiotic constraints; and (iv) infrastructural, institutional and policy constraints in facilitating technology exchange.

Two categories of impact data were developed during the implementation of the Research Evaluation and Impact Assessment (REIA) research program at ICRISAT beginning 1992. The first is a set of primary data on adoption and related variables generated from formal and informal on-farm surveys. The second is a set of secondary data based on input from partner agencies. On-farm reconnaissance and formal surveys may be primarily aimed at continuously assessing the extent of adoption of improved technology from the secondary database. This confirms the extent of utilization of improved technologies by farmers in the target regions. Research lag is a major parameter determining the present value of research, and the cost of miscalculating it in terms of erroneous priority ranking can be substantial. Verification of research and adoption lags used can be accomplished by crosschecking ex post data from various sources.

Farmers' opinions on important constraints as well as their perceptions of desirable cultivation and management technology options may also be generated from primary surveys. These farmers' perspectives provide the following information: (a) they identify the constraints and research opportunities, (b) they provide an empirical basis for the expected ceiling levels of adoption, i.e. technologies introduced in an environment characterized by significant bottlenecks to adoption cannot be expected to have high adoption ceilings unless these constraints are addressed, and (c) they identify the research options that directly address the users' needs and are most likely to be adopted.

Estimates of yield losses due to important constraints and on-farm gains due to improved technology are also vital pieces of information for deciding research priorities. Impact studies can be used to validate estimates of expected yields. Furthermore, the estimates generated from these surveys (i.e., yield gains or unit cost reductions) also provide a way of predicting the potential supply shift, a necessary parameter for estimating potential impacts in cost/benefit analyses.

Another important outcome from impact studies is the assessment of researchers' perceptions or constraints, which can be technological, institutional, infrastructural and policy. Two aspects are relevant for seed policy and priority setting: (a) standard variety release procedures of breeders' selecting materials that can make it through the formal release system; and (b) criteria for varietal release do not necessarily match farmers' needs and preferences.

Referring to the reverse flow illustrated in Figure 1, the results of monitoring and evaluation should also have implication for setting priorities and for formulating new projects. This is based on an assumption that such research information can be included in a priority setting exercise. Ex-ante studies will inform hypotheses testing during the process of formulating ex-post impact assessment studies, which in turn should confront the predictions of ex-ante assessments. Also by comparing results of ex-ante and ex-post assessments it is useful for learning about predictive accuracy of ex-ante impact assessments particularly the assumptions which they were based.

Figure 2 illustrates the evolution in impact studies and priority setting at ICRISAT showing that since 1972, the institute research agenda has expanded impact focus from crop improvement, sustainable resource management, distribution, gender and capacity building. As mentioned earlier in the paper, priority setting at the institute also changed from productivity gains to achieving equity and environmental stability. The priority setting methodology developed provided criteria for establishing choices among competing research activities across regions, and considering spillover effects.

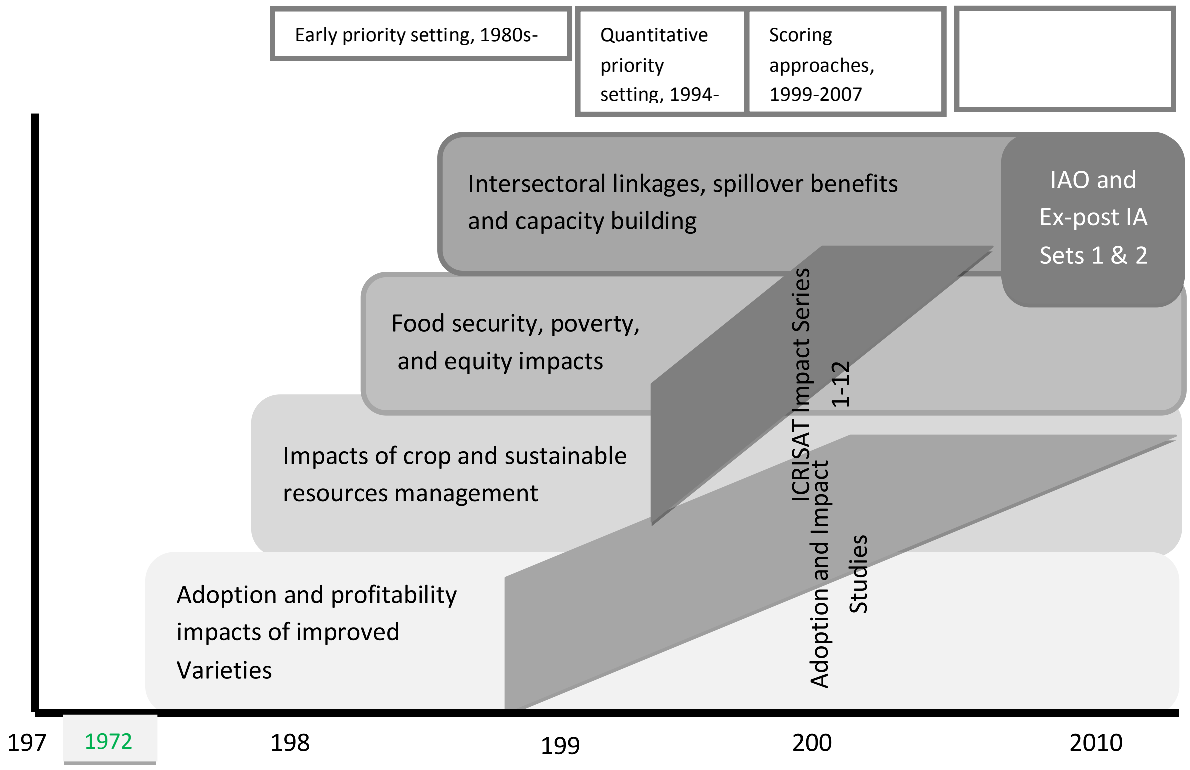


Figure 2. Evolution of ICRISAT's impact assessment research and priority setting agenda

2.6 *Overview and New Directions*

Attention on revitalizing the Institute's capacity to apply priority setting tools to support decisions was strongly emphasized by its last External Program and Management Review of 2008. This especially highlighted the potential application concerning the allocation of research investments across regions and production environment. In particular, key recommendations include:

1. The Panel recommends that ICRISAT continue to enhance investments in personnel and infrastructure in the SSA and use the potential for spillover to SSA as one of the explicit criteria used in prioritization of strategic investments in research conducted at the Patancheru headquarters.
2. The Panel recommends that ICRISAT take ownership of and celebrate the strategic planning and research prioritization process based on: (i) proactive engagement of staff, Board, stakeholders, partners, and donors; (ii) analysis and understanding of recent crop yield and production trends, and projected growth in production and demand for its mandate crops, (iii) scenario analyses that utilizes geospatial analysis, ecosystem and crop modeling, and an appropriate socioeconomic framework.
3. The Panel recommends a thorough analysis of past and likely future research spillovers between Africa and Asia to guide ICRISAT resource allocations between those two regions
4. The Panel recommends that ICRISAT capitalize on its core social science strengths to enhance activities in three areas and their interactions
    a. research prioritization and project planning (at all levels within the Center);
    b. technology development and adaptation; and
    c. impact assessment
5. The Panel recommends that GT-IMPI develop set of hypotheses concerning the IPG potential of ICRISAT's downstream work on technology development, testing and adaptation.

Key action points promptly followed with full support of management:

1. Enhance and expand investments in sub-Saharan Africa (SSA) and optimize benefits to SSA from research conducted in Asia through strategic planning and priority setting
2. Periodic strategic planning and priority setting to effectively respond to the priorities of stakeholders for the sustainable development of semi-arid agriculture. Towards this, develop and implement a knowledge-based process that is inclusive, seeking inputs from key partners and stakeholders, and building from our successes and comparative advantage in improving agricultural systems in the semi-arid tropics
3. Expand work on studying research spillovers to guide strategic planning and

resource allocation across regions and programs with special focus on identifying common biophysical and socioeconomic conditions that enable the adaptation and sharing of innovations

4. Continue to harness core social science resources to improve research targeting, development, delivery and impacts. This is institutionalized further as an integral part of our strategic research and planning process whereby insights gained from technology development and adaptation and impact assessment will be used as a guide.
5. Using impact assessment and other tools, identify lessons and testable hypotheses that offer new insights to facilitate scaling up of technologies. This is implemented through wider dialogues among scientists across research themes and locations and with partners to reconcile our impact-oriented downstream work with the delivery of IPGs.

ICRISAT harnesses its core social science strengths to enhance activities in three areas and their interactions: (1) research prioritization and project planning (at all levels within the Center); (2) technology development, adaptation and adoption; and (3) impact assessment. These three areas are integrally related. They are seen as a continuum with feedback loops from area (2) to area (1) and from area (3) to (2) and (1). There is scope for these feedback loops to be made more explicit, systematic and value-adding for decision making at all levels, including project planning and implementation. This may be visualized by referring to Figure 3 which illustrates the Research Impact Pathway drawn by the economists at ICRISAT (along with bio-physical scientists colleagues) during the recent Annual Social Scientists Meeting on Dec 2012. Prerequisites for this occurring in an optimal fashion are staff with appropriate skills (which are in place) and resource availability (presently supported) as well as a corporate framework that allows the flow of information to be meaningfully processed at the relevant level within the organization (project/ theme/ institution). There is scope for this schema to even become an IPG, by teaching it, or elements of it, to NARS.

The Management responses to the External Program and Management Review (EPMR) involve a range of impact and priority setting activities. Many are likely to involve adapting the scoring model approaches used in the past. An important response though was accepting the need to more rigorously and systematically quantify spillover effects between Africa and Asia from ICRISAT research. It is this component of the Management Response (3) which is the focus of the rest of this paper and the focus of this Workshop. The paper summarises the process ICRISAT used to choose a framework to undertake the detailed studies of research spillovers. It then outlines progress with applying this framework and some preliminary results. How this work is being linked to wider CGIAR modelling to support priority setting is also discussed.

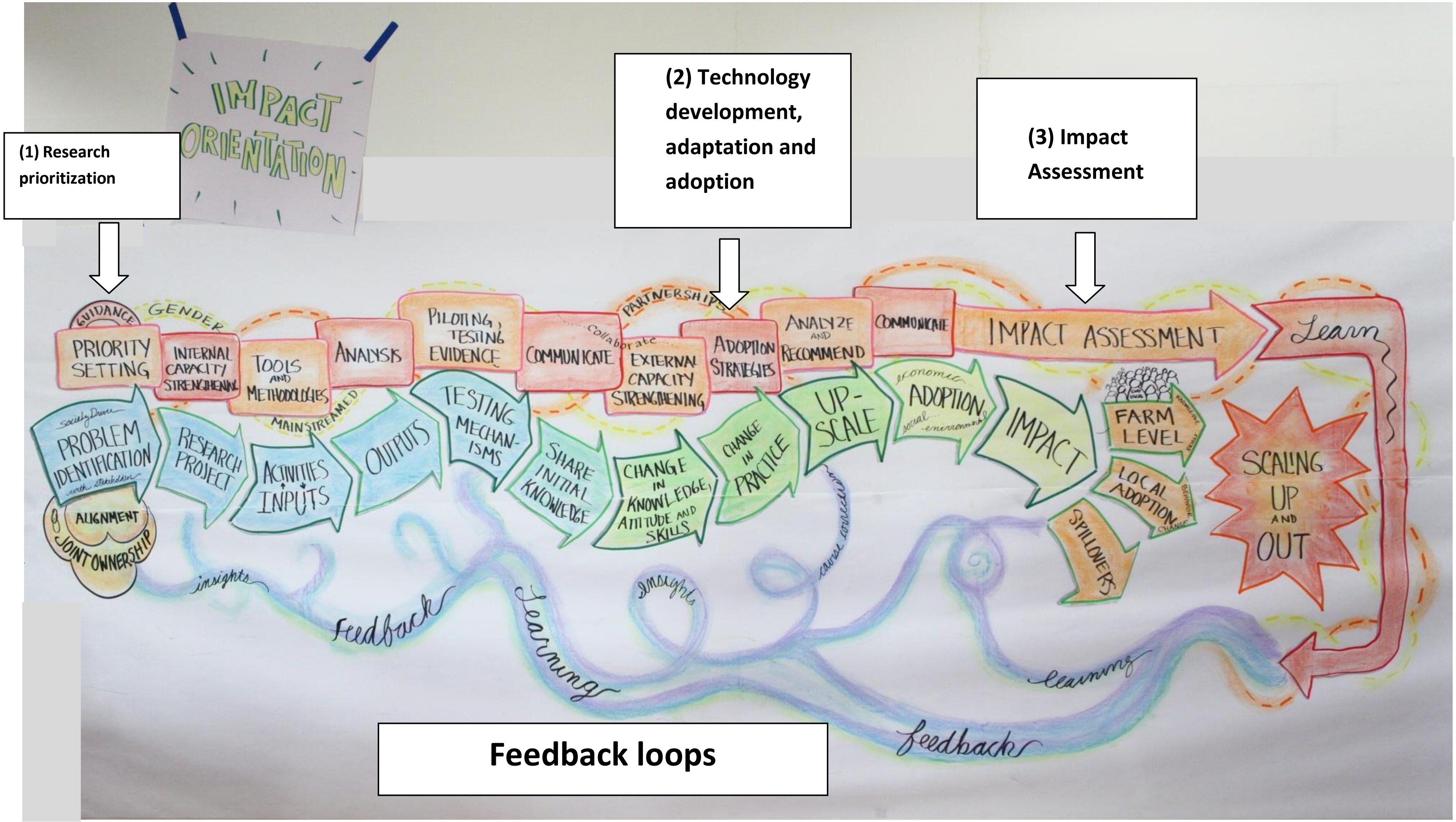


Figure 3. Social science research impact pathway

3 Better Modeling for Research Priority Setting – Economic Surplus Based Impacts and More Focus on Quantifying Spillovers.

3.1 Multi-region traded good model and economic framework for spillover estimation – an overview of past applications

As discussed in the previous section ICRISAT Management has directed a better understanding of the applicability of research and therefore spillover impacts between countries and regions and to quantify these to better support decision making. It has established a group to achieve this. The early task of the group has been to identify an appropriate framework to facilitate this. This section summarises the outcome of this activity.

An applied welfare economics (economic surplus) based framework has been evolving to evaluate the impact of agricultural research for over 60 years. It was not until about 30 years ago that explicit modelling of research spillovers was incorporated into these analytical models. Before this applicability/spillover of research was implicitly include in an aggregate shift in the commodity supply and/or adoption parameters used to estimate final welfare gains or simply ignored.

Deb and Bantilan (2001) provide a detailed review of this literature, here only a brief summary is provided with emphasis on the areas specifically important for ICRISAT's application and this Workshop.

Edwards and Freebairn (1981, 1982,1984) were first to formally incorporate spillover supply shifts between countries/regions in a two sector model, in their case Australia and the rest of the world (ROW). A diagrammatic representation of this model is given in Figure 4, the shaded areas indicate the welfare changes due to research in the country undertaking the research and spillovers to the ROW.

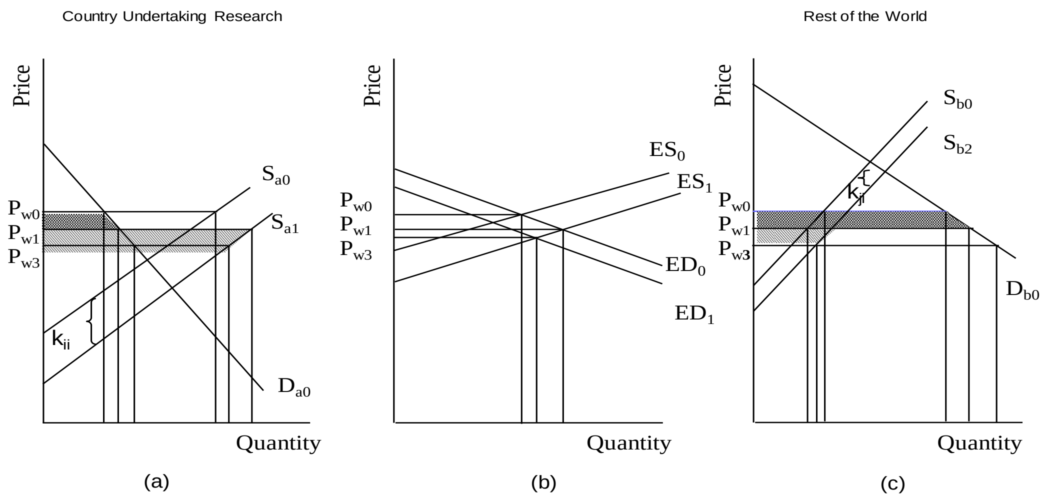


Figure 4: Research Spillovers in One Country and Rest of the World (ROW) Model

Edwards and Freebairn used the model and analysis to support research priority setting for the Australian Council for Rural Research and Extension. In this application the direct and spillover effects of possible research were modelled as a net shift in the Australian and ROW supplies using a single parameter 'k' for the direct effects in Australia and 'h' for the spillover impacts for the ROW. Both supply shifts were measured as unit cost reductions (vertical supply shifts). The model they presented did not separate effects, such as, the need for and therefore chance of success of adaptive research in the ROW or the adoption process, that is, levels and lags. As had been the case in many previous studies these were all (implicitly) assumed to be incorporated in the net final unit cost reduction level used in the analysis. For their application this was all that was needed to highlight the potential importance of spillover impacts from research. The potential for price effects from spillovers and the importance of considering the applicability of research done both in Australia and elsewhere (spillins) and the implications of these for research decision making in Australia was the primary focus of their study.

In their empirical analysis they assumed that 'h' the final net unit cost reduction in the ROW was half the unit cost reduction from the original research in Australia. This is equivalent to a spillover index of 0.5, note though this implicitly includes adjustment for factors such as the need for adaptive research and its chance of happening in all countries in the ROW plus factors affecting likely adoption of new technologies in all countries.

Davis et al (1987) extended this two sector model to multiple sectors, countries or regions. This extended framework also included more detailed modelling of a range of parameters to better represent and explain the complex relationships underlying research applicability between countries and regions and therefore final spillover impacts. In addition the framework they developed also made explicit provision for, in an ex ante context, the need for adaptive research by each country/region where the original research might be applicable and the expected adoption levels and rates in each country/region.

Over a period of 15 years the Australian Centre for International Agricultural Research (ACIAR) used this multi sector framework to quantify potential welfare gains for the wide range of countries and commodities in its funding mandate. To facilitate effective institutionalisation of this framework to support ACIAR's complex decision making, the framework in Davis et al (1987) was adapted and refined based on interactions with management. Ryan and Davis (1991) and then Lubulwa et al (2000) provide examples of the summary information which was developed as part of this institutionalisation process. The managers (or their nominated experts) who used the information to support priority setting were used to provide the necessary subjective estimates of the key spillover and other parameters; this was found to be crucial for successful institutionalisation. Even without this rigorous systematic framework these managers were implicitly making the underlying subjective assessments anyway. These priorities related to identifying which commodities, of the 100 or more produced, in which of the relevant five geographical regions (40 countries) should limited research funding be targeted.

Refinements to the framework also evolved based on feedback during the institutional use. This took many forms but with respect to spillover modelling and subjective estimation of the research applicability and spillover impact, Davis (1991) provides a good summary. Davis et al (1989) and Fearn and Davis (1991) outline how this expanded framework was applied to the forestry and fisheries sectors which were an important part of ACIAR's priority setting focus. The latter especially required development of production environments based on factors other than the agriculturally oriented ones which suited the agricultural commodities.

With ACIAR's collaborative multilateral mandate better understanding the applicability of research internationally and its implications for maximising welfare gains from a limited budget and therefore better modelling this was very important. Edwards and Freebairn's use of a single region (the ROW) was too aggregated for ACIAR's research objectives. For ACIAR though it was the welfare gains to all countries in the five focus geographical regions plus Australia which were important not the price effects from applicability of the funded research. The distribution between countries was also important. Instead of a single unit cost reduction resulting from applicability to the ROW it was the disaggregated set of individual country potential unit cost reductions (supply shifts) which were important to ACIAR. In addition whether these potential impacts are likely to be realised, adapted and adopted and how, was important for determining funding priorities.

Davis et al (1987), Davis et al (1989), Davis (1991), Fearn and Davis (1991), Alston et al (1995) and Deb and Bantilan (2001) provide the full mathematical representation of the multi-sector model, its derivation and how estimates of welfare gains are developed. Here only a condensed version is presented to highlight the main features and facilitate discussion.

The present value of total international (world) welfare gains from farm level research undertaken in country ‘y’ for a particular commodity is:

$$E[PV(GB_{yw})] = \sum_{t=1}^{T}\sum_{f=1}^{n} \frac{p_{yt}\, a_{yft}\, x_{yft}\, k_{yft}}{(1+d)^t} Q_{sft}$$

$$+ \sum_{t=1}^{T}\sum_{f=1}^{n} \frac{p_{yt}\, \beta_f (\sum_{i=1}^{n} \beta_i\, a_{yit}\, x_{yit}\, k_{yit})^2}{2(1+d)^t (\sum_{i=1}^{n}(\beta_i + b_i))^2}$$

$$+ \sum_{t=1}^{T}\sum_{f=1}^{n} \frac{p_{yt}\, \beta_f}{2(1+d)^t} [a_{yft}\, x_{yft}\, k_{yft} - [\frac{\sum_{i=1}^{n} \beta_i\, a_{yit}\, x_{yit}\, k_{yit}}{\sum_{i=1}^{n}(\beta_i + b_i)}]]^2$$

$$+ \sum_{t=1}^{T}\sum_{f=n+1}^{N} \frac{p_{yt}\, a_{yft}\, x_{yft}\, k_{yft}}{(1+d)^t} Q_{sft}$$

$$+ \sum_{t=1}^{T}\sum_{f=n+1}^{N} \frac{b_f\, \beta_f\, p_{yt}\, a_{yft}\, x_{yft}^2\, k_{yft}^2}{2(1+d)^t\, (\beta_f + b_f)} \quad \text{..........} \quad (1)$$

Where:

E[PV (GB_{yw})] is the expected present value of total international benefits from research undertaken in a specified country 'y' on the commodity of interest summed over 't' years (t = 1... T). Note y = 1....N the number of countries the analysis is undertaken for;

p_{yt} is the probability of success of innovative research undertaken in country 'y' in year 't' ($0 \leq p_{yt} \leq 1$);

a_{yft}	is the probability of success of adaptive research undertaken in country 'f' on a technology developed by innovative research in country 'y' in year 't' ($0 \leq a_{yft} \leq 1$). Note that in the early applications of this framework this parameter was used to adjust the spillover index before calculation of the final unit cost reduction, k_{yft}; see Davis et al (1987; pp37-39). It has been included in equation (1) to make this adjustment more transparent;
x_{yft}	is the expected level of adoption of the technology developed in country 'y' by producers in country 'f' (f = 1 … N) in year 't' ($0 \leq x_{yft} \leq 1$);
k_{yft}	is the cost reducing effect from research in country 'y' in country 'f' (f = 1 … N) in year 't'. For the country where the research takes place this 'k_{yyt}' is the direct effect of the research; for the remaining N-1 countries producing and/or consuming the commodity the k_{yft} will be the spillover effects of research. For many countries this could be zero.
d	is the social discount rate in real terms.
Q_{sft}	is the quantity of the commodity produced in country 'f' in time period 't' without research, that is, the initial equilibrium output.
b_f and b_i	are the slope parameters (dQ/dP) of the demand function in country/region 'f' or 'i'. Note that $b_i = e_{di}$ $[Q_{dit}/P_{it}]$, where e_{di} is the elasticity of demand for the commodity in country 'i' evaluated at the original equilibrium prices and quantities, Q_{dit} and P_{dit}. Note because negative signs are included in the demand specification the absolute value for these parameters are entered in the formulae.
$ß_f$ and $ß_i$	are the slope parameters (dQ/dP) of the supply function in country/region 'f' or 'i'. Also note, $ß_i = e_{si}$ $[Q_{sit}/P_{it}]$ where e_{si} is the elasticity of supply.
N	is the total number of countries/regions (aggregations of some countries) in the world.
n	is the number of countries/regions where the commodity of concern is produced or consumed and is internationally traded.
N-n	is the number of countries/regions where the commodity is only traded domestically (that is, closed economies) if any.

A further set of equations for each individual country/region's benefits and the distribution of these benefits between consumers and producers in each country/region are also available in the above reports. They are not reported here to save space. However, these are important since the computation of GB_{yw} is usually achieved using the individual country versions of the equations adding a sub-set of these to give required totals. Welfare benefits to producers and consumers are also usually calculated using these equations not the aggregated version.

At ACIAR it was not the total international welfare gains but subsets of the welfare gains accruing to each of its five major regions and individual countries within them that were extracted from these totals for the priority setting exercise. In addition the welfare gains were estimated for the possibility that research was undertaken in all countries/regions, that is, for y= 1....N. This was because ACIAR's role was to develop collaborative research activities with most countries in its mandate regions.

If equation (1) is compared with those used by Edwards and Freebairn (1982; pp39-40) it is seen that they are the same except for the parameters, p_{yt}, a_{yft} and x_{yft}. These are the probabilities of innovative and adaptive research success and adoption levels. As discussed earlier, in many studies these have often been assumed (implicitly) to be 1 or included (implicitly) in the estimate of the net unit cost reduction, k_{yft}.

In the original ACIAR application Davis et al (1987) adopted the same approach as Edwards and Freebairn and used a spillover index to develop the estimates of k_{yjt}. However, because of the relatively large number of countries ACIAR had to consider funding innovative research with, the set of spillover indices required was a large matrix rather than a two cell vector as was used by Edwards and Freebairn.

As summarised in Davis (1991) incorporation of this spillover index into the k_{yjt} 's used in equation (1) can be represented in matrix notation as:

$$K = K^*S \quad \text{.........} \quad (2)$$

Where:

- K is a matrix of monetary direct and indirect spillover unit cost reductions. K is an N x N matrix where N is the number of countries/regions in the world. Each component of K , that is, k_{yjt}, is then the unit cost reduction in country/region 'j' resulting from research undertaken in country/region 'y'. This is what is used in equation (1).
- K* is a diagonal matrix of potential cost reductions for each country. k^*_{yy} is the potential cost reduction in country 'y' where the (innovative) research is undertaken, with all $k^*_{yj} = 0$.
- S is a matrix of research spillover indexes. In most cases it is expected that $0<s_{yj}<1$; although this is not a necessary condition of the framework.

In the original applications the s_{yj}'s were subjectively estimated by experts with detailed knowledge and experience of agriculture and research systems in many countries but especially the ones of importance to ACIAR. These estimates although judgements were, however, supported by identification of homogeneous production environments which were applicable to most countries. The FAO AEZ system was chosen as the most comprehensive and applicable at that time and the maps available with this system used to facilitate making the final judgments for the estimates. Details of this process are in Davis et al (1987; pp22-27, 36-37) and also Davis (1991). Despite this systematic approach and considerable expertise, with the large number of regions (countries) involved and the diversity of production environments within some of them, the judgmental weighting process involved often taxing mental gymnastics. As the application expanded to more and more diverse commodities it became apparent that a clearer step by step process, complemented whenever possible by available statistics and mathematical manipulation, was needed.

The driving force for developing a more mathematical approach to estimating the spillover index was to make the task less demanding and to try to separate components which may be easier to estimate separately or be available as published data. Initially used in Davis et al (1989) for the forestry sector the framework was summarised and discussed in more detail in Davis (1991). It involves estimating the 'S' matrix in equation (2) using:

$$S = R\ C\ F \qquad \text{.............} \quad (3)$$

Where:

- S is the same NxN spillover index matrix as in equation (2).
- R is an N x m matrix of potential research focus parameters; 'm' is the number of production environments (research domains) relevant to production of the commodity and for a particular type of research problem being considered. Research can be focused on one production environment or a mix of them in different proportions by assigning an index r_{yi} ($0 \le r_{yi} \le 1$) and $\sum_{i=1}^{m} r_{yi} = 1$ for country 'y'.
- C is an m x m matrix of the research applicability's between production environments for each commodity, c_{ij}.
- F is an m x N matrix of the shares of commodity production (production proportions) in each production environment for each country, f_{iy}. Again $\sum_{i=1}^{m} f_{iy} = 1$ for country 'y'.

If the production environments are identified in consultation with research scientists and managers they can be linked directly to specific research problems and therefore identifiable technologies. Production conditions are likely to be closely related so unit cost reductions from the technologies should be similar within a production environment. This is especially so the more finely developed are the production environments. Estimation of the research applicability matrix, c_{ij}'s, while still complex was found by all experts to be much easier than the original spillover index which was country to country oriented. The reason for this is can be seen from equation (3), the production environment research focus strategy (R) and the commodity production proportions by production environment for each country (F) can be estimated/specified or data on them collected as separate exercises. In some cases different experts may be better suited to estimate each set of information.

Even though the experts/managers found subjectively estimating the c_{ij}'s much easier than the s_{yj}'s, this is still a complex task. It requires detailed knowledge of production environments and the likely farmer costs associated with them. To be consistent with equation (1) the applicability index has to be linked to the unit cost reductions in each production environment for each type of research and technology. Therefore it was important to ensure before the subjective judgement was undertaken that the scientist/manager appreciated the following relationship:

$$c_{ij} = u_{ij} / u_{ij}. \quad \text{............ (4)}$$

where:

u_{ij} is the unit cost reduction in production environment 'j' if the technology developed from research focused on production environment 'i' is used in production environment 'j', (i, j = 1....m). If $u_{ij}<0$ then $c_{ij} = 0$. Also $c_{ii} = u_{ii} / u_{ii} = 1$, that is, the diagonal of the C matrix is all 1's.

The interpretation of u_{ij} is crucial when subjectively estimating c_{ij}. It is the unit cost reduction in production environment 'j' if the technology developed specifically for production environment 'i' is used in 'j'. For u_{ij} to be positive the technology must be superior to the best already available technology already used in production environment 'j'. Note this in many cases could be a different technology than the pre-research technology in 'i'. In most cases it is expected that $c_{ij} < 1$, that is, the cost reduction is less in a production environment where the technology was not specifically designed for, however, this is not a requirement so is an empirical question.

If we now reflect on the comparison of equation (1) with the Edwards and Freebairn model we see that including up to equation (4) now adds a lot more underlying parameters and relationships to understanding and estimating the spillover unit cost reduction, k_{yjt}. As well as parameters p_{yt}, a_{yft} and x_{yft} there are k^*_{yy}, r_{yi}, c_{ij} , f_{iy}.and u_{ij}, plus a complex weighting process. The data required to use the framework to its full potential - let alone to expand it further - is extensive. The application of this framework at ACIAR with its mandate covering up to 100 commodities (agriculture, forestry and fisheries) in around 40 countries required some simplifying and pragmatic choices for many of the parameters based on professional judgments by a multi-disciplinary team.

There are many aspects in the expansion of the framework in equation (1) through equations (2) to (4) which can be discussed and debated, as is usually the case while the additions make some areas clearer they usually open up more complexities, some of these have been discussed in Davis (1991) and Pardey and Woods (1994) and there are still more which are important. Alston et al (1995; pp343-349) develop a spillover framework which appears to be between Edwards and Freebairn and the above framework. It explicitly includes adoption and a 'transferability' coefficient which provides a weighting system to convert maximum potential unit cost reductions into a realised unit cost reduction. However, this 'transferability' coefficient is still at a country to country level so has the potential issue of requiring complex mental gymnastics if subjective estimation is required. They also caution strongly about the possible double counting when estimating spillovers. They raise strong doubts regarding whether scientists and managers have the capacity to make the necessary subjective judgements. These are very important points and need to always be kept in mind, however, their relevance also depend a lot on the type of decision-making situation the analysis is being used to support and how the results are presented.

The experience at ACIAR was, however, that this disaggregation to a production environment/research domain level made the managers much more comfortable making their expert judgements about these research impacts. In many cases they even commented that this enhanced their overall thinking about research strategies. Importantly it gave them much more confidence in the whole quantification process; this considerably increased their ownership of the priorities identified and therefore improved institutionalisation of the whole process. It is important to remember that even without this systematic quantitative support system these managers were making these judgements implicitly and often not consistently through time. Many recognised this so appreciated the system more.

At a national level the same framework was used in an exercise similar to that at ACIAR for institutions in the Philippines and Thailand. See for example, Bantilan et al (1991) and Setboonsarng et al (1991).

Ryan and Davis (1991) suggested an adaptation of the framework in equations (1) to (4) to support decision-making from an internationally focused research organisation perspective – the Technical Advisory Committee (TAC) of the CGIAR. This adaptation involved expanding the number of 'countries/regions' from N to N+g, where 'g' is the number of research domains (production environments) which an international research organisation may focus its research efforts on. In the application the TAC identified eight continental agro ecological zones (CAEZ's) as the research domains they wanted to focus on. Their issue was; which of the range of commodities they could concentrate their research on produces the highest welfare gains to different regions. Since these CAEZ's were in fact simple aggregations of some of the FAO AEZ's used for the ACIAR production environments for agricultural commodities, it was a relatively straight forward adaptation of the ACIAR analysis; adding eight extra rows to the R and F matrices and using equation (1) with y=1...g, that is, each CAEZ research focus. Regional subsets of the welfare gain estimates in the analyses for each CAEZ were used to develop commodity priorities.

3.2 Adaptation of Past Models to Suit ICRISAT's Requirements.

ICRISAT has decided it needs to quantify and better understand research spillovers and use this understanding to support its priority setting process and develop research strategies.

As summarized in section 2 many of the past scoring model exercises have used the notion of research domains or homogenous production environments to identify research priorities. These priorities need to cut across many countries but ensure that maximum welfare gains to the poorer groups are achieved. Enhancing these existing assessments with a more detailed and systematic spillover framework is a logical next step.

Since ICRISAT operates in an international (public good) environment it needs to develop research strategies which are not specifically tied to countries. The extension developed by Ryan and Davis (1991) suits, but instead of general aggregated production environments, like those identified by the TAC, ICRISAT is interested in identifying which specific research domains/production environments offer the highest welfare gains to its target groups. It is also important for ICRISAT to better understand how the adaptive capacity of its national agricultural research system (NARS) partners and adoption constraints impact on realising potential gains from the applicability of its (their) research outcomes.

Management has decided to adapt the framework summarised in equations (1) to (4) to suit these decision making requirements. This adapted framework can be represented in a slightly revised form as:

$$E[PV(GB_{gw})] = \sum_{t=1}^{T}\sum_{f=1}^{n}\frac{p_{gt}a_{gft}x_{gft}k_{gft}}{(1+d)^{t}}Q_{sft}$$

$$+\sum_{t=1}^{T}\sum_{f=1}^{n}\frac{p_{gt}\beta_{f}(\sum_{i=1}^{n}\beta_{i}a_{git}x_{git}k_{git})^{2}}{2(1+d)^{t}(\sum_{i=1}^{n}(\beta_{i}+b_{i}))^{2}}$$

$$+\sum_{t=1}^{T}\sum_{f=1}^{n}\frac{p_{gt}\beta_f}{2(1+d)^t}[a_{gft}x_{gft}k_{gft}-[\frac{\sum_{i=1}^{n}\beta_i a_{git}x_{git}k_{git}}{\sum_{i=1}^{n}(\beta_i+b_i)}]]^2$$

$$+\sum_{t=1}^{T}\sum_{f=n+1}^{N+m}\frac{p_{gt}a_{gft}x_{gft}k_{gft}}{(1+d)^t}Q_{sft}$$

$$+\sum_{t=1}^{T}\sum_{f=n+1}^{N+m}\frac{b_f\beta_f p_{gt}a_{gft}^2x_{gft}^2k_{gft}^2}{2(1+d)^t(\beta_f+b_f)} \quad .... \quad (5)$$

The individual national benefits for country/region 'f' from ICRISAT research focused on research domain/production environment 'g' with an internationally traded environment (f = 1 ... n) are given as:

$$E[PV(G_{gf})]=\sum_{t=1}^{T}\sum_{f=1}^{n}\frac{p_{gt}a_{gft}x_{gft}k_{gft}}{(1+d)^t}Q_{sft}$$

$$+\sum_{t=1}^{T}\frac{p_{gt}(Q_{dft}-Q_{sft})\sum_{i=1}^{n}\beta_i a_{git}x_{git}k_{git}}{(1+d)^t\sum_{i=1}^{n}(\beta_i+b_i)}$$

$$+\sum_{t=1}^{T}\frac{p_{gt}b_f(\sum_{i=1}^{n}\beta_i a_{git}x_{git}k_{git})^2}{2(1+d)^t(\sum_{i=1}^{n}(\beta_i+b_i))^2}$$

$$+\sum_{t=1}^{T}\frac{p_{gt}\beta_f}{2(1+d)^t}[a_{gft}x_{gft}k_{gft}-\frac{\sum_{i=1}^{n}\beta_i a_{git}x_{git}k_{git}}{\sum_{i=1}^{n}(\beta_i+b_i)}]^2 \quad ..... \quad (6)$$

Consumer benefits for country/region 'f' from ICRISAT research focused on research domain/production environment ‘g’ with an internationally traded environment (f = 1 ... n) are given as:

$$E[PV(G_{cgf})]=\sum_{t=1}^{T}\frac{p_{gt}Q_{dft}\sum_{i=1}^{n}\beta_i a_{git}x_{git}k_{git}}{(1+d)^t\sum_{i=1}^{n}(\beta_i+b_i)}$$

$$+\sum_{t=1}^{T}\frac{p_{gt}b_f(\sum_{i=1}^{n}\beta_i a_{git}x_{git}k_{git})^2}{2(1+d)^t[\sum_{i=1}^{n}(\beta_i+b_i)]^2} \quad (7)$$

Producer benefits for country/region 'f' from ICRISAT research focused on research domain/production environment ‘g’ with an internationally traded environment (f = 1 ... n) are given as:

$$E[PV(G_{pgf})] = \sum_{t=1}^{T} \frac{p_{gt} Q_{sft}}{(1+d)^t} [a_{gft} x_{gft} k_{gft} - \frac{\sum_{i=1}^{n} \beta_i a_{git} x_{git} k_{git}}{\sum_{i=1}^{n} (\beta_i + b_i)}]$$

$$+ \sum_{t=1}^{T} \frac{p_{gt} \beta_f}{2(1+d)^t} [a_{gft} x_{gft} k_{gft} - \frac{\sum_{i=1}^{n} \beta_i a_{git} x_{git} k_{git}}{\sum_{i=1}^{n} (\beta_i + b_i)}]^2 \quad \text{........ (8)}$$

National benefits for country/region 'f' from ICRISAT research focused on research domain/production environment ‘g’ with an internationally non-traded environment (f = n+1 ... N+m) are given as:

$$E[PV(G_{gf})] = \sum_{t=1}^{T} \sum_{f=1}^{n} \frac{p_{gt} a_{gft} x_{gft} k_{gft}}{(1+d)^t} Q_{sft}$$

$$+ \sum_{t=1}^{T} \frac{p_{gt} b_f \beta_f a_{gft}^2 x_{gft}^2 k_{gft}^2}{2(1+d)^t (\beta_i + b_i)} \quad \text{(9)}$$

Consumer benefits for country/region 'f' from ICRISAT research focused on research domain/production environment ‘g’ with an internationally non-traded environment (f = n+1 ... N+m) are given as:

$$E[PV(G_{cgf})] = \sum_{t=1}^{T} \frac{p_{gt} \beta_f a_{gft} x_{gft} k_{gft}}{(1+d)^t (\beta_f + b_f)^2} Q_{dft}$$

$$+ \sum_{t=1}^{T} \frac{p_{gt} b_f \beta_f^2 a_{gft}^2 x_{gft}^2 k_{gft}^2}{2(1+d)^t (\beta_f + b_f)^2} \quad \text{........ (10)}$$

Producer benefits for country/region 'f' from ICRISAT research focused on research domain/production environment ‘g’ with an internationally non-traded environment (f = n+1 ... N+m) are given as:

$$E[PV(G_{pgf})] = \sum_{t=1}^{T} \frac{p_{gt} b_f a_{gft} x_{gft} k_{gft}}{(1+d)^t (\beta_f + b_f)} Q_{sft}$$

$$+ \sum_{t=1}^{T} \frac{p_{gt} \beta_f b_f^2 a_{gft}^2 x_{gft}^2 k_{gft}^2}{2(1+d)^t (\beta_f + b_f)^2} \quad \text{........ (11)}$$

The changes to the model are relatively subtle but important. Instead of the innovative research being undertaken by a country it is now undertake through an ICRISAT research strategy ‘g’. This involves focusing the research on a specified research domain/production environment. While the number of these can be as many as required it is expected that g= 1....m, but perhaps less than this. Recall ‘m’ is the number of production environments appropriate to a particular commodity (crop) and research issue. With the flexibility available for ICRISAT the number of production environments will most likely be different between crops and research issues.

Notice now instead of N countries and regions the model now includes N+m. These should now be referred to as countries, regions and research strategies. Adapting the framework requires adding these ‘m’ rows and/or columns to the matrices K, K*, S, R and F. These are not repeated here since they only involve a change in matrix sizes. Importantly, though the entries in the R matrix for the ‘m’ ICRISAT strategies are directly focused on each research domain/production environment and although not required will be set so r_{ii}=1 and r_{ij}=0 for each ‘g’. In addition the unit cost reductions in K* for the ‘g’th ICRISAT production environment research strategy will be specific to that research domain rather than a country level weighed unit cost reduction as in most other applications.

There are several aspects of ICRISAT’s environment which will mean the application of the adapted framework will be significantly different than for ACIAR. These include:

i. ICRISAT has a mandate for a relatively small number of crops: 3 grain legume crops, 2 dryland cereal crops and a group of minor millets. This reduces considerably the scale of the data collection and management task relative to ACIAR. In turn this means various aspects of the framework can be individually tailored to suit each crop and type of research (technology).
ii. ICRISAT has been undertaking research on these crops at an international level for over 40 years so has a strong pool of world experts in most areas of each crop in many countries. These experts have strong collaborative links with peers in many countries. This provides potential for strong confidence in any subjective judgments which might be required.
iii. ICRISAT has assembled comprehensive databases covering many facets of each of the crops much of which is required in the analysis using this framework. These include extensive surveys of farm unit costs for many production environments and technologies.
iv. ICRISAT has a well develop GIS facility which can interactively and quickly develop research domain/production environments well suited to each crop and even types of research within crops.

Further details of this adaptation and the importance of the above institutional issues will be covered in some of the individual papers and presentations.

The analytical results are generated from a spreadsheet model which has been adapted from Lubulwa (1998). This spreadsheet format facilitates considerable flexibility in modelling between commodities. In the original ACIAR computational system a FORTRAN based program (RE4) with a series of spreadsheets to generate inputs files required each commodity analysis to follow a relatively rigid format. Therefore with currently available computer technology this rigidity is no longer required.

3.3 Integrated ex-post assessments using the same framework

The economic surplus model described above formed the theoretical framework underpinning the impact assessment exercises (ex-ante and ex-post). This section gives a brief description of the on-going ex-post impact assessment at ICRISAT while subsequent sections will describe in detail the ex-ante assessment for research priority setting.
Ex-post impact studies at ICRISAT have broadly employed two approaches to calculate returns to research and to estimate its impact on society:

1. The economic surplus approach estimates returns on investment by measuring the change in consumer and producer surplus from a shift to the right in the supply curve due to technological change.
2. The econometric approach treats research as a variable and allows a marginal rate of return on investment to be calculated.

These two methods lead to impact assessment results that can be used to convince donors and policymakers that resource allocations to research at ICRISAT represent good investments. These approaches demonstrate impact on production, income, or marketable produce as this is what donors and policymakers check as indicators of project success. In addition to the use of economic indicators, ex-post impact assessment was broaden to include participation of disciplines other than economics. As described in section 2.4 This will enable inclusion of indicators not amenable to monetary valuation such as biodiversity, social gains, and environmental protection. Additional needs for testing and validating more qualitative methods derived from the sociological and anthropological traditions in development studies, as complements to economic-based impact assessment approaches that could form part of a multi-dimensional comprehensive approach to the study of impact. One difficulty in using ex-post impact assessment for real time institutional learning is it mostly involves assembling information on investments made over outputs adopted for a decade or more previously. With fading institutional memories, the relevance of ex-post impact assessment for informing current and institutional organizations and management can be a contentious issue, and largely depends on the stability of the mandate of the research institute, the dynamics of change in the external environment, and generalizability of individual ex-post impact assessment findings to thematic research areas. Walker et al (2008) suggested one way of addressing the problem of time lags by starting ex-post impact assessment sooner, in the early stages of adoption. But there is the risk of generating imprecise estimates for accountability. Chilver et al (1999) saw value in carrying out ex-post impact assessment in technologies that do not take off as having value for learning and contributing to identifying where and when a more generic version of the technology could work over time.

Ex-ante impact assessment will have advantage over ex-post impact assessment of being able to employ some models that provide a basis for decision making with an eye to the future rather than the past. Ex-ante methodologies pool information from a large number of qualified experts and provide a means of explicitly relating the research effort to a set of goals. The disadvantages are that those methods which draw on the opinion of a large number of specialists can be quite costly and time consuming and the pooling of a large number of opinions may do little more than to pool ignorance. It is probably for these reasons that the more complicated methods have rarely been used more than once, although selected models may provide a means of feeding some rigorous analytical research into the decision-making process.

3.4 Complementary models to generate sound research strategies

The Consultative Group on International Agricultural Research (CGIAR) has now completed 40 years of its existence and contributed to agricultural productivity growth, poverty reduction, and environmental sustainability though its research and development activities implemented through 15 centres in different crops, natural resources and policies. Currently CGIAR is undergoing various change management by implementing CGIAR Research programs to demonstrate higher impacts on social welfare and environmental sustainability and also to prove that research and development investments in the international research represent money well spent. In this context ICRISAT joined hands with other CGIAR centers (IFPRI, CIAT, CIP, ILRI, CYMMT, ICRAF and IRRI) in advancing methodologies towards development of integrated complementary model to support priority setting. The initiative at ICRISAT for in depth consideration of spillovers complements with this effort to undertake scenario analysis using geo-spatial, ecosystem and crop modelling and an appropriate socioeconomic framework. Thus the two projects on research spillover and scenario analysis (Global Future Project) were identified as two pillars in the priority setting exercise at ICRISAT.

The literature on ex-post impact assessment reveals that substantial work on assessing the impacts of a wide variety of CGIAR research using state-of-the-art evaluation techniques was done by CGIAR under Standing Panel for Impact Assessment (SPIA). But under current scenarios of inherent complexities of agricultural systems with accelerating challenges - from rapidly increasing agricultural trade in high value crops to climate change to high energy prices - makes it ever more critical to provide a quantitative framework that facilitates ex-ante evaluation of possible policy and technology futures for food availability and nutrition security, particularly in the developing world. The CGIAR does not currently have a system of priority-setting that can clearly evaluate alternative investments and interventions to address the challenges arising from globalization and climate change.

Since there is no methodological framework to guide the allocation of resource to international agricultural research, CGIAR stressed the need for further research in this field of research planning and management. In this juncture, IFPRI (International Food Policy Research Institute) along with other CG commodity centres including ICRISAT initiated a collaborative project – Global Futures Project – with central goal to provide the tools to assist the priority setting body of the CGIAR (currently the Independent Science and Partnership Council - ISPC) in making strategic decisions on research needs and resource allocations among the various centres. In the past, each of the research centres with the CGIAR developed its own interpretation of system goals with respect to its mandate crops, agro-ecological regions or thematic research areas. The Global Futures Project will enable CGIAR decision-makers (including management of CG centres, CGIAR Research Programs, ISPC and Fund Council) and others to better understand the consequences of income growth, diet change, climate change and other drivers on the functioning of agricultural systems and their ability to deliver services. In this project an interdisciplinary team consisting of breeders, physiologists, crop modelers, economists is working together to identify the new promising technologies and management systems to conduct ex-ante evaluation.

As explained in the previous section, ICRISAT is using the economic surplus, multi-region spillover model to guide priority setting and resource allocation across regions. The aim of this initiative is to provide complementary results with additional information of reduction in malnutrition and hunger to guide resource allocation and priority setting of research focus.

In this paper we explain the modeling tools developed by integrating partial equilibrium multi commodity trade model (IMPACT), water simulation model, DSSAT crop model, adoption model and economic surplus model to assess the potential welfare gain of groundnut promising technologies identified by the crop improvement team at ICRISAT which will be released for farmers' adoption in the coming years in the target countries and production domains. This integrated model will also make it possible to carry out a direct comparison of technological interventions and policy interventions in improving the current and future productivity of agriculture.

4 Preliminary Results

In this study, we estimate the expected international benefits for ICRISAT's mandate crops (Groundnut, pigeonpea, pearl millet and sorghum) research by fully accounting for global research benefits including spillover effects by adopting a methodology developed by ACIAR to estimate spillover benefits. This will inform and guide ICRISAT management in prioritizing millets production domain for achieving highest benefits and to allocate scarce resources among different regions based on the potential welfare gains and impacts.

It is noted that earlier efforts have in fact commenced in early 2000 at ICRISAT for refinement of empirical estimates and collection of relevant data from all possible sources. These efforts were related to analysis of experimental data and surveys of national research system to gather data on realize spillover across countries and location. For example, technology spillover potential from enhanced sorghum germplasm was estimated using experimental data generated by (i) International Sorghum Varietal and Hybrid Adaptation Trial (ISVHAT), and (ii) All India Coordinated Sorghum Improvement Project (AICSIP). ISVHAT data included information on trial locations and cultivars (phenology, plant height, grain yield and response to important pests and diseases) for the period 1989 to 1992 which were conducted in 59 locations spanning 26 countries in Asia, Africa and Latin America. The details of this earlier estimation are given in Appendix 4.

The above initiative was clearly constrained by availability of data during that period as well as lack of methodological advancement in systematically quantify the spillover benefits from ICRISAT's own research and development investment to fully demonstrate the comparative advantages of international and national research system. This section advances four important issues which warrants methodological investigation and applications, and perhaps even new research which were needed in order to address the persistent questions on research prioritization in the institute. These are:

i. New application of spatial tools and GIS to estimate K=K*S and S=RCF
ii. Revisiting adoption and adaptive capacity to estimate p_{yt}, a_{yf}t and $x_{yft,}$
iii. Transactions costs and their implications for innovative and adaptive capacity and adoption, how we estimate p_{yt}, a_{yf}t and x_{yft} better over time
iv. Complementary results generated form alternative models to generate sound research strategies.

The following sections presents some preliminary results using the economic framework discussed in Chapter 3. These initial results identified further enhancements in the parameters of the impact estimates to support priority setting.

4.1 Initial estimates on groundnut, pigeonpea, millets and sorghum

4.1.1 Groundnut and Pigeonpea

Benefits across zones and countries

Benefiting the largest possible number of people in the world to the greatest extent possible is hugely driven by the widest possible distribution of ICRISAT technologies. To achieve this global availability of improved technologies it is of crucial importance to understand the flow of technologies across countries and zone boundaries and the determining factors underlying this movement. The central question is on which environment ICRISAT should emphasize in order to maximize its impact in terms the desired outcome (be it poverty reduction, nutritional improvement or others). The main target of this paper is providing evidence to compare likely outcomes across countries or zones and utilizing these to improve targeting and thus impact achievements with respect to the desired outcome(s) from groundnut and pigeonpea research.

Using the research focus of ICRISAT as the main targeting parameter the initial estimates build on the assumption that ICRISAT would target only one HZ at a time. The results show which HZ has the highest potential benefits and will thus provide an initial indication which HZ focus would generate the maximum returns. The resulting benefits can also be utilized to simulate the outcomes when targeting multiple HZs simultaneously by setting the share of effort in each HZ and multiplying the benefit level for the maximum effort with the share of effort in this HZ. Thereby, the total benefit level is calculated from the multiplication of the vector of effort levels in each HZ by the vector of benefit levels for each HZ given full effort on the individual HZs. Results for the individual HZs are given in Table 3 for groundnut and in Table 4 for pigeonpea. While the Asia and Africa column includes all countries to give a better overview, the ICRISAT total column only sums up all countries set as focus countries in the newly established Consortium Research program 3.5 (CRP) as this is the main framework for future work in the CGIAR. These focus countries exclude some big producers like China which is the main reason for the differences between the sum of Asia and Africa as opposed to the ICRISAT total.

Table 3 Benefits by focused HZ with and without cross-HZ applicability – Groundnut

HZ	Applicability CRP total	Asia	Africa	NO applicability CRP total	Asia	Africa	production covered
	US$ mill	US$ mill	US$ mill	US$ mill	US$ mill	US$ mill	%
10	1363	1313	233	818	699	121	15.3%
9	1336	1444	239	462	380	112	16.9%
7	1254	1378	217	35	35	0	2.9%
15	1015	1156	176	400	310	90	10.5%
13	961	1119	158	128	127	1	2.1%
12	843	1031	146	86	84	2	1.1%
5	802	1438	136	13	759	0	9.4%
8	642	859	121	41	42	13	3.1%
4	631	776	108	36	36	2	0.7%
11	557	1004	93	1	12	0	1.9%
6	449	540	86	12	14	12	0.8%
0	69	365	21	69	365	21	6.8%
2	1	1924	1	1	1924	1	18.7%
3	0	543	0	0	543	0	5.1%
14	0	426	0	0	426	0	4.0%
1	0	0	0	0	0	0	0.0%

Note: Results sorted according to Total in focus countries under applicability assumption.
Source: Own calculations

The most obvious point from the comparison above is the huge difference between the benefit levels from the two scenarios with and without applicability across HZs. This not only highlights the importance of spillover effects across HZs but also highlights that effort put into promoting the movement of varieties across countries and continents are well spend as they do generate huge benefits. All in all, comparing the different benefits levels across the HZs, there is not one or a couple of HZs that dominate the benefit levels but there are several that generate high and comparable benefit levels with a rather equal distribution thereafter.

For Pigeonpea the distribution is very different based on several factors. First of all, the high degree of photoperiod sensitivity hugely reduces the potential for cross zones applicability as seen in the applicability matrix and thus the benefits levels align much more with the production proportions. The exception is only zone 2 from which high levels of benefits arise to other zones. Zone 2 and 7 are also the only two zones where the two scenarios with and without applicability to make a significant difference for the total benefit levels. Which suggest that the efforts in pigeonpea should be concentrated in making the seed available within each zone but it would almost never be economically beneficial to try and make varieties available across zones – this is with the exception of zone 2 material that could benefit other zones huge.

Table 4 Benefits by focused HZ with and without cross-HZ applicability – Pigeonpea

	With applicability			**Without applicability**			**Production covered**
HZ	**CRP total**	**Asia**	**Africa**	**CRP total**	**Asia**	**Africa**	
	US$ mill	US$ mill	US$ mill	US$ mill	US$ mill	US$ mill	%
4	702	687	16	610	601	10	62.4
2	592	577	15	9	9	0	1.5
7	429	416	13	119	111	8	17.3
3	153	153	0	153	153	0	15.8
5	8	3	5	5	3	2	2.7
1	5	3	2	8	3	5	0.2
6	0	0	0	0	0	0	0.1

Source: Own calculations.

Another big difference between the two crops is that the pigeonpea production and also the benefits are, in the 'with applicability' and thus the reality case, very concentrated in 2-3 zones. This calls for a much more targeted research effort as compared to groundnuts where many more zones have to be taken into account and thus different material has to be produced catering for the different needs.

Based on the differences in the size and relevance of each HZ across countries, the resulting benefit distribution across countries varies tremendously. This effect is highlighted in Figure 5 (for groundnut) and Figure 6 (for pigeonpea) where the four most promising HZs (highest total benefit levels) are compared across countries. It also highlights that in most scenarios the benefits to India dominate the result as India is also the biggest producer and consumer for both crops.

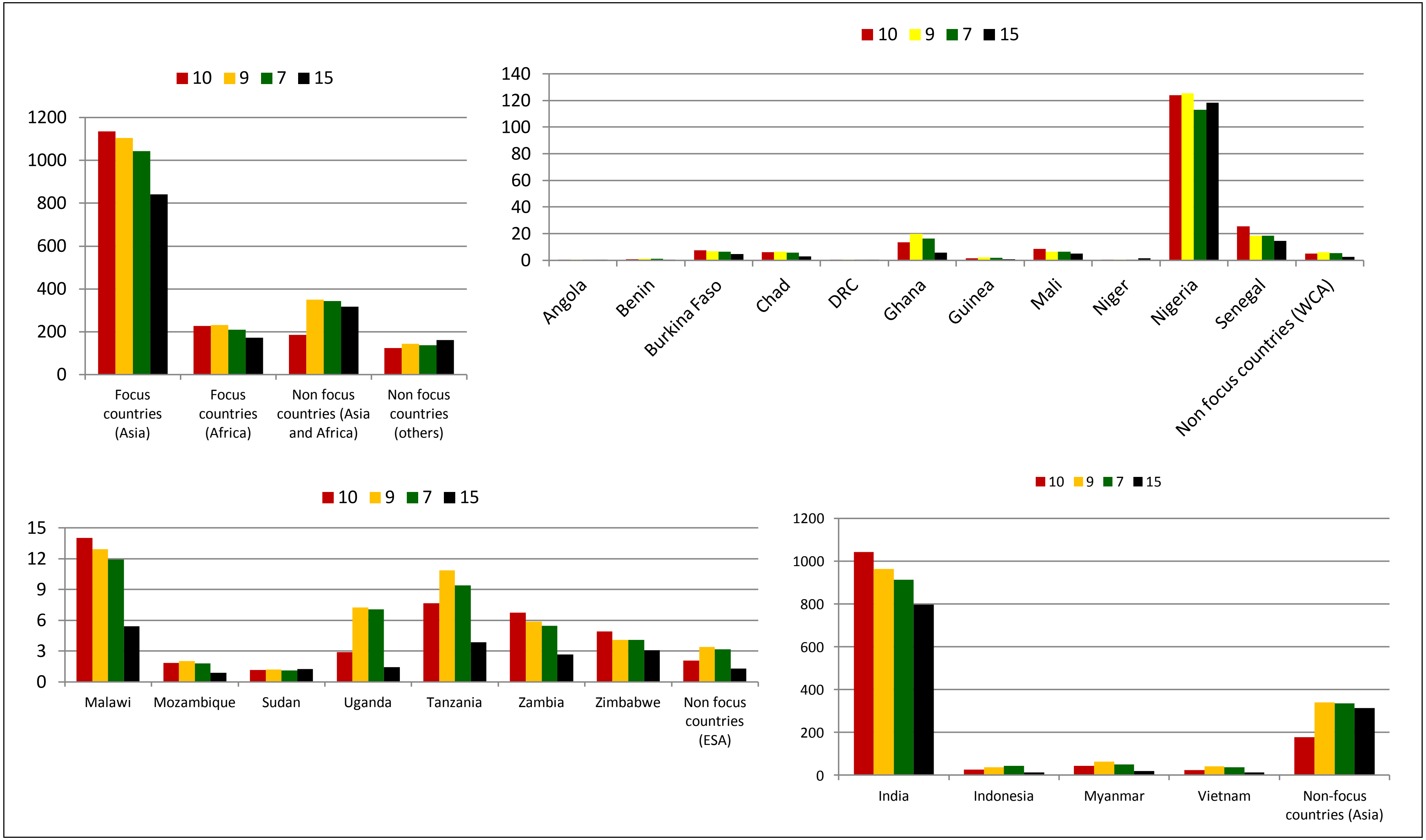


Figure 5 Realistic scenario country level groundnut benefits (mill. US$) for 4 main HZs. Source: Own calculations.

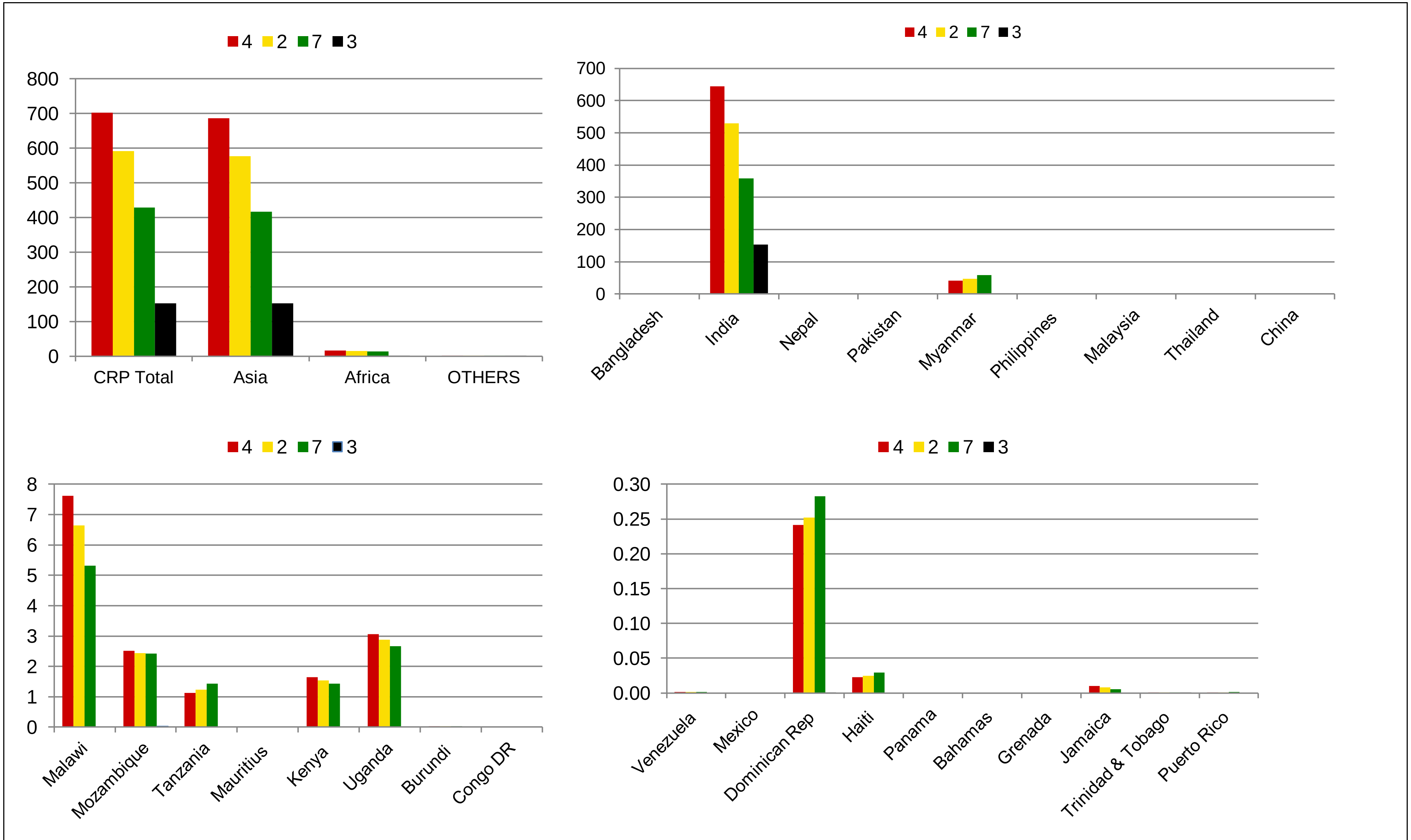


Figure 6 Realistic scenario country level pigeonpea benefits (mill. US$) for 4 main HZs. Source: Own calculations.

While for some countries like Nigeria the results are fairly constant based on their size and the diverse environments that incorporate many different zones, others fluctuate much more. Taking the case of Malawi and Tanzania as one of the most prominent East African groundnut producers, the move from HZs 7, 9 or 10 to number 15 significantly reduces the benefits while for some of the non-focus countries like China it wouldn't make a difference in benefit levels and in Niger it would even more than double the resulting benefits – although these are still minimal due to their very limited production level. However, it is also obvious that most of the benefits will be generated in India and therefore the overall aggregate ranking is hugely influenced by the presence and size of each zone in India itself.

One of the major differences between groundnut and pigeonpea is the cross country distribution of the benefits. While India is the major beneficiary of groundnut research for most scenarios, many countries do benefit to an often large extend. In pigeonpea however, the share of benefits to India is close to 100% no matter on which zone the research focuses. Furthermore, the difference in the total benefit levels between the main zones research benefits is much higher than in groundnut. The targeting of zones and the funding allocation between those is thus even more important in efforts to maximize the benefits.

- Results for both crops show that huge differences in the potential impacts do exist and that those do not solely depend on the share of production covered as often - implicitly or explicitly - assumed during targeting efforts when projects are set up in the "major production areas". Nevertheless, the total benefit might not be the most important factor to consider. The potential areas that could benefit from the research are often not taken into account where research in an area that has huge applicability to other zones is not targeted as the direct benefits are lower than in other zones. However the total benefits could be by far larger. This comparison can be highlighted by looking at the results for zone 7 in groundnut where only marginal benefits accrue in the zone itself but many other zones could benefit hugely. Comparison of the results for groundnut and pigeonpea highlights the significant difference in total potential global benefits across crops due to research spillovers. Relating to the preliminary results we find that the C matrix for pigeonpea was sparse (relative to groundnut) indicating weak applicability across production environments which, according to pigeonpea scientists, are due to photoperiod sensitivity of the crop.

4.1.2 Millets

The results of the quantitative analysis to prioritize the target production domains of millets research to achieve greater welfare benefits is presented in three sub sections:

1. The first sub- section discusses the results to identify the most payoff production domain for millets based on its welfare benefits to each countries and target regions.
2. The second sub-section presents the individual country level welfare benefits if the millet research is focused in the high payoff domains.
3. The last sub-section will present the different scenario results to comparison of the current (real world) welfare benefits with ideal world situation.

Welfare benefits across production domains and regions

Since ICRISAT is an international research organization, it may consider spillover research benefits along with direct benefits to prioritize the resource allocation and research investments. The expected benefits (with and without applicability[8] scenarios) from millet research with an assumption that ICRISAT will focus its research effort in single millet production domain at a time and annual benefits are discounted at 5% per annum are given in Table . The model result show that millet research which focused on the production domain -warm tropics drylands, 120-149 days- would generate the highest expected welfare benefits over 30 year time horizon of around $720.48 M among the 17 production domains delineated for millets since the production of millets is highest the production domain -warm tropics drylands, 120-149 days- the benefits from research is also the higher. The results also show that when research is focused on production domain like desserts[9] it generates about $326 m benefits (Table 5) but in that about 95 % of the benefits would accrue from spillover benefits (Figure 7).

The regional disaggregation of benefits shows that the highest payoff production domain is not the same for all regions. In Asia, the warm tropics drylands, 120-149 days is the highest

[8] The without applicability scenario was run with off-diagonals of applicability matrix with 'zero' assuming that the technology developed for one production domain will not be suitable for other production domains. The total expected benefit from this scenario is the direct benefits to the production domain without any indirect or spillover benefits from the other production domains.

[9] The production domain dessert is very harsh environment with zero length of growing periods (LGP), high temperature, scanty rainfall and poor soil fertility which does not suit for crop production. But about 2.6 % of millet is produced in this production domain. This is mainly because millet is the only crop grows with very little water and withstands high temperature. So wherever little irrigation is available in the desserts of North Africa, Middle East countries, Pakistan and western part of India, millet is the only crop grown for food and fodder.

payoff production domains with $479.85 M benefits but for WCA and ESA the highest payoff production domains is warm tropics drylands, 90-119 days and warm tropics subhumid, >150 days with expected benefits of $242.42 M and $15.06 M respectively (Table 5 and Figure 8). For ROW (include developed countries like Russia, China, Spain, and Hungary) the highest payoff production domain is temperate drylands, 90-119 days with expected benefits of about $43.93 m.

Figure 8 indicates the disaggregation of expected benefits into direct and indirect/spillover benefits when millet research is focused in one specific production domains. The results show that when millet research is focused on a production domain, the spillover benefits represent a high proportion of the aggregate total benefits in all the production domains excluding warm tropics drylands, 120-149 days- about 56% of benefits are through direct benefits and 44 % accrue in the form of spillover effects. This is mainly because large share of millet production is from this particular production domain. However, for research focus in other production domains like desserts, only 5% of benefits are from direct benefits and about 95% from spillover benefits. This is mainly because of applicability of millet crop technology across production domains. If international institute like ICRISAT fails to take these spillover effects into account in determining the expected benefits to research undertaken with focus on production domains, then their investment decisions may be based on the considerable underestimation of total benefits.

Table 5 Total present value (PV) welfare benefits (with and without applicability) to each of production domains from millet research resulting in 10% unit cost reduction (in M US$)

S No	Production Domains	Production ('000 tons)	Total	ICRISAT –focus[a]	Asia	WCA	ESA	ROW[b]	Total	ICRISAT -focus	Asia	WCA	ESA	ROW
			With applicability						Without applicability					
1	Warm tropics drylands, 120 - 149 days	6600.22	720.48	718.64	479.85	228.75	10.04	1.84	405.59	405.52	314.00	89.57	1.95	0.06
2	Warm tropics drylands, > 150 days	3098.35	676.33	673.69	464.53	197.83	11.34	2.63	199.97	199.90	161.37	36.06	2.46	0.07
3	Warm tropics drylands, 90 - 119 days	3687.02	636.68	634.83	383.40	242.42	9.02	1.85	145.69	145.61	45.33	99.10	1.19	0.08
4	Warm tropics drylands, 60 - 89 days	2842.61	559.39	557.10	324.51	222.81	9.78	2.29	112.70	112.68	35.92	75.44	1.32	0.02
5	Warm tropics subhumid, > 150 days	2716.09	549.04	546.75	376.62	155.07	15.06	2.29	127.29	127.24	82.05	33.62	11.57	0.05
6	Warm tropics drylands, < 60 days	730.23	472.30	460.64	272.99	179.42	8.23	11.66	23.94	23.94	2.04	21.22	0.68	0.01
7	Subtropical drylands, > 150 days	355.70	374.10	371.98	255.93	108.10	7.95	2.12	11.34	10.60	10.60	0.00	0.00	0.74
8	Deserts	654.08	326.93	321.99	194.37	120.91	6.70	4.94	18.05	13.27	5.41	6.01	1.85	4.78
9	Subtropical Humid, 120 - 149 days	695.97	290.18	279.98	246.36	27.98	5.64	10.20	59.21	58.72	58.71	0.01	0.00	0.49
10	Subtropical Humid, > 150 days	342.55	289.55	281.25	239.28	34.93	7.04	8.29	23.26	22.27	22.25	0.00	0.02	0.99
11	Subtropical Humid, 90 - 119 days	583.25	218.33	211.04	190.35	17.61	3.08	7.29	49.16	48.69	48.68	0.01	0.01	0.47
12	Subtropical Humid, 60 - 89 days	334.63	173.56	168.06	151.26	13.98	2.82	5.50	26.80	26.77	26.76	0.00	0.00	0.03
13	Temperate drylands, 90 - 119 days	1293.96	167.60	123.67	123.66	0.01	0.01	43.93	91.97	66.58	66.58	0.00	0.00	25.38
14	Subtropical Humid, < 60 days	165.01	153.53	148.13	129.17	16.08	2.89	5.39	12.88	12.75	12.75	0.00	0.00	0.13
15	Temperate drylands, 60 - 89 days	537.17	141.45	101.60	97.22	4.25	0.14	39.85	40.73	27.95	27.95	0.00	0.00	12.77
16	Temperate Humid, > 150 days	411.76	133.29	102.32	102.31	0.01	0.01	30.97	33.85	29.73	29.73	0.00	0.00	4.12
17	Temperate drylands, < 60 days	281.89	124.40	86.57	77.81	8.49	0.27	37.83	16.45	0.36	0.36	0.00	0.00	16.09

Note: [a] Total welfare benefits in Asia, West and Central Africa (WCA) and Eastern and Southern Africa (ESA) countries where ICRISAT focus its research investments; [b] ROW – Rest of the world

Source: Authors calculation

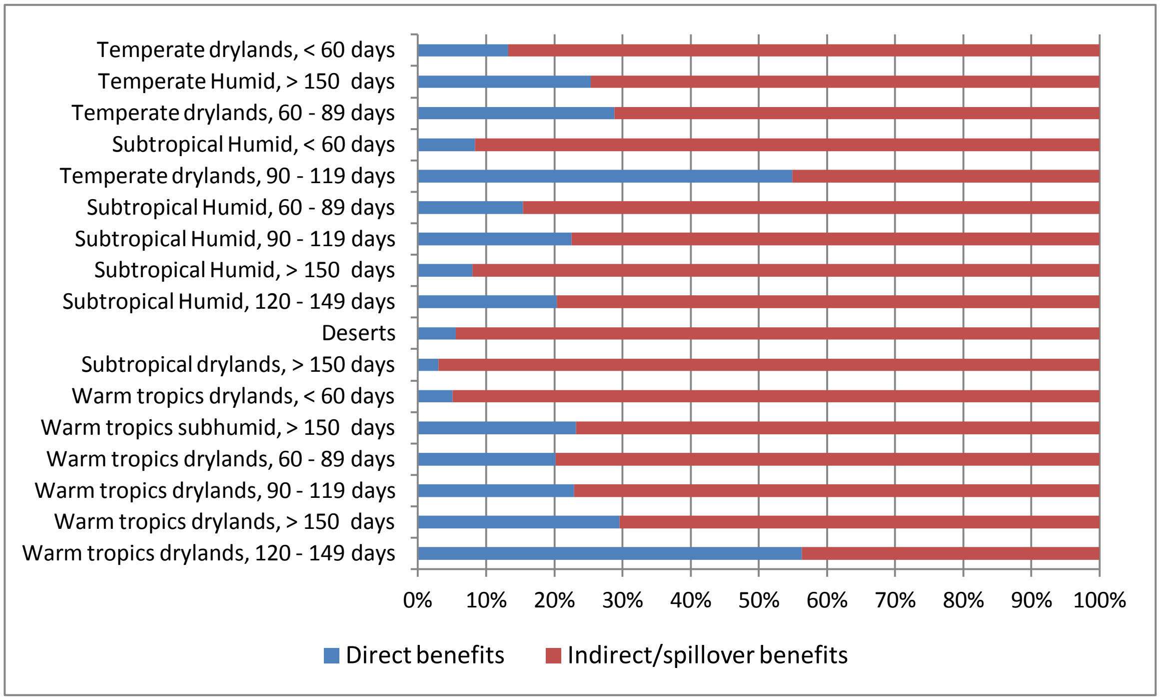


Figure 7 Direct and indirect (spillover) benefits (in %) to each of production domains from millet research resulting in 10% unit cost reduction (in M US$)

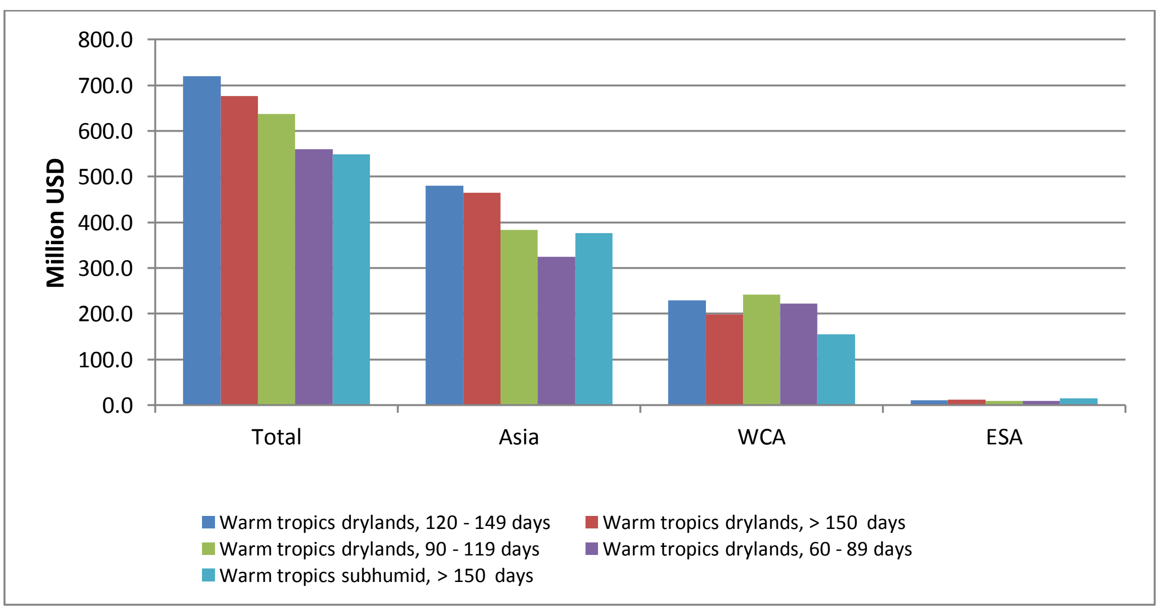


Figure 8 Region wise total welfare benefits (in Million USD) from different production domain focus

Scenario Analysis: sensitivity of welfare benefits to important model parameters

The most important parameters to estimate the welfare benefits are the adaptive capacity and adoption rate of the individual countries. To assess the magnitude of change in potential benefit when the real world moves to ideal world, we run different scenarios with the assumption that research will be conducted in the high payoff production and compare the current conditions (real world) with:

1. where the adaptive research capacity reaches the maximum(Adaptive capacity = 1) and adoption rates remain the same;
2. where adoption rate is maximum (Adoption rate = 1) and the adaptive research capacity remains the same, and
3. the ideal world (Adoption = 1; Adaptive = 1).

Figure 20 reveals that in the ideal world situation the expected world benefits would be doubled (from $ 720.48 m to $1530.57m) compared to real world which clearly shows that there is lack of capacity to adapt research innovation which suits their production domains among countries and also there is poor adoption of technology by the farmers. The results also indicate that the Asian countries are already having higher adoption rate and also adaptive capacity, so there is no higher magnitude of change in welfare benefits but the untapped benefits is very high in WCA regions. The results show that when the adaptive capacity of research and adoption of technologies by farmers reaches the maximum level, the expected benefits would increase from $228.75 m to $826.05 m that is three folds higher than real world benefits (Figure 9), which is higher that of the Asian region.

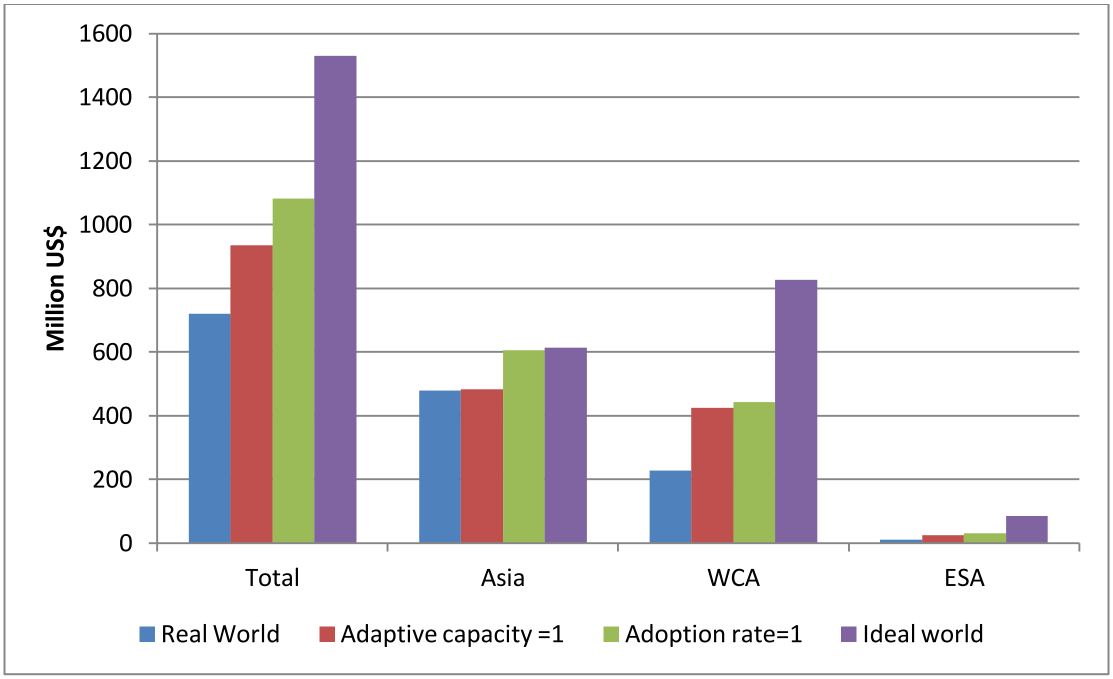


Figure 9 Welfare benefits (in M US$) by regions under different scenarios (Targeting the highest payoff production domain - Warm tropics drylands, 120 - 149 days)

Implications

The analysis indicated that millet research could generate substantial benefits when the research focuses on production domain –warm tropics drylands, 120-149 days. But to generate higher benefits in WCA and ESA, the millet research should focus in warm tropics dryland, 90-119 day and warm tropics subhumid, >150 days respectively. The contributions of spillover/indirect benefits to total benefits were substantial mainly because of applicability of millet technology across production domains. The results also indicate that by improving the adaptive research capacity and adoption rate of the SSA countries could generate welfare benefits by 3-4 times higher than the current level.

The following conclusion can be drawn from the results from millets:

- The high payoff production domains are different among regions.
- The spillover benefits contribute substantially to total benefits that vary between 45 to 97% depending upon the production domain research focus. Without accounting for spillover, the total benefits for millets research could be under estimated.

- The results indicate that the contribution of different countries to total benefits can provide evidence for targeting countries and production domains to achieve higher benefits.
- The potential benefits can be increased by 3-4 times higher by improving the adaptive capacity and adoption of technology among farmers.

4.1.3 Sorghum

Figure 10 presents the shares of production portions across the 13 updated homogenous sorghum research domains in the world. The single largest domain having nearly 25 production share was Research domain-13. Research domains-6 and 7 occupy the next places with 20 and 15 per cents respectively. All the remaining research domains contributing less than 10 per cent share in the total production.

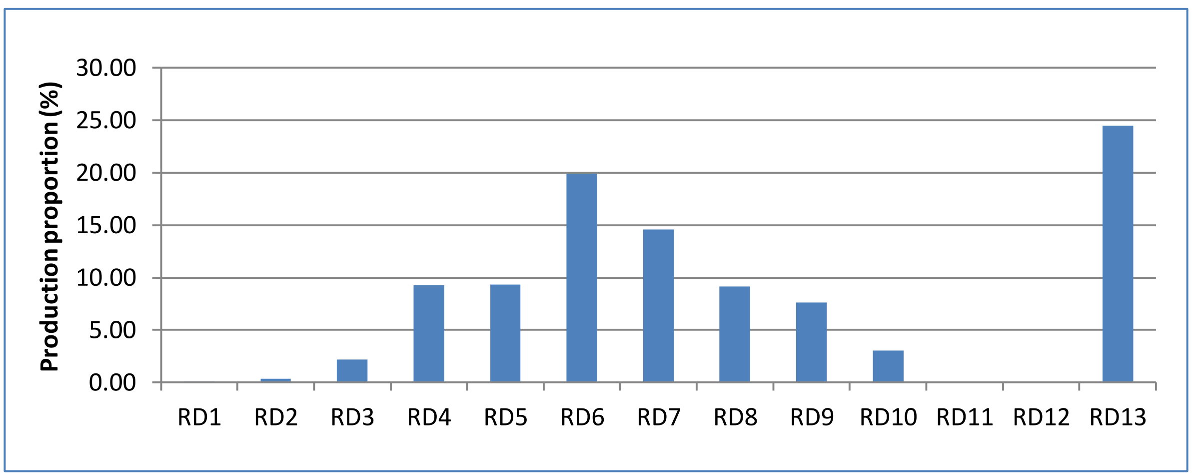


Figure 10 Production proportions across Research domains

These estimation of welfare benefits ($ US M) across research domains for each individual research focus were obtained under real world (where the actual adaptive and adoption levels for each country applied with 10 per cent unit cost reduction on 2008 FAO prices) conditions with research applicability between research domains and summarized in Table 16. The benefits are arranged in descending order based on ICRISAT Focus (includes benefits from Asia, ESA and WCA only) values. Research domain-6 (Warm tropics drylands, 120-149 days) stood on the top with 1094.9 $ US M (ICRISAT Focus) and 1793.1 $ US M (Total benefits). It was followed by Research domain-7, 5 and 13 respectively. The top three welfare benefits in research domains were observed in one only agro-climate i.e., Warm tropics drylands with different LGP periods. These results clearly conclude that RD-6 is high-pay-off research domain for ICRISAT Focus sorghum research. It was closely followed by RD-7 and RD-5. Similarly the estimation of welfare benefits under real world without applicability across research domains for each individual research focus is also presented in Table 6. The total and ICRISAT Focus benefits have gone down significantly across research domains because only the direct benefits were considered in targeted regions. However, Research domains-6 and 7 were on the top order respectively. But, total and ICRISAT Focus research benefits have declined to 40 and 55 per cents respectively in case of Research domain-6. Once again results clearly confirm that RD-6 is high-pay-off domain even applicability was not considered.

Table 6 Welfare benefits ($ US M) for each individual research focus and domains

With spillovers						***Without spillovers***					
RDs	ICRISAT Focus	Asia	ESA	WCA	ROW	RDs	ICRISAT Focus	Asia	ESA	WCA	ROW
RD 6	1094.9	900.1	86.1	108.7	698.3	RD 6	601.4	553.7	6.3	41.4	123.1
RD 7	898.2	703.7	95.6	98.9	708.0	RD 7	368.5	317.4	23.5	27.6	291.6
RD 5	874.4	686.4	86.0	102.1	872.6	RD 13	274.9	128.4	92.0	54.5	161.3
RD 13	770.2	554.7	115.9	99.6	422.4	RD 10	228.1	228.0	0.0	0.0	116.5
RD 10	538.3	476.8	24.6	37.0	1285.5	RD 9	111.0	109.6	0.5	0.9	936.8
RD 8	485.6	451.3	14.5	19.8	1680.8	RD 5	81.5	31.5	18.5	31.5	88.1
RD 9	383.0	348.2	12.3	22.5	1432.4	RD 4	73.0	31.5	18.2	23.3	102.2
RD 4	359.2	251.6	55.1	52.5	804.9	RD 8	56.4	50.1	5.5	0.8	934.2
RD 3	16.6	0.0	16.5	0.0	177.0	RD 3	16.6	0.0	16.5	0.0	177.0
RD 2	5.3	0.0	5.3	0.0	7.3	RD 2	5.3	0.0	5.3	0.0	7.3
RD12	3.8	3.8	0.0	0.0	36.8	RD12	3.8	3.8	0.0	0.0	36.8
RD 1	0.8	0.0	0.8	0.0	7.3	RD 1	0.8	0.0	0.8	0.0	7.3
RD 11	0.0	0.0	0.0	0.0	0.1	RD 11	0.0	0.0	0.0	0.0	0.1

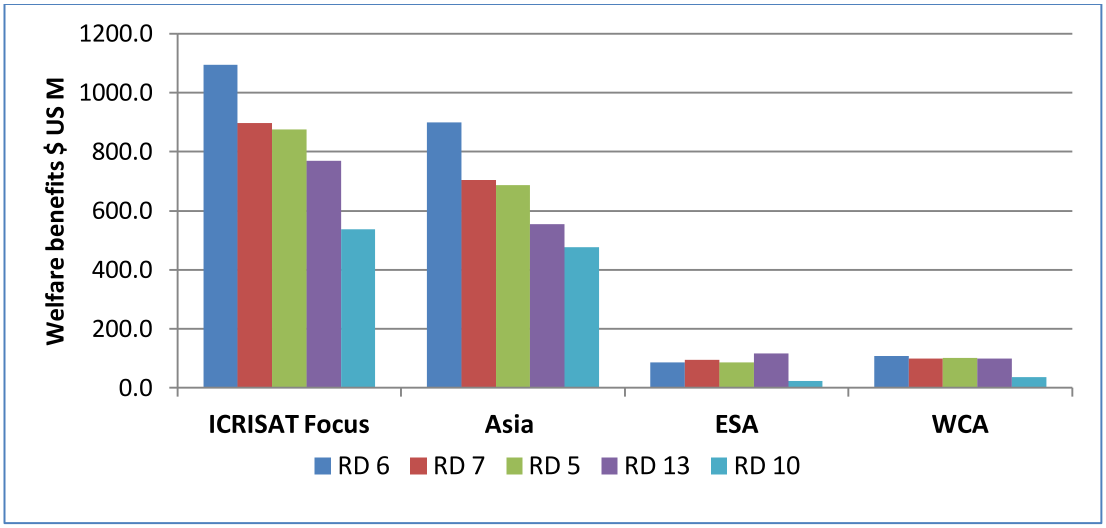


Figure 11 Region-wise welfare benefits under top five ICRISAT research focuses in Real World

The region-wise break-up of welfare benefits are presented in Figure 11 for top five research focuses under Real World scenario. The results clearly dominated by Asia followed by WCA and ESA regions. More than 70-90 per cent welfare benefits are accruing alone in Asia, especially in India. This may be because of quicker and high adoption rate of improved cultivars in India when compared to WCA and ESA regions. Lack of NARS strategic and adaptive capacities may be another reason for lower research benefits in those regions.

Within Asia, nearly 94 per cent benefits are accrued to India and only 7 per cent to China. Mexico (56%), USA (24%) and Brazil (5%) are major beneficiaries in the ROW region. The research benefits were marginal in both African (WCA and ESA) regions. Nigeria and Mali are the dominant beneficiaries in WCA region while Ethiopia, Tanzania, Sudan and Uganda are top receipts of spillovers in ESA region.

The sensitivity analysis showed that huge scope for gaining sorghum welfare benefits under ICRISAT Focus than in ROW. Among the three regions in ICRISAT Focus, WCA has indicated vast potential in the region when compared with other regions (see Fig 12). The real and ideal benefits are pretty closer in case of Asia because of strong NARS capacity and high rate of adoption of improved cultivars. Countries like Nigeria, Burkina Faso and Mali in WCA region and Sudan, Ethiopia and Tanzania in ESA region have exhibited enormous potentials for sorghum welfare benefits in the sensitivity analysis under different iterations.

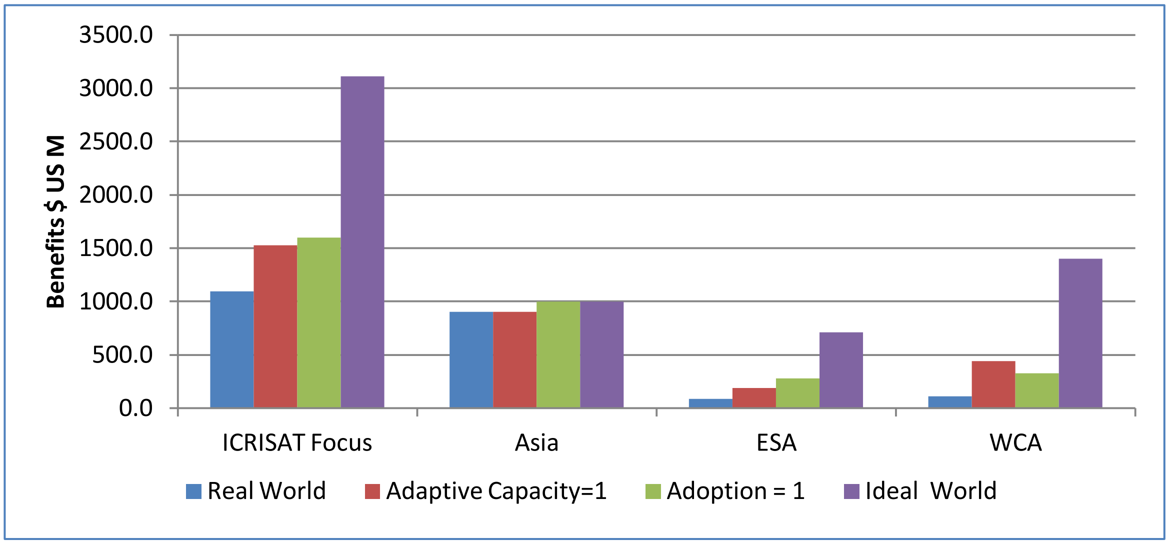


Figure 12 Region-wise welfare benefits under different scenarios (RD-6 research focus)

Implications

Based on the above analysis, the study concludes that the future research should be focused more in WCA and ESA regions for realizing higher research benefits. Countries like Nigeria, Burkina Faso, Sudan and Ethiopia should be targeted first for strengthening NARS research capacities as well as for increasing the adoption rates through institutional innovations. Correspondingly, ICRISAT Management has to allocate more resources and research towards WCA followed by ESA and Asia regions.

4.2 Estimates on adoption and adaptive capacity

DIVA results from WCA

In general, the expert elicitations gave high rates of adoption estimates among the three crops. However, scientists found it extremely difficult to estimate the levels of adoption. They found easy to locate the environments on maps at villages, districts and regions where the varieties are likely to be adopted. The improved cultivars have been classified in two categories (AMV: All modern varieties and NMV: New modern varieties) based on the year of release. Varieties released since 1970 categorized as 'AMV' while cultivars made available less than 20 years ago identified as 'NMV'. Adoption rates high for varieties released since 1970, but low for varieties released less than 20 years ago.

Three methods of monitoring and evaluating adoption including expert opinions, community and household surveys, identifies the drivers of adoption and assesses the impacts of modern groundnut varieties on rural livelihoods in Nigeria (Table 7). Results indicated that adoption rate of modern groundnut varieties are estimated to be 62.55% through expert opinions, 59.38%through community surveys and 31% when using household surveys. There are differences between experts and community and household surveys. There are seemingly no differences between estimates from community groups and expert opinions. Expert opinions are over-estimated by more than 20% compared to household surveys. The visual consistency between expert opinions and focus groups hide the differences in the number of varieties reported and the adoption estimates at variety level. The inconsistency between expert opinions, community estimates and household surveys may partially be explained by some methodological issues related to expert opinions and community group surveys. Household surveys remain the best method of evaluating adoption.

Table 7 Adoption estimates for groundnut varieties in Nigeria using different methods of elicitation

Name of variety	Community	Expert opinion	HH(%A)	HH (%S)	D(C-E)	D(C-HH)
55-437	9.4	40.63	14.79	14.84	-15.02	-5.39
69-101	0	Nr	0	0		0
F 452.2	0.05	Nr	0.04	0.04		0.01
ICIAR 19 BT	0.25	3.53	0.45	0.41	-5.22	-0.2
ICIAR 6 AT	0.03	Nr	0.11	0.06		-0.08
ICIAR 7B	0.03	Nr	0.01	0.01		0.02
RMP 12	0.34	9.02	1.14	1.12	-4.87	-0.8
RRB	0.81	Nr	1.24	1.3		-0.43
SAMARU?	1.96	Nr	2.09	2.07		-0.13
SAMNUT 21	0.70	2.45	3.2	3.2	-3.77	-2.5
SAMNUT 22	2.10	2.45	3.21	3.17	-1.89	-1.11
SAMNUT 23	1.42	4.48	4.21	4.22	-5.52	-2.79
Others	-	0.67	-	-	-	-
Varieties < 20 years	6.5	21.92	13.28	13.15	-14.37	-6.78
All modern varieties	59.38	62.55	31.00	31.07	0.19	20.38
All local varieties	40.63	48.81	69.00	68.93	-8.18	-28.37

Note: HH – Household survey; C – community/key informants; A – area estimates; S – source of seed

DIVA results from ESA

The national representative household sample surveys were conducted for identification of cultivar-specific groundnut, sorghum and pigeonpea varieties in Tanzania covering 14 districts,

77 wards, 104 villages and 1622 households under Objective-2. Further, the expert elicitations generated from workshops were compared with national statistics information available at district level/recommended crop domain level. The results clearly indicated that adoption is far from homogenous within Tanzania but rather concentrated in some regions.
These two results (community and expert panels) are compared at more aggregate level of region. Although the results from expert panels are wider at times, these two estimation methods leads to much more comparable results. Most of the community estimates are within the boundary of expert elicitation except in few cases.

Overall, the adoption estimates generated from these three different methods gave wide differences at aggregation level. Not a specific pattern or trend was observed among the three estimates. However, the comprehensive and systematic expert elicitations with more number of iterations would generate the close estimations to household surveys. The cultivar specific adoption information narrowed down the gaps between the different methods of estimates.

TRIVSA results from SA

In case of Rice, the expert elicitation and household surveys have showed close correspondence between their estimates. The experts were able to provide reliable estimates of area under dominant varieties. Presence of strong NARS and well development extension system and other secondary sources of information in India might have helped the experts for better prediction of cultivar specific adoption information. However, the composition of experts and process of expert elicitation matters the quality of output from the discussions.
In case of five mandate crops, ICRISAT has joined hands with NARS (ICAR and crop specific AICRPs) and conducted more extensively and deeply. Overall, ICRISAT has conducted the expert elicitations in two rounds. First round of expert elicitations were conducted with scientists of respective AICSIP centres located in that state. Based on the group knowledge and skills, the information was collected either at regional or state level. After obtaining this preliminary adoption estimates from each state, ICRISAT has conducted the second round of elicitation with state/national level experts in a separate crop specific workshop conducted at ICRISAT. Overall, the expert judgments were much closer to the secondary data estimates provided by the department of Agriculture. The results are more comparable with 1998 baseline estimates, but ICRISAT has to validate this information with primary household surveys to be carried out very soon in Maharashtra state.

4.3 Institutional factors enhancing innovative and adaptive capacity and adoption

An empirical in depth study is currently underway to enhance the role of institutional factors and application of transaction costs in measuring the adaptive capacity and adoption parameters. The initial studies have reference to the empirical application for groundnut in Asia and ESA.

4.4 Initial results from application of integrated model

Potential economic benefits and return on investment of groundnut technologies

The welfare benefit of the adoption of new promising (drought, heat tolerant and combination of drought, heat and higher yield potential) cultivars of groundnut in the target countries and its impact on world price, production, consumption, change in malnutrition and poverty is assessed using IMPACT model. For this analysis, the productivity gain of the promising technologies over the baseline cultivars in each countries and regions are simulated using the DSSAT spatial crop model and incorporated in the IMPACT model and compare the baseline scenario without new technologies and simulation scenarios with the adoption of new promising technologies. The shift in the supply of the groundnut attributed to the new technologies developed from ICRISAT are likely to reduce the unit cost of production and increase the income of the farm household who adopt the technologies and reduce the market price which benefit the consumers. In the analysis, the spillover effects of promising technologies on non-target countries due to change in world groundnut production and change in world prices are identified.

Global Welfare benefits and Internal Rate of Return (IRR) of different promising technologies

The potential global welfare benefits due to the adoption of promising groundnut cultivars are given the Table 18. The potential global net benefits over a time horizon of 30 years (2020 to 2050) derived from adoption of heat and drought tolerant cultivar in the target counties are about $302.39 million and $784.08 million with IRR of 30% and 41% respectively. The promising technology with combination of three traits (drought, heat and yield potential) will produce potential net benefits of $1.5 billion with IRR of 50% (Table 8).

Table 8 World potential welfare benefits and Internal Rate of Return (IRR) from groundnut technologies

Technology	Net Benefits ($M US)	IRR (%)
Heat Tolerant	302.39	0.30
Drought Tolerant	784.08	0.41
Heat + Drought + Yield Potential	1519.76	0.50

Overall producers lose some of the surplus owing to the decrease in world market price of groundnut (Figure 13). However, the negative producer surplus occurs mainly in the some non-target countries like USA, China, etc. who are major exporters offsetting the positive producer surplus gained in the target countries where the new technology is adopted. Interestingly, a few countries which were not targeted registered relatively large increases in their surplus (Figure 14). The global consumers gain significantly due to decrease in price in the world market caused by the increased production.

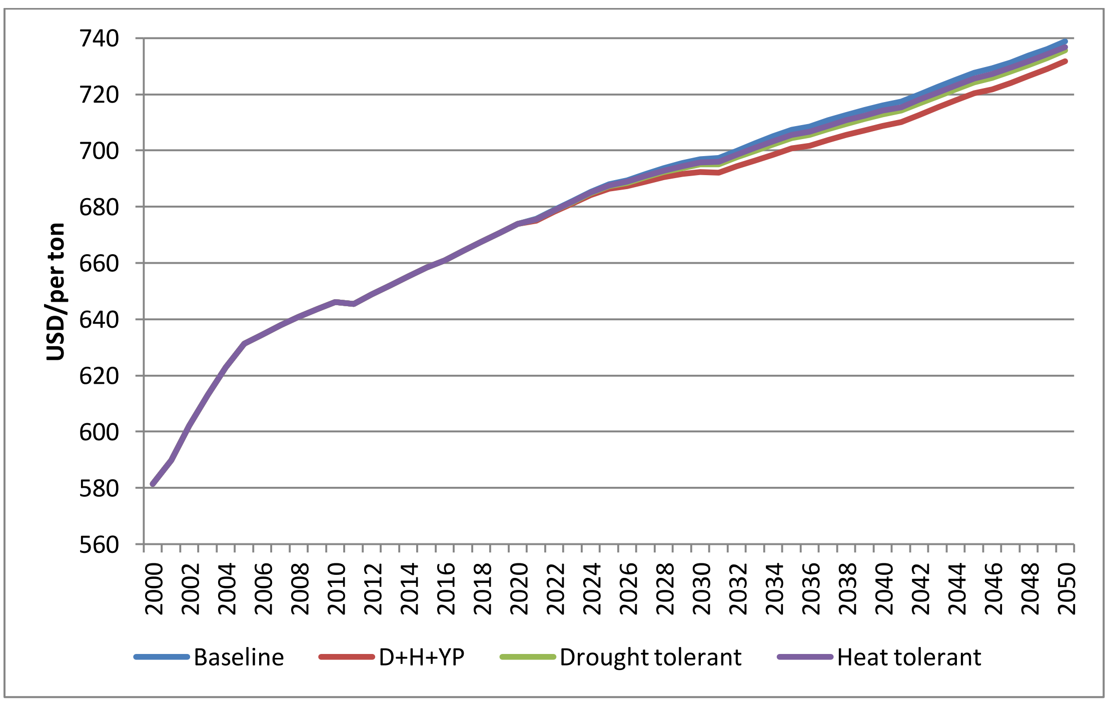


Figure 13 The world market price of groundnut under different scenarios (USD/ton)

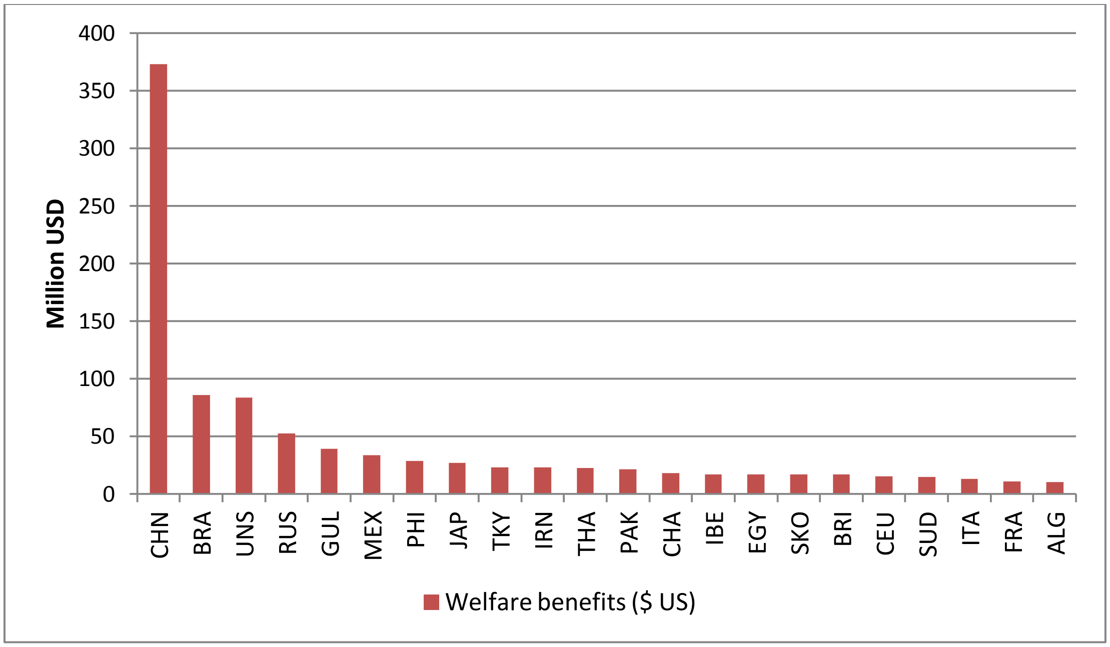


Figure 14 Welfare benefits ($M US) in the non-target countries for adoption of improved groundnut technologies (heat + drought + yield potential)

Potential economic benefits and return on investment in target countries

The estimated potential net benefits of the groundnut promising technologies developed and released in 2020 in the target countries are presented in the Table 9. The groundnut technology with combined traits like drought, heat and higher yield potential will generate higher benefits to all the target countries ranging from $286.32 to $1.47 million. The benefits are higher in India and Nigeria compare to other target counties since they are the largest producers and consumers of groundnut. The results shows that compare to heat tolerant groundnut technology the drought tolerant technology has the highest payoff in all the target countries since groundnut is grown in rainfed condition where drought is the major production constraint.

In WCA region groundnut is cultivated in marginal land with low inputs under rainfed condition, the adoption of drought tolerant with higher yield potential cultivars will generate both producer as well as consumer surplus in the target countries where the technology is adopted.

Table 9 Potential welfare benefits for groundnut technology adoption in the target countries

	Technology	Heat Tolerant		Drought Tolerant		Heat + Drought + Yield Potential	
Region	**Target Country**	**Net Benefits (M USD)**	**IRR**	**Net Benefits (M USD)**	**IRR**	**Net Benefits (M USD)**	**IRR**
ESA	Malawi	0.69	0.16	0.89	0.17	1.47	0.19
	Tanzania	0.59	0.14	3.76	0.28	8.30	0.41
	Uganda	1.01	0.18	4.09	0.28	8.66	0.40
WCA	Burkina Faso	3.63	0.34	15.28	0.86	22.49	0.99
	Ghana	0.82	0.18	0.41	0.10	2.19	0.15
	Mali	0.98	0.19	4.43	0.47	6.50	0.42
	Nigeria	23.32	0.51	37.39	0.65	64.67	0.95
	Niger	1.27	0.22	7.67	0.77	12.93	0.97
SSEA	India	37.70	0.33	129.73	0.96	286.32	1.16
	Myanmar	2.94	0.45	1.78	0.13	5.05	0.38
	Vietnam	7.31	0.58	14.34	0.80	19.28	0.74

Impact of technology intervention on welfare indicators of the target countries

The impact of adoption of promising groundnut cultivar with drought, heat tolerant and higher yield potential traits on welfare indicators like change in reduction in number malnourished children and number of people under hunger risk are presented in the Table 20. The simulation results show that if the promising technology of groundnut is adopted in the target countries, it will reduce the children malnourished under the age group of 5 in the target countries ranging from 942.1 in Nigeria to about 163 children in Vietnam for a million US$ investment (Table 10).

The higher production of groundnut as well as the increase in consumption of groundnut as source of food in the target countries has reduced the population under hunger risk by about 21176.3 people in Myanmar; 19303.1 people in Malawi; 16542.3 people in Niger; 11372.7 people in Tanzania and 7481 people in India for million US$ investment in groundnut research (Table 10).

Table 10 Impact of adoption of promising groundnut cultivar (Drought + Heat + Yield Potential) on malnourished children and population at hunger risk

Regions	Target countries	Malnourished-Cost Ratio (children/M USD)	Hunger-Cost Ratio (people/M USD)
ESA	Malawi	-410.3	-19303.1
	Tanzania	-215.8	-11372.7
	Uganda	-593.2	
WCA	Burkina Faso	-537.7	-5898.6
	Ghana	-290.5	
	Mali	-300.4	
	Nigeria	-942.1	-3164.2
	Niger	-472.5	-16542.3
SSEA	India	-209.2	-7481.8
	Myanmar	-308.9	-21176.3
	Vietnam	-163.6	-4124.4

Note: Malnourished-C_Ratio: Change in Malnourished children - cost ratio (children/million $US); Hunger-C_Ratio: Change in number of people at Risk of Hunger - cost ratio (people/million $US).
Source: Authors' calculation

5 Details of Framework Enhancement and Data Estimation/Collection

Introduction and Important Enhancements

In section 4 the preliminary results of the analysis highlighted that there can be large differences in welfare changes for changes in many of the underlying parameters. This is expected but as was discussed means understanding these parameters and ensuring they are estimated effectively is crucial.

This section discusses the details of the estimation of two important groups of the framework parameters including some enhancements the group have made to this estimation process. It then outlines efforts to enhance our understanding of the institutional aspects of some of these parameters and finally some empirical results for links to other models used for priority setting within the CGIAR system.

To provide a clear picture of these four enhancements it is important to list the full set of data and parameters required to quantify the welfare gains for ICRISAT research. These were listed in detail in section 3 (p. 31) and are summarised below:

1. The homogenous zones
2. Cross homogenous zone applicability (C, c_{ij})
3. Production proportions (F, f_{iy})
4. Research focus (R, r_{yi})
5. Unit cost reduction (K=K*S, k_{yft})
6. Probability of success of innovative research (p_{yt})
7. Probability of success of adaptive research (a_{yft})
8. Ceiling level of adoption (X_{yft})
9. Production and consumption (Q_{sft}, Q_{dft})
10. Producer and consumer price (P)
11. Elasticities of supply and demand (e_{si} and e_{di})

Items 9 through 11 are very important but information is taken from published sources or other studies. For several of these indicators data is available from FAO and other sources. The production and consumption data are used from FAO (2012) database. In the model the averages over the years 2005 to 2007 are used as the latest reliable estimates for several indicators. For the producer prices (farm gate prices) the FAO (2012) prices in US Dollar were used where available. For the remaining countries the average prices were used. The elasticities of supply and demand were used as estimated by IFPRI for the IMPACT model. These are the most consistent estimates available on a global level.

The remaining 8 parameters are the focus of the four enhancements discussed here. They can be summarised as:

i. New application of spatial tools and GIS to estimate K=K*S and S=RCF, that is, parameters 1-5.
ii. Revisiting adoption and adaptive capacity to estimate p_{yt}, $a_{yf}t$ and $x_{yft, \text{ that is,}}$ parameters 6-8.
iii. Transactions costs and their implications for innovative and adaptive capacity and adoption, how we estimate p_{yt}, $a_{yf}t$ and x_{yft} better over time and use this to improve ICRISAT's effectiveness
iv. Complementary results generated form alternative models to generate sound research strategies.

The rest of the section provides details on each of these.

*5.1 New application of spatial tools and GIS to estimate K=K*S and S=RCF*

This section will explain the research applicability between production environments and countries and spillover welfare impacts i.e. K=K*S and S=RCF. This enhancement highlights research applicability modelling to support spillover estimation using spatial tools including Geographic Information System (GIS) techniques. It provides an important flexible tool for involving research stakeholders and thus supporting their decision choices. Application is highlighted using a comparison of results for selected grain legumes and dryland cereal crops.

The parameters 1-5 are estimated as discussed below.

5.1.1 Estimates for groundnut and pigeonpea

The homogenous zones

One of the crucial inputs in the model are the homogenous zones across the world for the crop in question. Therefore, the homogenous zones as developed by Mausch Bantilan (2012) were included for the groundnut estimation and using the same methodology pigeonpea zones were developed and included (Figure 16 and Figure 17). Both zones are mainly based on the agroecological zones (AEZ) developed by FAO (2000). These already include the most important features characterizing different environments and thus are a very useful starting point for the customization for different crops. Based on the AEZ in-depth discussions with crop expert were held to understand the specific needs of the crop and further refine the zones.

For groundnut the most important feature added was the length of growing period (LGP) and thereby the delineation between short and medium duration groundnuts and long duration groundnut growing areas. The cut-off point was set at 120 days based on international trial results conducted by ICRISAT over the last decades.

For Pigeonpea, the most important feature is the photoperiod sensitivity of the crop. This leads to a very limited applicability of one variety across latitudes. However, as the AEZ are already implicitly accounting for this factor as also the climate variable change along latitudes it was not necessary to incorporate an extra layer for this. Close investigation together with Pigeonpea scientists revealed that the photoperiod sensitivity is well taken care of using the AEZ.

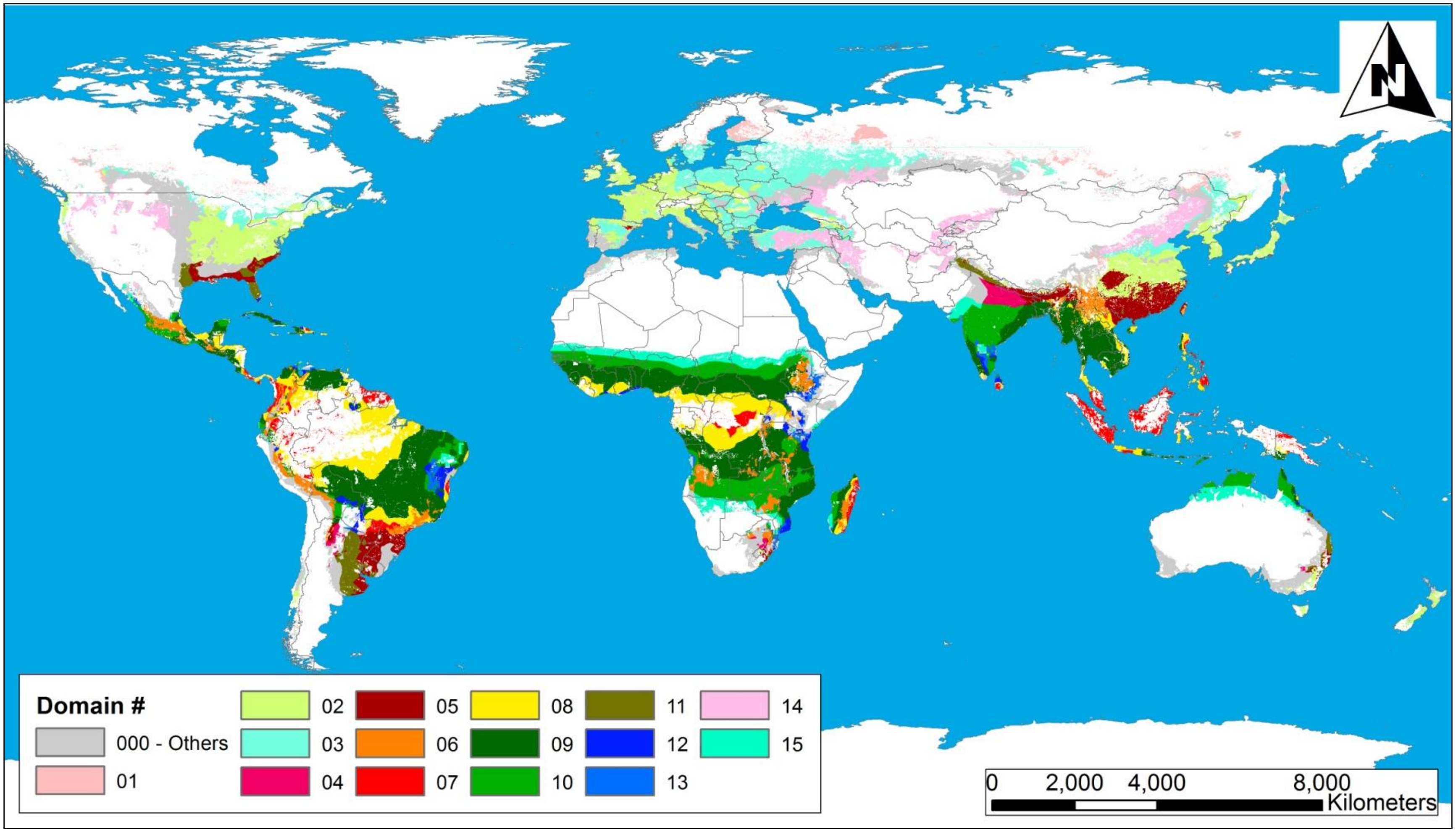


Figure 16 Groundnut homogenous zones. Source: Own presentation.

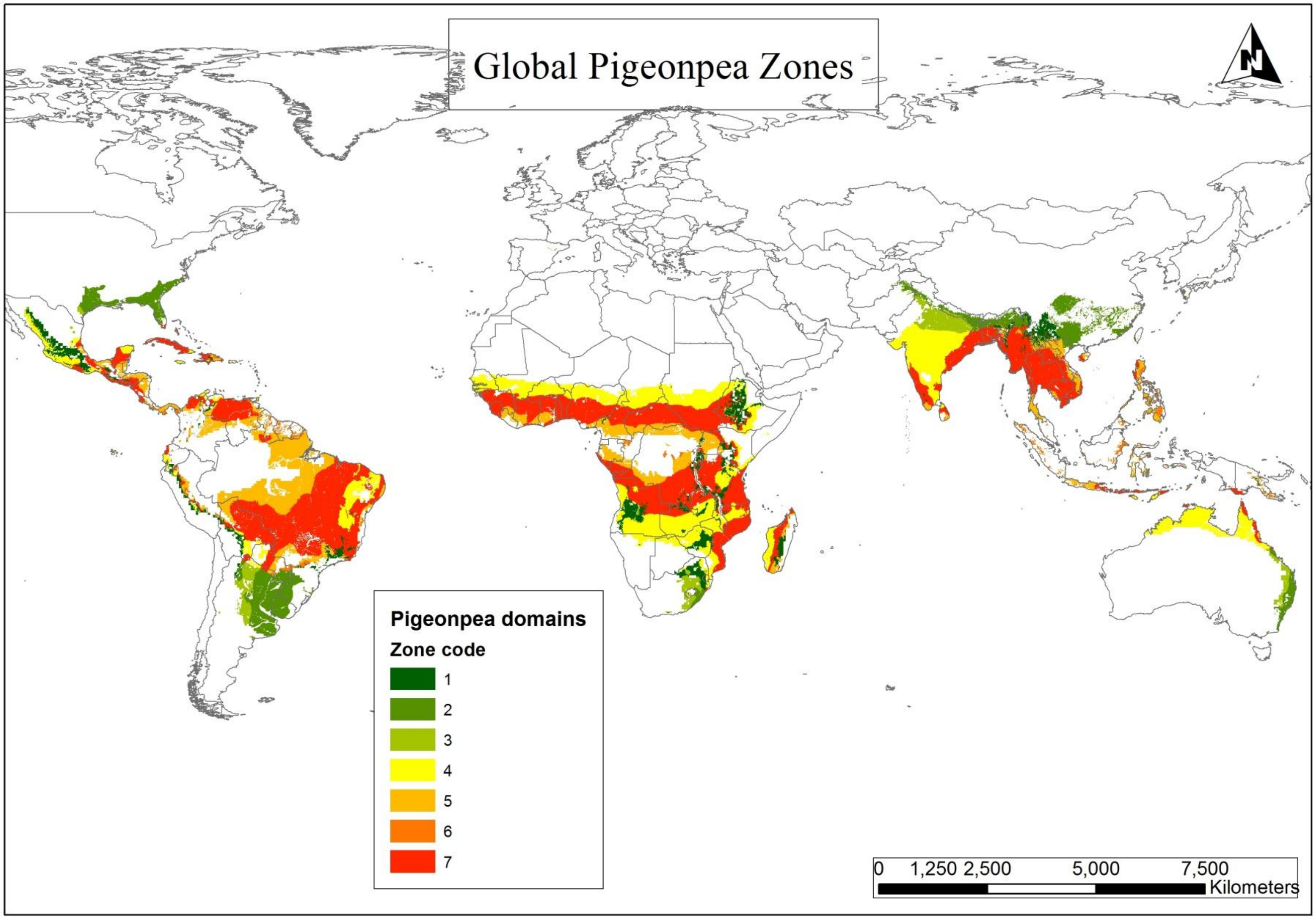
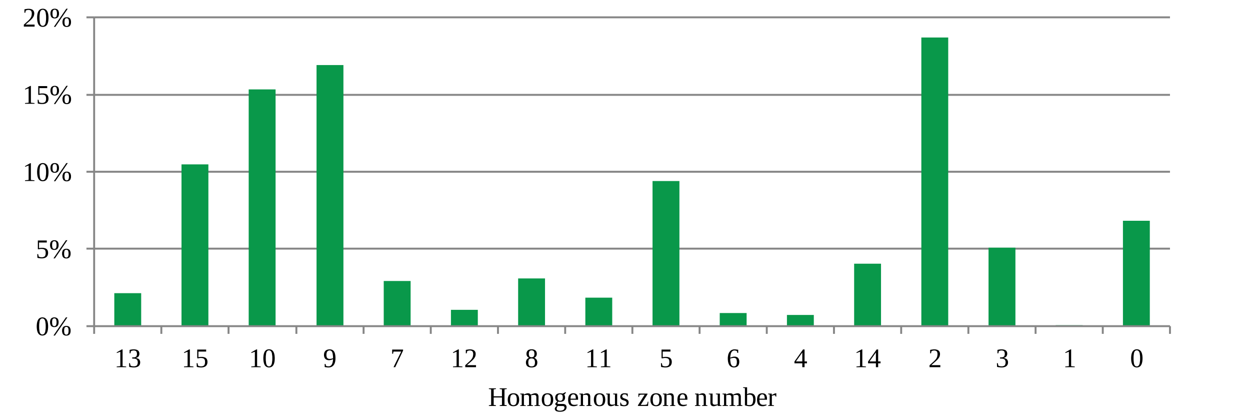
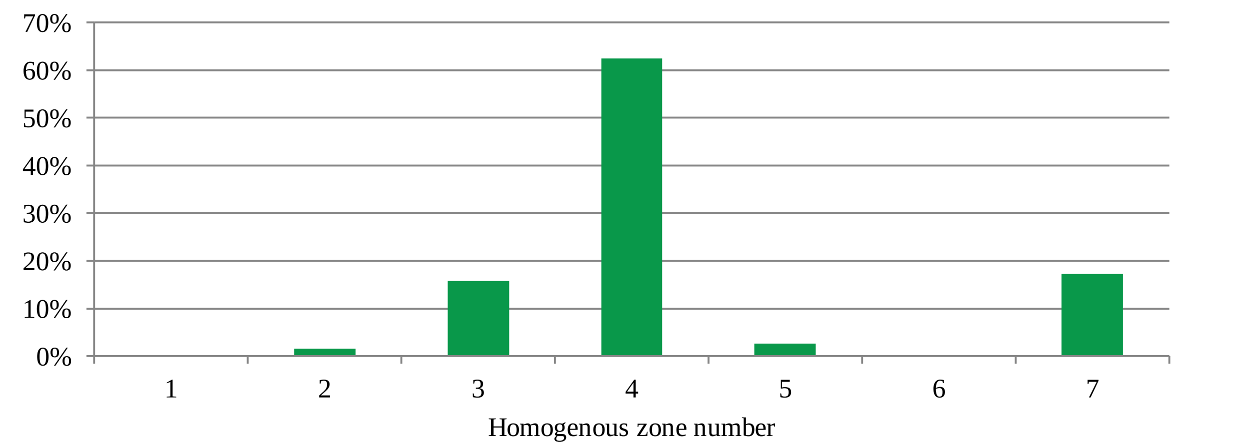


Figure 17 Global pigeon pea homogenous zones

Furthermore, temperature is a crucial factor for the growth pattern of Pigeonpea. (Silim 2006) Therefore, the elevation levels were closely investigated as an additional layer after the AEZ is already accounting for the major temperature differences. After overlaying the elevation levels of 1500m, which was mentioned as a cut-off point, it was found that this is also already covered in the AEZ. The warm and cold tropics are delineated along just this line and therefore the AEZ was the sole base layer for Pigeonpea. After accounting for climate the areas that currently grow pigeonpea (Monfreda 2008) or are suitable for legume production (FAO 2000) were overlayed to separate out the relevant areas from the AEZ. Finally, all areas with less than 90 days LGP were cut out to make sure that only zones that can grow pigeonpea under rainfed conditions are included. For the final homogenous zones, see Figure 16.



a: Production across groundnut HZs.



b: Production across pigeonpea HZs.

Figure 18 Production across HZs. Source: Own calculations based on SPAM.

The distribution of the total production already indicates differences in the benefit levels that potentially emerge from investments focusing on different HZs. This distribution will however be influenced by the other parameters in the model and is thus only a first indication of the most important producing zones. The main difference between these two crops is the wide distribution of groundnut production across many different zones while the pigeonpea production is very concentrated in one single zone.

Cross homogenous zone applicability

Based on the crop specific HZs developed, the applicability of varieties across these zones was established for each cop. The underlying question that was posed to the crop experts was 'what share of the varieties developed for one particular zone is likely to outperform the best local variety in each of the other zones'. Ideally, this could be econometrically established using the results of a vast set of international farmer field this would give the actual performance (see Maredia (1996) for an example using on station yield trial data as an approximation of performance enhancements in farmers fields). Unfortunately, the international trials ICRISAT conducted during the past 40 years do not cover all zones and do not include enough replications for individual varieties[10] to make econometric estimation viable. Furthermore, it is only possible to attribute the target zone for a few varieties that were officially released. Therefore, using these trials would not give a sufficient basis to fill the matrix. Nevertheless, as the most senior breeders in ICRISAT have been working in several locations and for several target zones already, their judgment is of high value for this exercise and therefore the applicability was estimated using their judgments and selectively cross checked with the data available. This approach was consistently taken for both crops.

For the actual discussion a large scale print out of the HZ maps as well as the Harvest Choice (2009) was taken to the discussion to familiarize the expert with the task at hand and to make discussions more targeted and visualize the zones in question. Starting from the location most familiar with each scientist the matrix was filled stepwise. Based on their experiences and targets during their time in that location and their multiple cooperating agencies and scientists a baseline was established for the estimations. Due to their work in the particular location confidence levels are high and they get more comfortable with the general idea. This led them to further estimate the factors for zones less familiar with them but for which they actually have a very good feel based on their long experience with partners across the world and their

[10] This is due to the fact that the objectives for these trials were different and rather based on demands by several countries than on the intentional applicability trial.

generally vast background knowledge of the distribution of varieties and the conditions in each country. Based on ICRISAT's mandate and mission, the breeding focus is on the semi-arid tropics, which is the reason for the zero estimates for zones 0,1,2,3 and 14. As the material developed by ICRISAT is not taking those zones into account the applicability is 0 as these particular zones are extremely different from the target zones. Admittedly, there is a chance that a certain degree of applicability exists between those zones but based on our work we are not able to predict this and it is not relevant in the framework of ICRISAT dissemination support information. Therefore we did accept this limitation and did not try to pursue the scientists to give us estimations for those zones or find others who would be able to do so.

After a first round of estimations, some numbers were adjusted based on the discussions during the process to better reflect some ideas mentioned. Here the numbers marked in red were lowered and the green ones were increased by 0.1 each. These adjustments were reconfirmed in a second visit which led to the final matrix as given in Table 11 and Table 12. Additionally, after the adjustments were made a few selected trials were and inspected for consistency with the results which confirmed the confidence in the expert estimates.

After initial estimations of the ex-ante welfare benefits and the implications of the matrix were discussed with the breeders in an effort to highlight the importance and confirm the assumptions made during the process. The welfare estimations with different key assumptions were made twice, once using the full applicability matrix as elaborated with the scientists and once using a matrix with all off-diagonal values set to zero assuming no applicability across HZs. These two sets of results were used to highlight the implications of the values indicated for the final estimation. During this process, the final (adjusted) numbers were confirmed.

Production proportions

The production proportions represent the share of the total production in each HZ. These proportions were calculated using the Harvest Choice (2009) and Monfreda (2008) for groundnut and Monfreda (2008) only for pigeonpea as the Harvest Choice (2009) does not account for pigeonpea individually. Therefore, we have the exact production of groundnuts and pigeonpea in each HZ in aggregate as well as by country and HZ. The aggregate is depicted in Figure 18.

Table 11 Adjusted applicability matrix for groundnut

	13	15	10	9	7	12	8	11	5	6	4	14	2	3	1	0
13	1	0.8	0.4	0.3	0.3	0.3	0.1	0.5	0.4	0	0	0	0	0	0	0
15	0.8	1	0.4	0.3	0.3	0.3	0.1	0.5	0.4	0	0	0	0	0	0	0
10	0.3	0.3	1	0.7	0.6	0.3	0.2	0.4	0.2	0.2	0	0	0	0	0	0
9	0.4	0.3	0.7	1	0.8	0.6	0.6	0.2	0.4	0.3	0.4	0	0	0	0	0
7	0.3	0.3	0.7	0.8	1	0.8	0.6	0.2	0.4	0.3	0.4	0	0	0	0	0
12	0.3	0.3	0.3	0.6	0.8	1	0.6	0.2	0.4	0.3	0.4	0	0	0	0	0
8	0	0	0.2	0.7	0.7	0.7	1	0	0.4	0.2	0.6	0	0	0	0	0
11	0.5	0.5	0.2	0.2	0.2	0.2	0	1	0.7	0	0.1	0	0	0	0	0
5	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.7	1	0.2	0.3	0	0	0	0	0
6	0	0	0.3	0.3	0.3	0.3	0.2	0	0.2	1	0.2	0	0	0	0	0
4	0	0	0.4	0.4	0.4	0.4	0.7	0.1	0.3	0.2	1	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Source: Own presentation based on elicitation with several ICRISAT scientists.

Table 12 Applicability matrix for pigeon peas

	1	2	3	4	5	6	7
1	1	0	0	0	0	0	0
2	0	1	0	0.8	0	0	0.8
3	0	0	1	0	0	0	0
4	0	0.8	0	1	0	0	0.7
5	0	0	0	0	1	0	0
6	0	0	0	0	0	1	0
7	0	0.8	0	0.5	0	0	1

Source: Own presentation based on elicitation with several ICRISAT scientists.

Research focus

In the original model as set up and further developed by the Australian Centre for International Agricultural Research (ACIAR) the research focus reflected the focus of the various national research programs in each country. In this adjusted version we introduced ICRISAT which does research on its own and is not depended (although influenced by) on national programs for their own priority setting. Therefore the ICRISAT research focus is variable and reflects different scenarios of different possibilities ICRISAT has in distributing their efforts. As the research focus is one of the main determining factors for the outcome in terms of the distribution of benefits across countries this is a crucial parameter in the model.

Unit cost reduction

The unit cost reduction represents the anticipated yield gain and takes possible increases in input levels into account that result from the research conducted. A range of plausible scenarios were investigated based on past experience as well as results from other projects' ex ante estimations using expert judgments and crop models. The level used here is 10% unit cost reduction which already sets a rather conservative estimate of the potential given household survey evidence ranging between 20 and 60%[11]. In the case of groundnut, these 10% were then applied to the average FAO farm gate price during the years 2007-2009 as these are consistent with ICRISAT household survey evidence. For pigeonpea, due the very high farm gate price in FAO the price was determined from the average ratio of groundnut and Pigeonpea prices available from several surveys conducted by ICRISAT.

In the model, the level of benefits is directly linear to the unit cost reduction and will not influence the relativities across countries or zones. Furthermore, the unit cost reduction cannot be altered across countries or zones based on the model set up. It is therefore assumed that within one homogenous zone the unit cost reduction will be the same and only across homogenous zones or for different technologies the reductions will alter.

5.1.2 Estimates for pearl millet

Shiferaw et al. (2004) reported that until 2001, about seven varieties developed at ICRISAT-Patancheru had been adopted and adapted in eight African countries. Prominent among these are WC-C75 (ICMV 1) and ICTP 8203 (Okashana 1). On the other hand, about 17 varieties developed by ICRISAT and/or NARS in Africa had been released in some 16 African countries. These include the downy mildew-resistant variety SOSAT-C88 developed through NARS ICRISAT partnerships in WCA and GB 8735 developed by ICRISAT-Niamey. These varieties have been released in a number of countries in the region for instance a number of drought resistant varieties introduced in Southern Africa were developed by ICRISAT(Bulawayo) and by the regional NARS using ICRISAT's material. SMDV93032(Okashana 2), which seems to have a good

[11] Mali (30.11%), Niger (33.7%), Nigeria (60.61%) (Ndjeunga, 2012), Malawi (20.2%) (Baseline data of Tropical legumes II project) and Uganda (44%) (Shiferaw et al., 2009)

potential for expansion in to Eastern African countries would be a good example of such success stories of ICRISAT.

Homogenous zones for millet

Use of Research Domains for Millets at ICRISAT

Homogenous research domains[12] for millets were developed in early 1990s (Figure 8) with the intention of helping breeders to manage genotype-environment interactions and to facilitate the transfer of technology from the region of origin to places where it might be beneficial/potential use. These domains were designed to reflect the main characteristics and group of countries in Africa and Asia (the main target regions of ICRISAT) according to the most important characteristics like length of growing periods, major production constraints and cropping pattern (ICRISAT 1992). Even though useful today, their accuracy was limited (Mausch et al. 2012) because it did not take into consideration of important indicators like temperature, latitude, crop suitability and distribution. Besides, there was an exclusion of other millet production regions around the world without which the estimation of global welfare benefits and spillover effects would be underestimated.

Refining and Defining Production domains of millets

Following the methodology developed by Mausch et al. (2012) and discussed in details in the previous section of this paper, we delineated the homogenous production domains using available spatial information on millet production; agro-climatic suitability based on agro ecological zones by FAO; land cover images to attribute only the crop land; and population density as a proxy to market access to define the 17 production domains of millets (Figure 8). The characteristics of production domains of millet are given in the Table 3. The millets are cultivated under extremely harsh conditions of frequent drought, high temperatures, low and erratic rainfall, and infertile soils with poor water holding capacity, about 70% of the world millets are produced in the warm tropics dryland climate. Within warm tropics dryland climate, about 26.1% of millets are produced in production domains with LPG between 120 to 149 days and 14.6% and 1.2% are produced in production domains with LPG between 90-119 days and 60-89 days respectively (Table 13).

Since millets are better adapted to driest and marginal soils than most other cereals about 2.9 and 2.6% of millets are produced in production domains with LGP less than 60 day and deserts

[12] The homogenous research domains for millets was drawn based on scientists and experts judgments on climate, length of growing periods and biotic and abiotic stress in the particular domains.

respectively. Another 30% of millets are produced in other production domains like warm tropics sub-humid, sub-tropical humid and dryland and temperate dryland.

Cross homogenous zone applicability

In the absence of the required multi location trail data across all the production domains of millets to estimate the performance of technology all production domains, we used expert knowledge and judgment of several ICRISAT millet scientists representing different regions to provide a value between 1 to 0 on the applicability[13] of a technology from one production domain to another production domains taking into consideration all the constraints (physical, biological, social, cultural and political) to technology spillovers between production domains. Table provides the summary of the cross production domains applicability of millet technology developed and validated through discussion with ICRISAT millet scientists from different regions namely Asia, West and Central Africa (WCA) and East and Southern Africa (ESA).

Production proportions

Among seven major climatic production domains, the warm tropics drylands produces about 67% of millet global production followed by warm tropics humid (10.7 %), subtropical humid (8.4%) and temperate dryland (8.3%). Interestingly, about 2.6% of the total millet production comes from desserts especially in the Northern African and Middle East countries.

The research focus for millets is derived in the same way as discussed in section 5.1.1.

Unit Cost reduction

The farm level impact assessment of pearl millet cultivars in India and few African countries in 1990s revealed that the adoption of improved pearl millet cultivars contributes to unit cost reduction to the range of 18-59% (Appendix 3, Table 3). On the basis of the results from the regional survey, a conservative 10% unit cost reduction[14] for millets improvement research was assumed for all countries and regions i.e. the unit cost reduction is equal to 10% of the initial equilibrium price of millet in the countries and regions.

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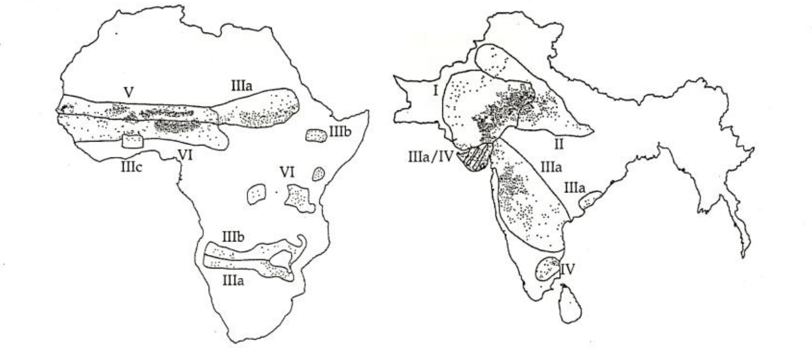
[13] Applicability matrix which shows how the varieties developed for one particular production domain is likely to outperform the best local variety in each of the other production domains.

[14] The genetic improvement in millet increases the productivity, i.e. higher output for each level of inputs or higher yield for same level of inputs. The increase in yield with no increase in costs per hectare will reduce the cost per tons. This is referred as unit cost reduction for the proportionate change in productivity by adopting new technologies.

Pearl Millet Domains



Domain	Production system characteristics	Major constraints	Locations
PM I	Sandy, arid zone. Early-maturing, low-yielding traditional cultivars. Dual-purpose grain and fodder type.	Heat and drought. Need for reduced photoperiod insensitivity	India (Rajasthan, N Gujarat, S Haryana), Pakistan, other W Asia.
PM II	Early-maturing (but later than I). WC-C75 predominant. Dual-purpose grain and fodder type.	Downy mildew, smut, and general yield improvement. Need for reduced photoperiod insensitivity	India (N and E Haryana, Uttar Pradesh, Madhya Pradesh).
PM IIIa	Medium-maturing hybrids (Asia only) and improved varieties. Grain types. Moderately later-maturing in Africa where traditional cultivars predominate.	Downy mildew, drought, and general yield improvement. Photoperiod sensitivity less of a problem than in I and II.	Southern Africa (Botswana, Zimbabwe, N Namibia, S Angola), E Africa (Sudan, Chad), India (S Gujarat, Deccan).
PM IIIb	Medium-late maturing traditional and improved varieties. Grain types.	Downy mildew, drought, and general yield improvement. Photoperiod sensitivity less of a problem than in I and II.	E Africa (Ethiopia, high altitude), Southern Africa (Angola, Zambia, Malawi, Mozambique), Latin America (some areas).
PM IIIc	Early- and medium-maturing traditional cultivars with large grain size. Grain types.	Downy mildew, drought, and general yield improvement. Photoperiod sensitivity not a problem.	W Africa (Ghana, Togo)
PM IV	Postrainy season/irrigated, improved cultivars. Fodder and dual-purpose types	Rust, downy mildew, general yield improvement. Photoperiod sensitivity not a problem.	India (Tamil Nadu, Gujarat).
PM V	Sandy, arid zone, rainfed staple cereal, low-yielding traditional cultivars with long panicles. Hill sown.	Heat and drought, head caterpillars, *Striga*	W Africa northern tier.
PM VI	Semi-arid, rainfed transition zone; low-yielding traditional photoperiod sensitive cultivars with long panicles. Hill sown.	Downy mildew, stem borers, drought, *Striga*	W Africa middle tier, E Africa (Kenya, Zaïre, Tanzania).

Figure 19 The pearl millet production domains (source: ICRISAT, 1992)

Table 13 Characteristics of Millets Production domains

S. No	Production Domains (PD)	PD Characteristics, Climate and Length of Growing Period (LGP)	Production ('000 tons)[1]	Production share (%)	Major Countries	Major Constraints
1	PD1	Deserts	654.08	2.6	Pakistan, Sudan, Mai, Niger, Burkina Faso, Saudi Arabia, Iran, Iraq, Yemen, Morocco, Libya, Australia	Heat and drought, head caterpillars, *striga*
2	PD2	Warm tropics drylands, < 60 days	730.23	2.9	Chad, Niger, Nigeria, Mali, Sudan, Zimbabwe, Australia	Downy mildew, drought
3	PD3	Warm tropics drylands, 60 - 89 days	2842.61	11.2	Chad, Mali, Niger, Kenya, Namibia	Downy mildew, drought, photoperiod sensitivity
4	PD4	Warm tropics drylands, 90 - 119 days	3687.02	14.6	India, Cameroon, Chad, Mali, Niger, Nigeria, Senegal, Burkina Faso, Namibia, Zimbabwe	Downy mildew, smut, Need for reduced photoperiod sensitivity
5	PD5	Warm tropics drylands, 120 - 149 days	6600.22	26.1	India, Cameroon, Chad, Benin, Gambia, Mali, Nigeria, Senegal, Burkina Faso, Angola, Mozambique, Zimbabwe, Zambia	Downy mildew, smut, drought
6	PD6	Warm tropics drylands, > 150 days	3098.35	12.2	India, Cameroon, Chad, Gambia, Angola, Malawi, Tanzania, Zambia	Drought, stem borer and *striga*
7	PD7	Warm tropics sub humid, > 150 days	2716.09	10.7	Myanmar, Cameroon, Central African Republic, Benin, Ghana, Guinea, Togo, Malawi, Mozambique, Uganda, Zambia	Drought, stem borer
8	PD8	Subtropical drylands, > 150 days	355.70	1.4	Nepal, Pakistan, Argentina, Mexico	Stem borer, ergot
9	PD9	Subtropical Humid, < 60 days	165.01	0.7	Pakistan, Zaire, Ivory Coast, Mexico	
10	PD10	Subtropical Humid, 60 - 89 days	334.63	1.3	Pakistan, Ethiopia, South Africa	Drought and heat
11	PD11	Subtropical Humid, 90 - 119 days	583.25	2.3	India, Pakistan, Bangladesh, Bhutan, South Korea, Australia	Downy mildew, drought and heat
12	PD12	Subtropical Humid, 120 - 149 days	695.97	2.7	India, Pakistan, Bangladesh, Bhutan, South Korea, South Africa, Australia	Downy mildew, drought and heat
13	PD13	Subtropical Humid, > 150 days	342.55	1.4	Nepal, Australia	Downy mildew, drought and heat
14	PD14	Temperate drylands, < 60 days	281.89	1.1	China, Hungary, Japan, Spain, Russia	Stem borer, ergot
15	PD15	Temperate drylands, 60 - 89 days	537.17	2.1	China, Romania, USA, Russia	Stem borer, ergot
16	PD16	Temperate drylands, 90 - 119 days	1293.96	5.1	China, Russia, Spain	Stem borer, ergot
17	PD17	Temperate Humid, > 150 days	411.76	1.6	China, North Korea, Australia	Stem borer, ergot

Note: [1]The SPAM (2010) spatial distributed production map of millets is used to estimate the production level in each PD.

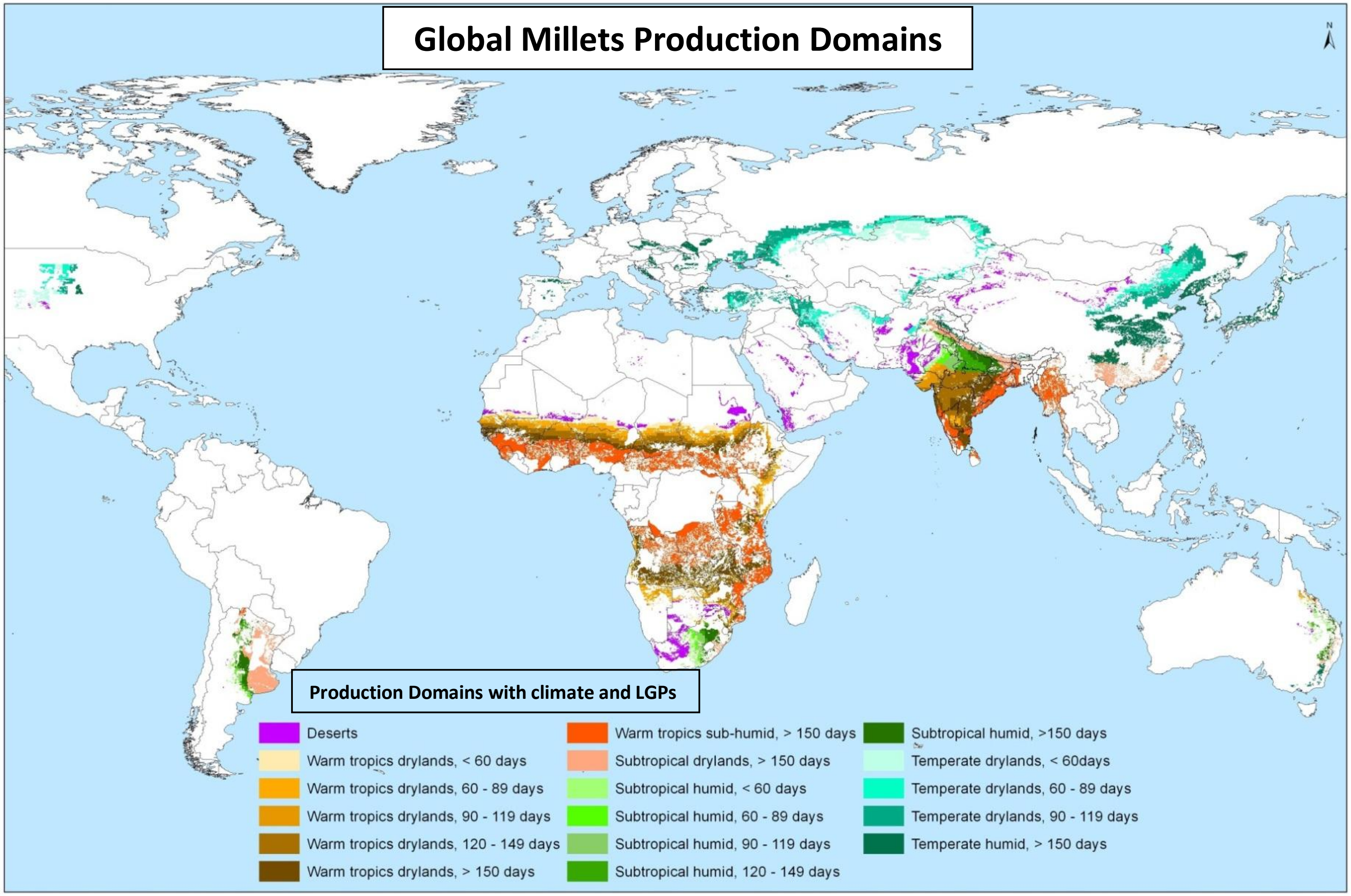


Figure 9 Global Millets Production Domains

Table 14 Applicability matrix for millet production domains

	Deserts	Warm tropics drylands, < 60 days	Warm tropics drylands, 60 - 89 days	Warm tropics drylands, 90 - 119 days	Warm tropics drylands, 120 - 149 days	Warm tropics drylands, > 150 days	Warm tropics subhumid, > 150 days	Subtropical drylands, > 150 days	Subtropical Humid, < 60 days	Subtropical Humid, 60 - 89 days	Subtropical Humid, 90 - 119 days	Subtropical Humid, 120 - 149 days	Subtropical Humid, > 150 days	Temperate drylands, < 60 days	Temperate drylands, 60 - 89 days	Temperate drylands, 90 - 119 days	Temperate Humid, > 150 days
Deserts	1	0.5	0.4	0.3	0.3	0.3	0.2	0.1	0	0	0	0	0	0	0	0	0
Warm tropics drylands, < 60 days	0.5	1	0.6	0.5	0.4	0.4	0.3	0.2	0.1	0	0	0	0	0.4	0.2	0	0
Warm tropics drylands, 60 - 89 days	0.4	0.6	1	0.6	0.5	0.4	0.4	0.3	0	0	0	0	0	0	0	0	0
Warm tropics drylands, 90 - 119 days	0.3	0.5	0.6	1	0.6	0.6	0.3	0.3	0	0	0	0	0	0	0	0	0
Warm tropics drylands, 120 - 149 days	0.3	0.4	0.5	0.6	1	0.5	0.4	0.3	0	0	0	0	0	0	0	0	0
Warm tropics drylands, > 150 days	0.3	0.4	0.4	0.6	0.5	1	0.5	0.2	0.2	0.2	0.3	0.4	0.5	0	0	0	0
Warm tropics subhumid, > 150 days	0.2	0.3	0.4	0.3	0.4	0.5	1	0.5	0.2	0.2	0.2	0.4	0.5	0	0	0	0
Subtropical drylands, > 150 days	0.1	0.2	0.3	0.3	0.3	0.2	0.5	1	0.2	0.2	0.2	0.4	0.5	0	0	0	0
Subtropical Humid, < 60 days	0	0.1	0	0	0	0.2	0.2	0.2	1	0.6	0.5	0.3	0.2	0.2	0.1	0	0
Subtropical Humid, 60 - 89 days	0	0	0	0	0	0.2	0.2	0.2	0.6	1	0.6	0.5	0.2	0.2	0.1	0	0
Subtropical Humid, 90 - 119 days	0	0	0	0	0	0.3	0.2	0.2	0.5	0.6	1	0.6	0.5	0.2	0.2	0	0
Subtropical Humid, 120 - 149 days	0	0	0	0	0	0.4	0.4	0.4	0.3	0.5	0.6	1	0.6	0	0	0.3	0.2
Subtropical Humid, > 150 days	0	0	0	0	0	0.5	0.5	0.5	0.2	0.2	0.5	0.6	1	0	0	0.2	0.3
Temperate drylands, < 60 days	0	0.4	0	0	0	0	0	0	0.2	0.2	0.2	0	0	1	0.6	0.5	0.3
Temperate drylands, 60 - 89 days	0	0.2	0	0	0	0	0	0	0.1	0.1	0.2	0	0	0.6	1	0.6	0.5
Temperate drylands, 90 - 119 days	0	0	0	0	0	0	0	0	0	0	0	0.3	0.2	0.5	0.6	1	0.6
Temperate Humid, > 150 days	0	0	0	0	0	0	0	0	0	0	0	0.2	0.3	0.3	0.5	0.6	1

5.1.3 Estimates for sorghum

In general, research systems generate technology for a target environment and commodity. Based on the potential, often the outcome of research is spread beyond its initial target. Thus, the research systems generate two types of benefit for its investors: direct benefits and spillover benefits. The traditional research evaluation methods consider only the direct benefits and ignore the spillover benefits. As a result, the output from research is underestimated. Based on the underestimated benefit level when the policy makers decides on the level of investment to be made for research, obviously becomes less than the desired level. If research spillovers (in-direct benefits) are quantified and being considered for the research investment decision then the justified level of investment can be made. Incorporation of spillover effects in the research policy design also strengthen the transparency in the decision making process. Research spillovers also have impact on the relative competitiveness of farm producers in different regions and countries. Until now, national research planning usually underestimate returns to research by not considering spillover effects and thus, tends to under invest in research. International research support, whether bilateral, regional or multilateral, is usually designed to complement national research activities and to generate maximum international rather than just individual national research benefits. It selects research portfolios with explicit considerations of the likely extent of spillover benefits among countries with similar agro-climatic and socio-economic environments.

International Agricultural Research Institutes like ICRISAT has made vital contributions towards achieving inter-regional sorghum research spillover benefits, but very little has been done so far in terms of assessing and systematically quantifying the potential and actual inter-regional spillovers from its own research and development efforts. Thus, the present paper making an attempt for quantifying the ICRISAT Sorghum spillover benefits across globe using vast experience, knowledge and human capital.

Sorghum Crop Improvement at ICRISAT, 1972-2012

International Crops Research institute for the Semi-Arid Tropics (ICRISAT) has been involved in genetic enhancement of sorghum since its inception in 1972. Sorghum research at ICRISAT started in four regions – Asia (1973), West and Central Africa (1975), Southern Africa (1984) and Eastern Africa (1984). There was also a program in Latin America based at the CIMMYT in Mexico from 1978 to 1993, and in Sudan from 1977 to 1985. The breeding goals (involving partners) have under gone significant changes since ICRISAT was established. The identification of geographic functional regions with a set of constraints has resulted in the gradual shift inbreeding strategy from initial wide adaptability to specific adaptations, and to trait-based breeding for threshold traits through the 1980s and 1990s.

The ICRISAT Patancheru-based wide adaptability approach was abandoned by early-1980s, and three research centres with regional hubs were established in Africa and one in Central America to take up breeding for region/production system-specific adaptations. Later, during the preparation of ICRISAT's medium-term plan (MTP, 1994-98) for 1994-98, sorghum breeders were explicitly defined six sorghum research domains in Asia and SSA for the first time. However, its fundamental approach has been to develop various breeding materials, varieties, hybrid parents(A/B/R lines), segregating populations, lines and improved sources of diseases and insect resistance to strengthen the breeding programs of the national agricultural research systems(NARS) and the seed sector.

ICRISAT Sorghum cultivar releases

The details of total number of improved sorghum cultivars (varieties and hybrids) released by ICRISAT either through supply of germplasms and breeding materials to NARS in different regions of world between 1975 and 2011 is summarized in Table 15. A total of 250 improved cultivars were made available in 44 countries of Asia, Africa and America. Almost 52.8 per cent of these releases were concentrated in African countries followed by Asia (33.2%) and America (14%). The top three individual country beneficiaries from ICRISAT research and materials are India (41 cultivars) followed by Mali (33) and China (24). Due to the presence of ICRISAT headquarters at India and existence of strong NARS system to make use of breeding materials might have helped to gain relatively higher advantage.

Table 15 ICRISAT global releases of sorghum cultivars, 1975-2011

Years	Africa	America	Asia	Total	India	Other Asia
1975-80	9	4	4	17	1	3
1981-85	5	7	11	23	2	9
1986-90	31	11	6	48	5	1
1991-95	28	9	19	56	11	8
1996-00	24	4	18	46	7	11
2001-05	21	0	10	31	3	7
2006-11	14	0	15	29	12	3
Total	132	35	83	250	41	42
% share	52.8	14	33.2	100	16.4	16.8

Homogenous zones

Sorghum Research Domains in 1992

ICRISAT always develop and design technologies that target to certain problems or regions on a global basis with a clear focus on the semi-arid tropics, the applicability of a technology is generally supposed to be in the regions in which these problems are endemic or that have similar characteristics. In an attempt to define and formalize these homogenous zones ICRISAT developed so called domain maps of its mandate crops in the Medium Term Plan 1994-98 (ICRISAT, 1992) in order to enhance the efficiency of its breeding program and to facilitate the "international mindset" of its staff. These domains were designed to reflect the main characteristics and group regions in Africa and Asia (the main target regions of ICRISAT) according to the most important characteristics (ICRISAT, 1992). Figure 10 illustrates the sorghum research domains drawn in 1992.

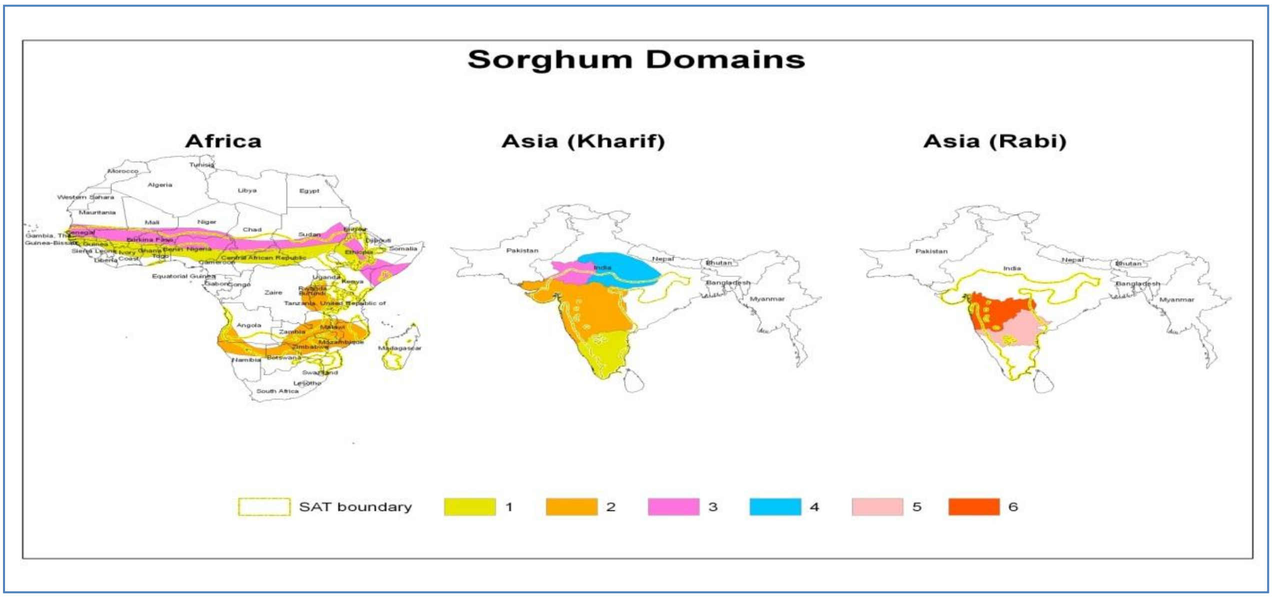


Fig 10 Sorghum research domains in 1992

The MTP Sorghum research domains being very useful even today, their accuracy was limited by the technology available during the early 1990s. Utilizing the progress in the area of Geographic Information Systems (GIS), they can be revised and improved in order to better guide scientists reflect the climatic changes that took place in the past decades. Their assessment of the 1992 homogenous zones indicated that they do not cover the real situations and are rather rough drawings mainly based on the LGP which has changed by today in many locations. Therefore, it was decided to start from scratch and redefine a new set of homogenous zones for sorghum. The available reliable resources like sorghum suitability map development by FAO, Spatial Production Allocation Model (SPAM) maps of Global sorghum physical area and production developed by Harvest Choice were integrated in the process. Similarly, Length of Growing Period (LGP) map and Global Agro-Ecological Zones (AEZs) prepared by FAO (2010) were also used to delineate the following 13 homogenous sorghum research domains (see Table 16 and Figure 11) in the World.

Updated Homogenous Research Domains, 2012

The characteristic details of research domains and their respective production shares are presented in Table 16. Research domain 13 is alone contributing nearly 25 per cent of global sorghum production in the World. It was followed by Research domain– 6 and 7 respectively at 20 and 15 per cent shares in total production. Among the 13 domains, the lowest production share was observed in Research domain-11. Research domain-wise major countries covered in sorghum production were also highlighted (Figure 11).

Table 16 Updated Research Domains and their characteristics

S.No	Research Domains (RD)	Climate type and Length of Growing Period (LGP)	Production ('000 tons)[1]	Production share (%)
1	RD1	Cool tropics mixed, < 90 days	36.6	0.11
2	RD2	Cool tropics mixed, 90-119 days	111.9	0.33
3	RD3	Cool tropics mixed, 120-149 days	752.4	2.21
4	RD4	Warm tropics drylands, < 90 days	3169.6	9.29
5	RD5	Warm tropics drylands, 90-119 days	3184.4	9.33
6	RD6	Warm tropics drylands, 120-149 days	6780.5	19.88
7	RD7	Warm tropics drylands, > 150 days	4971.3	14.57
8	RD8	Sub-tropical drylands, > 150 days	3110.7	9.12
9	RD9	Temperate drylands, < 90 days	2603.6	7.63
10	RD10	Temperate drylands, 90-119 days	1031.1	3.02
11	RD11	Temperate humid, 90-119 days	0.1	0.00
12	RD12	Temperate humid, 120-149 days	18.4	0.05
13	RD13	Warm tropics sub-humid, > 150 days	8342.7	24.46

Note: [1]The SPAM (2010) spatial distributed production map of sorghum is used for estimating the production.

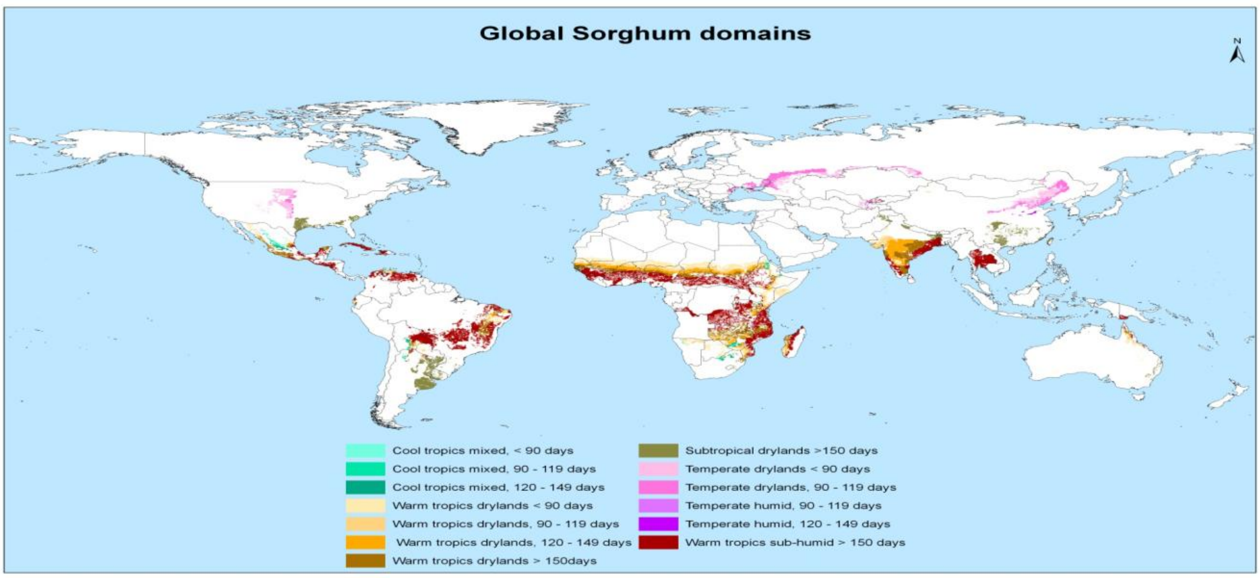


Fig 11 Updated sorghum research domains in 2012

Other parameters for sorghum

The other parameters 2-5 for sorghum are summarized in the Table 17. The subjective expert judgment on applicability of cultivars between research domains was elicited and presented in Table 18.

Table 17 Minimum dataset variables and their sources

Variable	Source of information
Sorghum area, production and consumption in major growing countries	FAOSTAT, 2012 from 1996 to 2010
NARS Strategic, Adaptive and Adoption parameters	ISNAR 1989, Evenson and Gollin (2003) and Diffusion studies (2010-12) supported by BMGF
Supply and demand elasticities	Adapted from IFPRI IMPACT Model
Farm harvest prices	2008 FAO prices
Applicability matrix (C-matrix)	Expert judgment from ICRISAT Sorghum scientists
Unit cost reductions	Assumed 10 per cent unit cost reductions on 2008 FAO prices

Table 18 Applicability (C-matrix) matrix across research domains

RDs	RD1	RD2	RD3	RD4	RD5	RD6	RD7	RD8	RD9	RD10	RD11	RD12	RD13
RD1	1	0	0	0	0	0	0	0	0	0	0	0	0
RD2	0	1	0	0	0	0	0	0	0	0	0	0	0
RD3	0	0	1	0	0	0	0	0	0	0	0	0	0
RD4	0.6	0.6	0.6	1	0.3	0.2	0.2	0.5	0	0	0	0	0.1
RD5	0.2	0.3	0.3	0.4	1	0.6	0.5	0.2	0.2	0.3	0.3	0	0.4
RD6	0.1	0.2	0.2	0.3	0.5	1	0.6	0.1	0.1	0.2	0	0	0.5
RD7	0	0	0.1	0.2	0.4	0.5	1	0.2	0	0	0	0	0.6
RD8	0	0	0	0	0.1	0.2	0.2	1	0.6	0.7	0	0	0
RD9	0	0	0	0	0.3	0.2	0.1	0.4	1	0.3	0	0	0
RD10	0	0	0	0.5	0.4	0.2	0.1	0.7	0.4	1	0	0	0
RD11	0	0	0	0	0	0	0	0	0	0	1	0	0
RD12	0	0	0	0	0	0	0	0	0	0	0	1	0
RD13	0	0	0	0.1	0.3	0.4	0.6	0	0	0	0	0	1

The new application of spatial tools and GIS to estimate the spillover matrix facilitated the identification of research domains which may be distinct for different crops. The interactions with crop scientists were more effective as we show different scenarios with changing length of growing period (LGP). The flexibility of the GIS enable better delineation of the homogenous zones for each crops using the relevant biophysical parameters like temperature, altitude, LGPs, etc.

The application of GIS tools also enabled the estimation of production proportions for each crop using the spatial production distribution maps (SPAM) developed recently through CGIAR Challenge Program on Harvest Choice.

5.2 Revisiting adoption and adaptive capacity to estimate p_{yt}, $a_{yf}t$ and x_{yft}

Based on the need for accurate estimates that feed into the ex-ante assessment and therefore the strategy, this revisit of the adoption and adaptive capacity parameters provides an insiders perspectives of the historic and recent efforts in ICRISAT and the CGIAR system to get accurate and global data on adoption as well as NARS capacities across countries. These efforts resulted in several methodological developments and refinements.

The development of improved, fertilizer-response high-yielding varieties of wheat and rice during the early 1960s and their widespread adoption by farmers, first in Asia and then in Latin America, marked the beginning of what is known as the 'Green Revolution'. Much has been written about this technological breakthrough and its impacts – both positive and negative – in the years since its effects were first felt in farmers' fields. Anecdotal evidence and specific case study examples are often cited in support of large positive effects as well as negative ones. The core of the debate centres on the nature and size of the impacts from improvements in the crop germplasms. By adopting improved varieties, many farmers lowered costs of production and generated higher rates of return from their land, labour and capital. This, in turn, had positive impacts on income and helped reduce poverty. An indirect spillover effect from modern variety adoption in other areas was also declining crop prices. In the areas not touched by the 'Green Revolution', costs of production did not fall, and this, in turn, had an adverse effect on farmers' income in these regions. Thus, the key challenge now for the CGIAR and its NARS partners is to target Crop Genetic Improvement (CGI) research investments to farmers who have thus far been bypassed by the Green Revolution, primarily in those resource poor, marginal environments (SAT areas) where modern varieties have not yet been adopted.

Against this backdrop, it is reasonable to step back and ask fundamental questions about the role of international crop research in Crop Genetic Improvement (CGI) programs. Does varietal improvement still matter? Is public sector research required? Have national systems grown to the point where an international research centre is unnecessary? Have past investments in crop research led to improvements in productivity? Are continuing investments likely to remain worthwhile? Have the international research centres produced anything of value? For answering questions like these requires a careful methodological approach and lots of massive periodical data on various parameters. Now the final question is who generates this kind of information? Fortunately, some of the studies could draw on more than 40 years of experience with many crop improvement programs in both IARCs and NARS. The datasets have helped to address some of these difficult questions. But these datasets are now more than 10 years old and lacks periodical up-gradation. Specially, the role of these datasets is critical in estimation of ***ex-ante*** or ***ex-post*** research impacts of international agricultural research on crop genetic improvement in developing countries including spillovers.

In general, the output of crop genetic improvement programs will be measured in terms of the number of officially released crop varieties. The design features of most International Agricultural Research Centre (IARCs) enabled them to specialize in one commodity or a small set of commodities and work with (and support) national agricultural research systems (NARS) in trying to use modern science to achieve productivity gains. From the beginning, however, IARC programs developed and maintained genetic resource collections (gene banks) and fostered free exchange of genetic resources between IARCs and NARS programs. IARCs also supported researchers in the private sector, although these were few in number and important in the developing countries. To take fully advantage from IARCs research programs, NARS and private firms should have equal or on par research strengths and capacities. The NARS strategic and adaptive capacities in a particular country would determine the extent benefits derived from particular IARCs crop improvement program. This in-turn will reflect in the number crop varieties released in that particular country and extent of their adoption etc. These two are the first and second measures of success respectively in an impact assessment study. The evidence of the adoption of varieties by farmers and of the production or productivity advantage of improved varieties over the replaced varieties will determine the farm-level production impacts. The increase in yields and corresponding unit cost of reductions will be the third measure of success. Further incorporation of these benefits in to market models (change in equilibrium prices, trade, consumption etc.) will assess the economic consequences of crop genetic improvement programs on poverty and malnutrition.

In 1989, International Service for National Agricultural Research (ISNAR) has taken-up the challenge of providing a data base on NARS that will contribute to this purpose and stimulate analysis of relevant policy and management issues. In 1998, the CGIAR's Independent Standing Panel on Impact Assessment (SPIA), which was then called the Impact Assessment and Evaluation Group (IAEG), initiated a major study of the impact of CGIAR's germplasm improvement activities since the beginning of the Green Revolution. The study covered both the production and diffusion of improved crop varieties for 11 important CGIAR mandate food and feed crops in developing countries over the period from 1960 through to the 1990s. However, because of its global emphasis and scarcity of funds for operating budget, the 1998 Initiative was not characterized by the use of standardized protocols in data collection across the participating IARCs. Substantial scope for improvement in data quality is another factor contributing to the felt need for generating reliable information on variety-specific adoption.

ICRISAT has been an active player since early 1990s and initiated a comprehensive and systematic system of Research Evaluation and Impact Assessment (REIA) in 1993. The results of such an assessment provided to scientists and research managers with a basis for setting priorities among alternative research options and deciding on resource allocation. It started with aim of institutionalizing the process and building a database to support information systems. Later, ICRISAT was also part of the 1998 global initiative led by SPIA with CG centers and documented the diffusion information on three (Sorghum, Pearl Millet and Groundnut) of its mandate crops. Subsequently ICRISAT has sustained these activities but at a lower scale.

ICRISAT is also the lead institution in implementation of major developmental projects on dryland cereals (referred as 'HOPE' project) and grain legumes (referred as 'Tropical Legumes-II' project) in SSA and SA supported by Bill and Melinda Gates Foundation (BMGF) since late 2000s. Several baseline, monitoring and evaluation studies were carried out with the help of NARS in different countries/states as a part of these projects. All the information generated through these activities is partial or in-complete in different regions. To complement these on-going activities, ICRISAT has again joined hands with BMGF for the conduct of diffusion studies in SSA and SA in 2009-10.

Diffusion studies in SSA and SA

The diffusion studies in sub-Saharan Africa and South-Asia are sister projects supported by BMGF. However, 'Tracking Varietal Change and Assessing the Impact of Crop Genetic Improvement Research in Sub-Saharan Africa' project was referred as 'DIVA' whereas the South-Asia project was called as 'TRIVSA' - 'Tracking Varietal Change and Assessing the Impact of Crop Genetic Improvement Research in South-Asia'. Even though the project target domains are different but their objectives, outputs and outcomes are identical.
The aim of these projects is to lay the groundwork for tracking the successes and failures of crop improvement investments and for understanding the impact of those investments on poverty, nutrition, and food security. This comprehensive effort examines variety-specific diffusion across 14 crops in 25 Sub-Saharan Africa (SSA) countries and six crops in five South Asia countries and will be implemented to complement monitoring and evaluation activities carried out under BMGF projects as well as other projects.

Broad objectives and different methods tested

Objective 1: To attain a wider understanding of key aspects of the performance of food-crop genetic improvement in priority country-by-commodity combinations. The following parameters were collected, collated and summarized as follows:
To document varietal output (release)

To assess the NARS strength and research investment patterns

To conduct expert elicitations for documenting the cultivar specific adoption estimate by crop and country

Objective 2: To verify and gain a deeper understanding about the adoption and diffusion of new varieties in selected priority countries and food crops. This learning objective embraces two purposes: to verify adoption estimates from expert opinions in Objective 1 through field surveys, and to enhance understanding of what worked and what did not work in developing varieties for use in staple food production and consumption in large producing countries. The project's sustainable vision is generating reliable information on varietal adoption based on both nationally representative adoption surveys (currently at least in one country) and low-cost methods to periodically estimate variety-specific levels of adoption. If the project meets its objectives, generates more complete adoption-and-impact related information that can be updated every five years in future. The varietal performance is heavily conditioned by genotype by environment interactions, these national representative surveys will be characterized by substantially greater spatial coverage than past diffusion enquiries. Both village- and household-level information will be elicited.

Results from the national-level surveys (both village and household level) will be compared to subjective estimates in Objective 1 to determine and better understand systematic biases in 'quick-and-clean' estimates. Validating expert-opinion methods with nationally representative surveys in a few large countries for several staple food crops should lead to more rigorous estimation methods in the next update on the road to a routine monitoring system of varietal adoption and impact assessment.

Objective 3: To gain a more comprehensive understanding of the impact of crop improvement on poverty, nutrition, and food security *(Only in DIVA project not in TRIVSA project).*

Estimation of parameters

Probability of success of innovative research undertaken in particular country (p_{yt}) or institution is the prime deriving factor for generating the direct and spillover benefits. Identification of right research problem which has more impact on major production environments/research domains should be prioritized in any innovative research. Similarly, it should also have higher probability of success. In general, International Agricultural Research Centres (IARCs) will undertake this type of research because of strong research capacities (a_{yft}) as well as financial support. The probability of success of adaptive research could undertake in a country determined by the National Agricultural Research Systems (NARS) capacity in that country. The strength of NARS and extent of use of gene pools/intermediate materials generated by IARCs will in turn help in quick generation of improved cultivars in any country. The time lag should be shorter from innovative research in a country/institution to adaptive research and to reap the maximum benefits from it. The most important parameter/determinant for generating the welfare benefits from crop genetic improvement was extent of adoption of improved cultivars in a country. Even though the improved technology has generated in a particular country does not reach the farmers in time because of various constraints, the research benefits generated from that particular technology will be minimal. Hence, all the three parameters have a crucial role in estimation of crop genetic improvement benefits. The definitions of these parameters in the model have been summarized below:

p_{yt}	is the probability of success of innovative research undertaken in country 'y' in year 't' ($0 \leq p_{yt} \leq 1$);
a_{yft}	is the probability of success of adaptive research undertaken in country ‘f’ on a technology developed by innovative research in country 'y' in year 't' ($0 \leq a_{yft} \leq 1$). Note that in the early applications of this framework this parameter was used to adjust the spillover index before calculation of the final unit cost reduction, k_{yft}; see Davis et al (1987; pp37-39). It has been included in equation (1) to make this adjustment more transparent;
x_{yft}	is the expected level of adoption of the technology developed in country ‘y’ by producers in country 'f' (f = 1 … N) in year 't' ($0 \leq x_{yft} \leq 1$);

The parameters were estimated as described below:

1. The probability of success of innovative research was assumed as one in all the iterations of the model because ICRISAT as an external entity generating the technologies and transferring these materials to different locations in the world unconditionally. ICRISAT has been transferring these materials (germplasms and intermediate materials like gene pools and hybrid parents) not only to the NARS in different countries but also equally to private seed companies since 1972 to till now. Around 750 improved cultivars have been released on five ICRISAT mandate crops in 78 countries in the world through collaboration with NARS partners is a testimony to this.

2. The probability of success of adaptive capacity undertaken in a country was assessed based on the NARS strength (FTEs) working on a particular crop in a country as well as on the number of improved cultivars released during a particular period. ICRISAT has put concerted efforts and collated this historic information from reliable

sources like ISNAR (Pardey et al., 1989), Evenson and Gollin (2003) and ASTI Reports. Recently, ICRISAT also initiated massive diffusion studies (sequel to 1998 baseline) in sub-Saharan Africa (SSA) and South-Asia with the support of SPIA and BMGF respectively. This activity has provided enough advantage to ICRISAT to update the 1998 CGIAR baseline as well as to add new potential crops in various countries. The information/data generated from all the sources have helped ICRISAT to estimate this parameter in different countries. However, ICRISAT also validated this information with bio-physical scientists through various workshops and conferences. The crop-wise estimated parameters were summarized in the annexures respectively.

3. The initial 1998 baseline to determine the extent of adoption of improved cultivators was established by Evenson and Gollin (2003). As a partner in this study, ICRISAT has generated this information for Sorghum, Pearl millet and Groundnut crops in major countries in South Asia and sub-Saharan Africa. However, this baseline is now ten years old and needs to be deepened and widened. Recently, ICRISAT (as a lead centre in the World) also put substantial effort in Dryland Cereals and Grain Legumes projects supported by Bill and Melinda Gates Foundation (BMGF) to update this information through various monitoring and adoption surveys under taken in different countries with the help of NARS partners. However, the recent initiate of diffusion studies carried out in SSA and SA have generated huge datasets to complement the on-going effort in different projects. By integrating all these sources of information (both primary and secondary), ICRISAT has estimated extent of adoption of improved cultivators under five mandate crops in different countries. The crop-wise estimations were summarized in the annexures respectively.

The second parameter above (a_{yft}) relates to the capacity of the national programs. The capacity of the national agricultural research programs (NARS) was implemented in steps that determine the likelihood that any material developed or introduced is successfully taken up. First, the capacity to conduct innovative research successfully and second, the capacity to adopt and/or adapt innovations from other sources was assessed separately. Here, the innovative capacity was set to 100% as for the estimations it was assumed that ICRISAT will conduct the innovative research and the final benefit levels are assessed based on the assumption that the research conducted will be successful. Therefore, the national programs only need the capacity to adapt the results.

Multiple crop specific indicators were used as a basis for the parameter estimates for NARS capacity, i.e. ASTI (2012) data on NARS Expenditure and personal strength as of about 2010, data on NARS Expenditure and personal as of the late 1990s, number of ICRISAT trials conducted in the country, number ICRISAT releases in the country, number of NARS scientists trained by ICRISAT and finally the agricultural land as of FAO (2012) was used to standardize the aforementioned indicators.

Initially, ICRISAT experts were used to generate a set of estimates of the perceived strength of all national programs based on their experience and interactions with them and their past collaboration. After this initial round of expert judgments on the 0-1 scale, the available data was taken into account to verify and adjust the expert estimations. Given the secondary data on capital and staff endowment the expert judgements were adjusted to better reflect data available. After these two rounds, estimates were critically investigated by the team to discuss if the relativities are representative and some were adjusted to better reflect these (Table 19). Furthermore, each indicator listed in (Appendix 3) was used (in absolute as well as per ha terms) to create a ranking of all countries covered and thereby ensure that the final estimate represents these ranking and the relativities involved as accurate as possible for each crop. In the end it turned out that, based on the nature of both crop being legumes and mostly not the major focus in the national research agendas, the capacity levels are equal for groundnut and pigeonpea as the crop programs are mostly clubbed into one 'legume program' in each country.

The third parameter (X_{yft}) is the ceiling level of adoption. The ceiling level of adoption is defined as the maximum attainable adoption rate given the current conditions facing the most important institutional and infrastructure conditions like market structure, road network or trader preferences. These are the basic conditions that influence adoption to a large extend but also take long time to be changed and therefore can be assumed fixed for this exercise.

In the absence of large datasets across countries expert judgments are the main tools we have to rely on to estimate the ceiling levels of adoption across all countries considered. Similar to the procedure utilized for the capacity levels, in a stepwise procedure, these judgments were validated using multiple discussion rounds with experts from different zones and from different backgrounds (economists, breeders and agronomists) which were along the process backed with available data from various countries. This process made sure that estimates are consistent across countries as starting from pure expert estimates the rates given were cross-checked against available data for adjustments. Based on those adjustments the relativities were revisited and it was made sure that these are still in line with the real picture on the ground. For the final estimates see Appendix 3.

The adoption pattern is determined by three main factors, i.e. the time lag from the start of the research until adoption starts, the annual adoption increase as well as the time until the ceiling level of adoption is reached. As this information is only available for some selected cases in some selected countries it was decided to leave it equal for all countries. Furthermore, it is believed that this pattern will be highly correlated with the NARS strength and all judgments that could be implemented would thus be likely to lead to double discounting for countries with a weak national research system. Furthermore, sensitivity analysis showed this factor does not influence the results to a significant extends when altered within a reasonable range.

Table 19 Indicators on adaptive capacity

CAPACITY	**Agricultural land FAO (1000ha)**	**Bantilan**	**Kai adjusted**	**Number of trials**	**Number of releases**	**LSU training**	**ASTI**		**Pardey (1989)**	
		adaptive	**adaptive**	**ICRISAT**	**ICRISAT**	**ICRISAT**	**spending**	**personal**	**Personnel**	**Expenditure (M USD)**
Bangladesh	9,133	0.5	0.5	128	3	17			1152	65
China	523,144	1	1	102	1	61			33454	1101
India	179,793	1	1	1626	*26*	253			8389	471
Indonesia	52,200	0.5	0.5	288	5	26			1372	139
Myanmar	12,234	0.5	0.5	401	5	76				
Pakistan	26,480	0.5	0.5	63	3	13			3431	49
Thailand	19,726	0.7	0.7	16	1	53			1429	85
Viet Nam	10,192	0.7	0.7	302	4	58				
Benin	3,345	0.3	0.3	126	2	9	22	115	56	2
Burkina Faso	11,862	0.5	0.5	235	1	10	19	240	110	140
Cameroon	9,246	0.4	0.4	75	0	3			245	24
Central African Republic	5,218	0.1	0.1	0	0	1			27	3
Chad	49,231	0.4	0.4	23	0	3			28	15
DRC	22,450	0	0	0	2	0				
Gambia	652	0.2	0.2	0	2	9	3	38	62	
Ghana	15,500	0.6	0.6	156	3	12	95	537	151	3
Guinea	14,220	0.2	0.2	216	3	18	4	229	177	5
Ivory Coast	20,300	0.4	0.4	0	0	1	43	123		
Mali	40,716	0.6	0.3	258	6	11	25	313	275	13
Niger	43,782	0.2	0.1	55	5	6	6	93	77	2
Nigeria	76,667	0.6	0.4	257	1	13	404	2062	986	74
Senegal	9,149	0.5	0.5	136	0	16	25	141	183	15
Sierra Leone	3,390	0.4	0.4	0	3	0	6	67	46	1
Ethiopia	34,858	0.8	0.5	36	2	13	69	1318	240	14
Malawi	5,339	0.9	0.4	177	5	65	21	127	92	5
Mozambique	49,133	0.8	0.2	0	3	24	18	263	77	7
South Africa	99,328	1	1	96	4	0	272	784	1647	126
Sudan	135,887	0.2	0.1	123	0	33	51	1020	248	11
Uganda	13,745	0.9	0.4	0	4	12		299	185	
Tanzania	35,100	0.9	0.3	0	9	15	77	674		
Zambia	23,152	0.8	0.5	46	8	37	8	209	153	2
Zimbabwe	16,367	0.5	0.5	18	4	9		139	193	19
WANA		0.1	0.1	-	-					
other ESA		0.2	0.2	-	-					
Other WCA		0.2	0.2	-	-					
other Asia		0.2	0.2	-	-					
Latin America		0.7	0.7	-	-					
Other developing		0.2	0.2	-	-					
Australia	417,255	1	1	-	-	4				
other developed		1	1	-	-					

5.3 Transactions costs and their implications for innovative and adaptive capacity and adoption

This section discusses how the institutional environment influences the probability of success in adaptive research and as well as adoption parameters (a_{yft} and x_{yft}) with implications on total return to investment. These parameters often depend on elicited expert judgements. It is important to get them right since they are critical in understanding the institutional conditions across countries and their implications on the role of IARCs in the research for development (R4D) process. In-depth case studies are suggested to provide a deeper understanding of the political economy of adoption and the context-specific considerations that underlie expert judgements of critical parameters. We discuss how such case studies can be used to further explain country-level conditions for each crop and hence improve the validity of estimated values of p_{yt}, a_{yft} and x_{yft}.

Comparative Advantage of CGIAR centers

International agricultural research developed to address the R&D capacity gap in many developing countries with the CGIAR being institutionalized as a key player. The traditional primary domains of Advanced Research Institutes (ARIs), IARCs, National Agricultural Research Systems (NARS), Non-Governmental Organizations (NGOs) and farmers are presented in figure 12 (Craswell and de Vries', 2001; cited in CGIAR, 2006). Four types of research are identified viz. basic, strategic, applied and adaptive research.

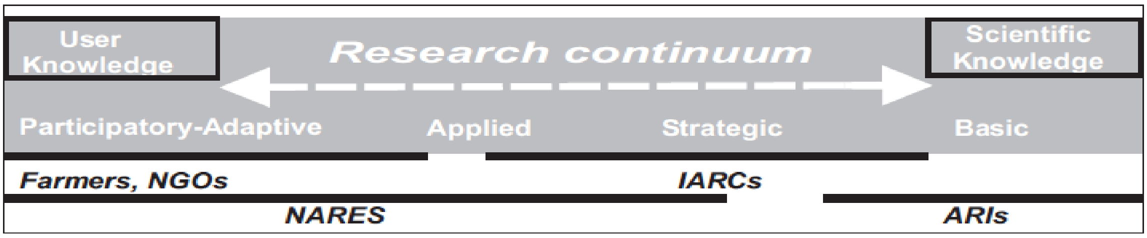


Figure 12 Primary Domains across the research continuum of INRM. Source: CGIAR Science Council, 2006.

The CGIAR has been expected to conduct strategic and applied research while working in partnership with ARIs in basic research, and NARS in adaptive research to diffuse the new knowledge and adjust technologies to fit relevant ecological and production conditions across the globe (CGIAR Science Council, 2006). Given the global mandate of the CGIAR, the IPG concept has long been discussed and emphasized as a criterion in setting system priorities (CGIAR Science Council, 2005) to ensure public investment in agricultural R&D obtains maximum spillovers without crowding out national players.

Harwood (2006, pp. 381) defines IPGs in the CGIAR context as:

"*Research outputs of knowledge and technology generated through strategic and applied research that are applicable and readily accessible internationally to address generic issues and challenges consistent with CGIAR goals*".

Ryan (2006) argues that IPG characteristics are easy to define but difficult to operationalize within the centres. IARCs face the challenge of defining what they mean by IPGs and how to strike a balance between focusing on these versus system goals. The IPG concept has been easily applied to traditional CGIAR work, like germplasm improvement and development of new varieties, than other types of technologies or knowledge.

Critics consider the IPG criterion as a conceptual barrier[15] with unrealistic division of labour between research and development (CGIAR Science Council 2008a). Since obstacles to achieving impact are greatest in developing countries, IPGs should not be a shelter to hide behind the institutional bottlenecks[16]. The critical argument is whether the CGIAR is focused only on producing IPGs, and not on their application. For instance, if seed markets are a limiting factor, would producing improved lines be a 'relevant' IPG? Strong emphasis on IPGs runs the risk of intellectualizing the CGIAR mission and distancing the system from reality. The results of research are published in scientific journals with the knowledge and technology options considered as IPGs even though they may not be relevant or accessible to other countries beyond the specific laboratories, institutions and locations where they were developed. This calls for a more specific definition of what constitutes an IPG output.

Types of Transactions in the Agricultural R-D Spectrum and Associated Costs

Planning Transactions: Include activities like as priority setting, resource mobilization and interaction with donors and CGIAR system level duties. They are associated with decision costs such as the direct costs of attending meetings, staff time spent in donor relations, and processes and personnel required to maintain the CGIAR as a system. Interface costs are higher when centres deal with a broader set of bilateral donors. Cutting down on these interfacing costs will lead to financial savings, but there is the opportunity cost regarding the quality of decisions made. Making suboptimal decisions may lead to decision-failure costs.
Production Transactions: Include activities like setting up infrastructure, human resources and partnerships required to do research, as well as the actual conducting of research. It includes set-up and maintenance costs, research costs and costs of shared services such as research support, financial management, procurement, personnel management project management, and information technology. Production failure costs may be incurred if the research is delegated to a partner that does not have sufficient capacity.

[15] Jonathan Wooley, during Special Session on IPGs at CGIAR AGM, Maputo, Mozambique November 27, 2008

[16] Gebisa Ejeta, during Special Session on IPGs at the CGIAR AGM, Maputo, Mozambique November 27, 2008

Promotion Transactions: Subject to availability of funding and manpower, promising technologies are promoted and disseminated to potential beneficiaries. The process includes costs of extension, technical assistance, policy advocacy, and training and capacity building for partners. It also includes the costs of shared services.

Monitoring and Evaluation and Reporting Transactions: Impact assessment and project reporting activities involve costs for data collection, analysis and write-up. The costs escalate when the centres have a large number of bilateral projects with small budgets that need to be reported separately. Projects that do not budget for evaluation activities may be unable to show accountability to donors and therefore run the risk of losing additional funding.

Transactions at the User Level: These are the activities that beneficiaries (e.g. farmers) need to undertake to access the technologies/ knowledge. They incur some costs aside from the cost of the products e.g. time and money used for travel or to access an extension agent.

With the CGIAR reform process, overall interface activities are expected to diminish as the consortium serves as the main interface with donors. Research will mainly be organized under CRPs with funds mobilized and flowing through the CGIAR Fund. This means that there will be a common monitoring and evaluation framework and reduced number of bilateral projects that have to be reported separately. However, there might be additional system-level costs and loss of benefits from direct engagement between centres and donors.

Comparative Cost-Effectiveness of Different Governance Structures

In order to achieve an economizing result and higher total welfare from a given set of resources, each transaction should be assigned to the actor who, in relative terms, is best at carrying it out i.e. has a 'comparative advantage'. For a start, we consider the above transactions as activities being carried out by either an IARC or a NARS. According to the discriminating alignment hypothesis (Williamson, 1991), we hypothesize that low transaction intensity, asset specificity, economies of scale and potential for spillovers are important attributes of transactions that increase the comparative advantage (cost-effectiveness) of IARCs over NARS in carrying out the transaction.

Hypothetical cost curves are shown in figure 2 when the above transactions are carried out by an IARC (TC^i) versus a NARS (TC^n). This is analogous to comparing a more centralized (IARC) to a more decentralized (NARS) structure. The vertical axis indicates costs arising for carrying out the activity; horizontal axis combination of attributes which increase the comparative advantage of IARCs in carrying out the activity. As these attributes become more important, IARC transaction costs increase less rapidly. This is indicated by the reduced slope of the respective cost curve. If these attributes are not relevant (moving to the left-hand side on the horizontal axis), NARS have a comparative advantage over IARCs. From point a1 onwards IARCs have a comparative advantage over NARS for performing the respective transaction. If capacity of NARS is increased, it will be able to carry out the activity at lower costs, indicating a downward shift of the respective cost curve (TC^c). The point from which IARCs have a comparative advantage over NARS for thus shifts from point a1 to a2.

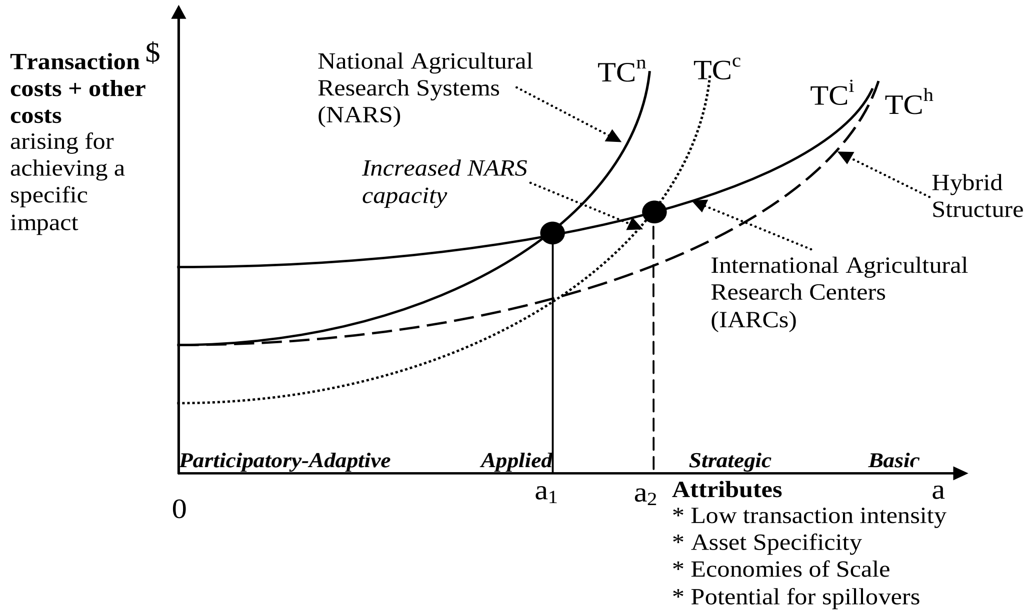


Figure 13 Comparative cost-effectiveness of IARCs versus NARS. Source: Based on Williamson (1991)

While the above discussion considers the comparison between IARCs and NARS, we recognize that there are many other actors in the agricultural R&D process. Most often, IARCs work in collaboration with these partners on joint research projects with each partner doing those types of transactions for which it has a comparative advantage. This type of hybrid governance structure is represented in Figure 13 by the cost curve TC^h. Transactions under basic and strategic research (right side of horizontal axis) have attributes of low transaction intensity, asset specificity, economies of scale and higher potential for spillovers compared to applied and participatory research (left side of horizontal axis).

In reality, generation and diffusion patterns for innovations depends on complicated set of factors and stakeholder interactions within the innovation system (World Bank, 2006). There are huge variations across locations and across different commodities making it difficult to apply similar intervention strategies in different regions.

Implications of Institutional Design on Returns to Investment

In assessing rates of return, the total benefits will be a joint output of the organizations involved and the associated costs. Full description of the role played by each actor in the

R&D process is thus required (Walker et. al, 2008). Reducing the total costs, including transaction costs of planning, research, technology transfer, monitoring and evaluation and uptake, through appropriate institutional design will result in higher internal rates of return.

Institutional choice has an effect on parameters including the probability of success in research, capacity to conduct adaptive research and the actual likelihood, timing and scale of adoption. Recalling equation 1 in section 3, that estimates the present value of total international welfare gains, these parameters are represented by p_{yt}, a_{yft} and $x_{yft.}$

CGIAR centres, having networks and respect in the regions where they work can play a facilitation role for a range of institutions which will influence the adoption parameters in two ways. First is advancing adoption so that benefits materialize earlier as indicated in Figure 14 by the reduced time to reach maximum adoption from T1 to T2. The other is an increase in the total level of adoption from A^{Max} to A^{Max2}.

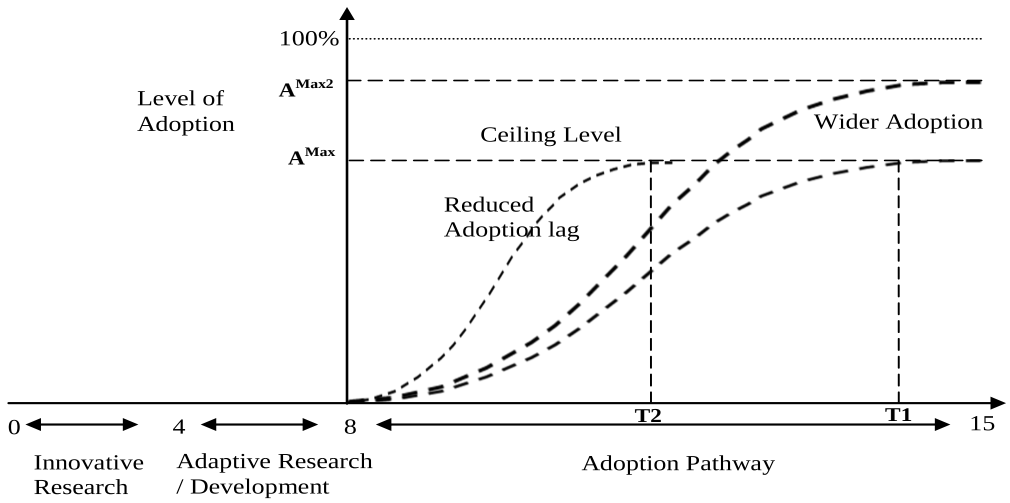


Figure 14 The Research-Adoption Pathway

The example of benefits to different countries from groundnut research targeting the homogenous zone with highest total benefits globally illustrates this point. With the adoption constraint, the benefits to India are about 1,040 million USD which is the real world scenario. By lifting the adoption constraint, the welfare benefits to India increase and are equal to an ideal world scenario at about 1,600 million USD. Since adaptive capacity is 1, we need to focus on intervention strategies that will enhance the adoption parameter. Before this is done, the binding constraints to adoption need to be identified and alternative solutions sought. In order to get the maximum benefits at least possible cost, the institutions that will carry out the identified solutions most efficiently (having a comparative advantage), should be assigned the responsibility. In many African countries, adaptive research capacity is also low and the reasons for this can only be understood through an institutional analysis. This will vary not only across countries but also across crops, thus the need for disaggregated contextual case studies. Alongside breeding, efforts can then be made to enhance both adoption and adaptive capacity in these countries. Using the example of Malawi, lifting only the adaptive capacity constraint will increase the benefits to the country from 14 million USD (real world scenario) to about 35 million USD. If the adoption constraint is lifted, the benefits further jump to about 50 million USD.

The adaptive capacity and adoption parameters (a_{yft} and x_{yft}) depend on local conditions. Although there have been attempts to characterize these conditions using indicators such as market access (Omamo et. al, 2006) and agricultural R&D capacity[17], data describing them are patchy and of questionable quality in many developing countries. In addition, these aggregate indicators do not take into account differences between commodities in a specific country. In our analysis, data on adaptive capacity (a_{yft}) has been refined by using variables such as number of ICRISAT trials conducted in the country, the number of ICRISAT releases in the country and number of NARS scientists trained by ICRISAT.

Where resources are not available to conduct extensive surveys, the adaptive capacity and adoption estimates are elicited as expert judgments. These are worked out implicitly in the experts mind based on their internalized experience in the R&D cycle in the locations of interest. However, this knowledge is likely to be lost when they leave the organization. Studies of the R&D process and institutional drivers of uptake and impact for different crops in different regions will make this implicit knowledge more explicit for future use. This would reveal the considerations that underlie expert judgments, which are often not well documented in adoption studies.

Applying the Framework

Based on review of literature, hypotheses can be derived on the attributes of transactions for which IARCs have a comparative advantage over NARS. Empirical research is required to test whether these hypotheses apply for specific innovations by collecting data on different transactions in the R&D process, relevant attributes, and contextual factors. Transactions along the impact pathway can be elicited from researchers, partners and beneficiaries using process-influence[18] maps. Information on costs incurred also needs to be collected.

Table 20 summarizes the attributes of transactions with an assessment, based on literature review, on the role that each attribute plays for each of the transactions. Transactions with high asset specificity, economies of scale and spillover potential should be ideally assigned to a centralized institution (IARC) while those with high transaction intensity to a more decentralized institution (NARS or other partner). While these implications are easier to

[17] http://www.asti.cgiar.org/

[18] http://netmap.wordpress.com/process-net-map/

derive for production and user level transactions, the other cases involve trade-offs depending on context and intended objective of those activities.

In planning within the CGIAR, the governance and funding structure of the system and centres determines how strategic plans are developed. The new system under CRPs will exploit economies of scale and reduce transaction costs of interface activities, but the opportunity cost is the risk of driving research decisions further away from local needs. The tools and methodologies used in priority setting and targeting such as models for forecasting, scenario analysis and ex-ante impact assessment can be applied elsewhere representing a spillover potential. Regarding asset specificity, while specific physical assets may not be required in planning, specialized experience of scientists and partners is important. In the promotion stage, activities like extension, capacity building and policy advocacy require high transaction-intensity suggesting a more decentralized organization. However, this is not straightforward. The transaction intensity, asset specificity, economies scale and spillover potential will depend on what is being promoted. For example, compared to information on new varieties, guidance on crop management practices requires more interactions with farmers and discretion making it difficult to standardize. Spillover effects can still arise from location-specific activities if there is a conscious intention to test the techniques used and draw lessons that can be adapted for application elsewhere e.g. on extension models, policy processes etc. In monitoring and evaluation, data on performance is collected through interactions along the R&D chain. Surveys or expert judgments, that are less transaction intensive, may be used. The scope of the evaluation will determine whether specialized expertise is required. Tools and methods used can be applied elsewhere and so can the lessons learnt from the evaluation if properly documented.

Table 20 Attributes of transactions in the agricultural R&D process

Transactions	**Type of Knowledge Required**	**Relevance of Attributes**			
		Transaction Intensity	Asset Specificity	Economies of Scale	Spillover Potential
Planning	Local & Technical	Dependent on governance & funding structure	Medium	High	Medium
Production	Technical	Low	High	High	High
Promotion	Local & Technical	Dependent on promotion objective	Dependent on promotion objective	Dependent on promotion objective	Dependent on promotion objective
Monitoring / Evaluation & Reporting	Local & Technical	Dependent on monitoring objective	Dependent on monitoring objective	Dependent on monitoring objective	Dependent on monitoring objective
User Level	Local	High	Low	Low	Low

Source: Authors, Adapted from Birner and von Braun (2009)

The standard approach in empirical transaction cost economics does not require a measurement of transaction costs (Shelanski and Klein, 1995). Empirically quantifying attributes of transactions may be challenging since variables such as asset specificity are difficult to measure. Regarding contextual factors, there is a wide array of literature on the dynamics of adoption and especially the factors that influence farmer adoption decisions. However, understanding of "what works" in diverse circumstances and the processes driving outcomes is still far from complete. Research is required to understand constraints in the entire innovation process comprising technology production, supply and use of different commodities. Case studies can be carried out of research programs that have achieved the best results as well as those that have experienced limiting political, cultural and institutional constraints. The synthesized lessons can help governments and the international development community in targeting investments and policy reforms while bearing in mind the local political economy. Ultimately, positioning strategies and institutional design to enable impact from CGIAR centres should be differentiated across matrices of biophysical and institutional conditions.

5.4 Complementary results generated from alternative models to generate sound research strategies

This section gives a brief summary of the background to the link of ICRISAT's priority setting project to the Global Futures research initiative which utilizes the IMPACT model as a complementary approach to priority setting. It demonstrates how it has developed and is used in the CGIAR in general and by ICRISAT in particular. It is noted that while the Global Futures initiative use of the IMPACT model is planned as an important part of the CGIAR wide priority setting support system, ICRISAT on the other hand needs a more detailed single commodity framework to look clearly at research domain focus.

The results obtained so far from the application of both the single commodity framework and multi-commodity framework by ICRISAT demonstrates the complementary results generated from two partial equilibrium models based on the principle of economic surplus. The single commodity economic surplus model estimates the welfare benefits resulting from research investments and allows measurement of global and regional research benefits in the context of international trade with in-depth analysis of the relevant production environments, applicability across environments to estimate both direct research benefits and spillover benefits of technology across environments. The multi-commodity model features as additional dimensions: i. Change in demand and supply over time based on income and population growth; ii. Cross price elasticities; and iii. Parameter estimates validated by crop models. This analysis highlights the consistency of results of both models to generate a sound research strategy.

Methodology

IMPACT modeling framework

The International Model for Policy Analysis of Agricultural Commodity and Trade (IMPACT) model combines a partial equilibrium model that has global coverage with hydrology and water supply and demand models and the DSSAT crop modeling suite (Rosegrant et al. 2012; Nelson et al. 2010).The IMPACT model is a partial equilibrium agricultural model for 40 commodities of crop and livestock, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes/meals, sugar/sweeteners, and fruits and vegetables. The model links the various countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, the rate of productivity growth, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth. IMPACT contains four categories of commodity demand – food, feed, biofuels feedstock, and other uses. The IMPACT model incorporates climate effects and productivity change due to technology improvement from the DSSAT modeling results as a shifter in the supply functions (Richard et al., 2012).

Spatial Coverage of IMPACT

While the primary IMPACT model divided the world into 36 countries and regions, the IMPACT-WATER model uses a finer disaggregation of 281 “food-producing units” – which represent the spatial intersection of 115 economic regions and 126 river basins – out of recognition of the fact that significant climate and hydrologic variations within regions make the use of large spatial units which are inappropriate for water resource assessment and modeling. Of the countries represented within the IMPACT-WATER model, China, India and the United States (which together produce about 60 per cent of the world’s cereals) have the highest level of sub-national disaggregation and are divided into 9, 13 and 14 major river basins respectively, while the other countries or regions considered in IMPACT account for the remaining 90 basins.

Crop Model Incorporation

The crop simulation model is incorporated in the IMPACT model as a shifter in the supply functions. The direct effect of the differing climates on the yield and area of various crops are assessed in the process-based simulation model. The system used in the IMPACT modeling suite is the Decision Support System for Agrotechnology transfer (DSSAT, Jones et al. 2003) which brings together programs to model weather/climate, soil dynamics and the crop models themselves (Figure 15).

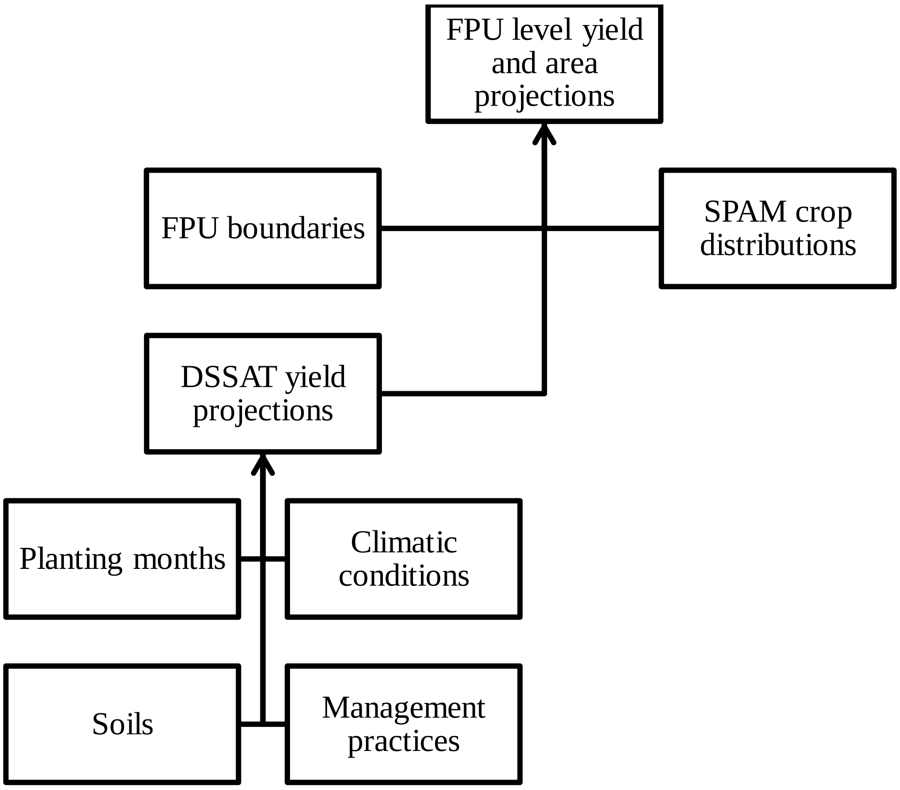


Figure 15 Incorporating productivity and climate effects on crops into IMPACT (Source: Richard et al., 2012)

The supply curve is shifted by several non-price factors like sunshine, temperature, rainfall, soil quality, technological improvements and regulation. Technological improvement is the most important shifter in this model. This is implemented as a multiplicative factor in the yield and area equations as an addition to the annual growth rate: (1+gY) where gY is the intrinsic yield growth rate.

At the end of the crop modeling work, we have gridded maps showing yield estimates for various climatic conditions. Then the yield for the whole food producing unit is computed using an area-weighted average yield. The area allocation by crops is taken from the Spatial Production Allocation Model (You and Wood, 2006). The yield estimates over the years are converted into growth rates for the time interval of interest which enter the supply functions as growth rates.

Integrating technology adoption and welfare estimation in IMPACT framework

To allow for area and yield of multiple cultivars to respond to the price of a single commodity, some minor structural changes are made in the IMPACT modeling suite. These include the addition of a nested activity structure for the cultivars.

Harvested area

To achieve the unique shares of the cultivar areas while maintaining the same total activity area, the shares of area are applied for the cultivars accordingly. Currently in the IMPACT model, the equation for area is a function of the price of the activity, the own and cross price elasticities of the activity, and the exogenous area growth rate, described in the equation below.

$$Area_{j,FPU} = \left(1 + Areagrowth_{j,FPU}\right) * PPV_{j,cty}{}^{AreaElast_{j,jj}} * Areaint,$$

where,

$Area_{j,FPU}$	=	the total area by activity, j
$Areagrowth_{j,FPU}$	=	the total rainfed area growth over time
$PPV_{j,cty}$	=	the producer price
$AreaElast_{j,jj}$	=	the own- and cross-price elasticities for the supply response
$Areaint$	=	the area intercept

To incorporate the nested cultivar shares of the area by food production unit, the equation is adapted as follows:

$$\mathrm{Area}_{\mathrm{cul,FPU}} = \mathrm{CulShare}_{\mathrm{cul,FPU}} * \left(1 + \mathrm{Areagrowth}_{\mathrm{j,FPU}}\right) * \mathrm{PPV}_{\mathrm{j,cty}}{}^{\mathrm{AreaElast}_{\mathrm{j,jj}}} * \mathrm{Areaint}$$

Subject to:

$$\mathrm{Area}_{\mathrm{j,FPU}} = \sum_{\mathrm{cul}} \mathrm{Area}_{\mathrm{cul,FPU}}$$

where,

$\mathrm{Area}_{\mathrm{j,FPU}}$	=	the total area by activity, j
$\mathrm{Area}_{\mathrm{cul,FPU}}$	=	the total area by cultivar, cul, for activity, j
$\mathrm{CulShare}_{\mathrm{cul,FPU}}$	=	the share of the total area by cultivar
$\mathrm{Areagrowth}_{\mathrm{j,FPU}}$	=	the total rainfed area growth over time
$\mathrm{PPV}_{\mathrm{j,cty}}$	=	the producer price
$\mathrm{AreaElast}_{\mathrm{j,jj}}$	=	the own- and cross-price elasticities for the supply response
$\mathrm{Areaint}$	=	the area intercept

Yield

The initial yield for each of the cultivars will be determined by using the yield of the activity for that food production unit which is calculated as the total production per hectare of area. The yield of the cultivars will respond to the prices of the activity, fertilizers, and wages based on the activity elasticities for each. The cultivar yield will also grow over time according to the exogenous yield growth rate.

Exogenous yield growth rate

The exogenous yield growth rate for each cultivar will be determined based on the intrinsic yield growth rate for the activity as a starting point for the growth over the time period. In the equation below, this growth rate is denoted as, a. The additional exogenous yield growth that is contributed by the promising cultivars is called b in the equation. This additional growth rate along with the productivity effect of climate change namely c will be added to the intrinsic yield growth rates, to form the rate of growth for the promising cultivars.

$$Y_{cul,FPU,t} = Y_{t-1}\left(1 + \left(a_{j,FPU} + b_{cul,fpu} + c_{j,fpu}\right)\right) * \left[\mathrm{PPV_{j,cty}}^{\mathrm{YieldPriceElast}} * \mathrm{PFER_{j,cty}}^{\mathrm{YieldFertElast}} * \mathrm{PWAG_{j,cty}}^{\mathrm{YieldWageElast}}\right]$$

where,
Y = the yield for the cultivar of j in each FPU
PPV = the producer price
PFER = the price of fertilizer
PWAG = the cost of wages
a = the intrinsic productivity growth of yield
b = the cultivar specific productivity growth of yield
c = the biophysical effects on productivity growth due to climate change
YieldPriceElast = the own-price irrigated supply elasticity
YieldFertElast = the elasticity of the supply response with respect to fertilizer
YieldWageElast = the elasticity of the supply response with respect to wages
FPU = the food production unit index
cty = the country index
cul = the cultivar index
j = the activity index

Welfare Analysis

The welfare module in IMPACT follows a traditional economic welfare analysis approach to estimate the benefits to society on the consumer- and producer-side. It allows policy makers to disentangle some of the effects of alternative plausible futures in changes to agricultural commodity prices, and quantities produced and consumed.

Consumer Surplus

On the demand-side a consumer surplus is calculated to estimate changes faced by consumers from changes in agricultural markets. Calculating the consumer surplus in IMPACT is straightforward, as we measure the area below the demand curve (Rosegrant et al. 2012) and above the market price for each agricultural commodity, and region. These consumer surpluses can be aggregated to give a measure of national and global consumer surplus.

Producer Surplus

The producer surplus is the area above the supply curve and under the equilibrium price. Calculating this area directly is relatively complicated. Thus, in IMPACT the producer surplus is calculated by calculating agricultural revenue (P* x Q*) minus total cost of production, which is the area under the supply curve.

Application of DSSAT groundnut model: comparison of yield advantage of groundnut promising cultivars with baseline cultivar

In this study to estimate the yield advantage of promising groundnut cultivar with traits like drought, heat and higher yield potential over the baseline cultivars, we applied DSSAT crop simulation model to develop 'virtual' promising groundnut cultivars (Singh et al. 2013). The results of the DSSAT model simulation under current climate scenario and change in climate for both baseline cultivar and virtual promising cultivars for India is presented in Table 21. Using the cultivar information estimated for each regions, crop yield was simulated for each pixel (10x10 Km) using spatial information on soil, climate, management, etc. and productivity change for each FPUs is estimated as explained in the previous section and incorporated in the IMPACT model for evaluation.

Table 21 Effect of incorporating drought tolerance and heat tolerance traits on the mean pod yield of virtual groundnut cultivars derived from cv. JL 24 at Anantapur, India. Percent change (% change) is the yield gain due to the trait with reference to the yield of a virtual cultivar.

	Baseline climate		Temperature		Temperature + CO_2		Temperature + CO_2+Rain	
Cultivar	**Kg/ha**	**% Change**	**Kg/ha**	**% Change**	**Kg/ha**	**% Change**	**Kg/ha**	**% Change**
				Drought tolerance				
Baseline	1271	3*	1049	5	1256	5	1225	5
10% short cycle	1067	5	897	5	1082	6	1054	5
10% longer cycle	1468	4	1186	5	1426	5	1373	4
Baseline + Yield pot.	1416	4	1175	5	1411	5	1376	5
10% short + Yield pot.	1184	5	1000	5	1204	5	1171	5
10% long + Yield pot.	1651	5	1324	5	1593	5	1534	4
				Heat tolerance				
Baseline	1246	1	1081	8	1299	8	1270	8
10% short cycle	1033	2	904	6	1091	6	1068	6
10% longer cycle	1461	3	1223	8	1478	9	1434	9
Baseline + Yield pot.	1382	2	1195	7	1449	7	1414	7
10% short + Yield pot.	1144	2	993	4	1199	5	1168	5
10% long + Yield pot.	1625	3	1357	8	1642	8	1588	8
				Drought tolerance + Heat tolerance				
Baseline	1292	5	1126	13	1358	13	1328	13
10% short cycle	1082	6	947	11	1139	11	1118	11
10% longer cycle	1511	7	1285	14	1546	13	1493	13
Baseline + Yield pot.	1451	7	1251	12	1510	12	1477	12
10% short + Yield pot.	1201	7	1044	10	1257	10	1231	10
10% long + Yield pot.	1694	7	1429	13	1716	13	1660	13

*Yield improvement from drought tolerance, heat tolerance, or both drought and heat tolerance compared to cultivar with same life cycle and yield potential traits within a climate scenario.

6 Concluding Remarks

This synthesis paper documented the evolution of the impact assessment analysis at ICRISAT to support its strategic research investment choices. It presented the methods and diverse applications with specific attention on methodologies and applications to improve the efficiency and reliability of the results from research priority setting processes. It discussed the impact assessment tools adapted to support decision making and the types of decisions that were supported.

ICRISAT has pursued a range of priority setting exercises over the last four decades. These ranged from expert consultation, scoring model, and multi-regional trade goods models with research domains for spillover benefits using the principles of economic surplus. The enhancements in priority setting procedures made explicit the benefits that would flow from additional investment to the institute as well as the opportunity costs corresponding to specific reductions in research funds. It generated milestones by which research outputs can be evaluated ex-post. The degree of scientific subjectivity of earlier approaches was significant. Increasingly, there is a need for a certain level of scientific rigor to priority setting, so as to incorporate basic economic principles. The multi-region traded good model and spillover estimation provided detailed understanding reflecting both direct and indirect benefits. Objective quantification along with better understanding of underlying parameters provided reasonable results to set research priorities. Results generated from alternative models provided complementary evidences to develop sound research strategies.

The on-going initiatives in priority setting at ICRISAT includes: (1) new applications of spatial tools and GIS on research applicability between production environments and countries to estimate spillovers, (2) revisiting adoption and adaptive capacity parameters estimation for impact assessment, (3) consideration of institutional factors and transactions costs which has implications for adaptive capacity and adoption of technologies, and (4) use of alternative models to generate complementary estimates and evidences.

Some observations from the preliminary results indicate the following.

- Comparison of the results for groundnut and pigeonpea highlights the significant difference in total potential global benefits across crops due to research spillovers. Relating to the preliminary results we find that the C matrix for pigeonpea was sparse (relative to groundnut) indicating weak applicability across production environments which, according to pigeonpea scientists, are due to photoperiod sensitivity of the crop.
- For sorghum and pearl millet, the research spillover benefits contribute substantially to potential total benefits depending upon the production domain research focus.

For example, maximum welfare gains for millets are achieved in west and central Africa (WCA) if research focus is given to millet production environment 1.

- The actual realization of the above benefits is constrained by adaptive capacity of NARS and level of adoption of technologies by farmers. For example, the large potential benefits from sorghum research in WCA region of sub-Saharan Africa is dampened by weak adaptive capacity and low level of adoption.
- The global, regional and country level benefits accruing from research on specific crops identify specific "hubs" for targeting future research. In this context, bio-physical scientists working on crop improvement can improve research efficiency through research focus on high payoff production environments for these crops.

The study has shown the usefulness of identifying homogeneous zones using spatial tools and GIS for a systematic analysis of applicability and research spillover benefits towards improving the efficiency and reliability of results for setting agricultural research priorities. Analysing past dissemination in the background of the zones will further strengthen the message and highlight which factors can be tackled to further increase impacts. The inherent applicability across production environments of improved technologies is seen to be mediated by the adaptive capacities in the region as well by the level of adoption. Strengthening NARS research capacities and innovations to increase adoption rates will substantially increase the realized global welfare benefits.

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8 Appendices

Appendix 1

Research Priority Setting and ICRISAT's Impact Assessment Agenda

Figure 1 discussed in Section 2.5 has shown the linkages among ex-ante impact assessment (priority setting), monitoring and evaluation, and ex-post impact assessment and forward and backward flows of information. Ex-post impact assessment studies carried out by ICRISAT in the past mainly dealt with the estimate of benefits from research activities. Table 1 presents a sample of impact assessment studies conducted by ICRISAT showing that the research activities generated benefits in excess of the opportunity cost of the capital invested in the programs. Work on the earlier impact assessment series focused on ex-post studies where benefit estimates were based on empirical evidence of adoption and adopter-levels for at least one year.

Table 1 Sample of ICRISAT Impact Studies, 1996-2006

S. No.	Source	Impact Study	Period	Summary Impact Results
1	Bantilan and Joshi, 1996	Returns to Research and Diffusion Investment on Wilt Resistance in Pigeionpea	1985-1993	The adoption (60%) of ICP 8863, an early maturing, improved, fusarium wilt-resistant pigeonpea in Karnataka, India led to57% yield gains and 42% cost reduction. Had a an NPV of US$62 million and IRR of 65%
2	Joshi and Bantilan 1998	Impact Assessment of Crop and Resource Management Technology: A Case of Groundnut Production Technology	1986-1991	Based on a survey conducted in Maharashtra, India, the study observed partial and step-wise adoption of different components of improved groundnut technology that range between 31% for raised-bed and furrow method of land management to 84% for improved varieties. In comparison to the prevailing technology, the groundnut production technology gave 38% yield gains, generates 71% more income, and 16% cost reduction. The NPV of benefits from collaborative research and technology transfer was more than US$ 3 million, representing an IRR of 25%.
3	Yapi, Debrah, Gehala and Njomaha, 1999	Impact of Germplam Research Spillovers: The Case of Sorghum Variety S35 in Cameroon and Chad	1986-1994	S 35 occupied 33% of the total rainfed sorghum area in Cameroon and 27 % in Chad. S 35 had yield gains of 27 % and reduced production cost by 20%. S 35 research spillover into African regions was estimated to be have an NPV of US$15 million in Chad and US$4.6 million in Cameroon, representing IRR of 9 5% in Chad and 7 5% in Cameroon.
4	Rohrbach, Lechner, Ipinge and Monyo 1999	Impact from Investments in Crop Breeding; the Case of Okashana 1 in Namibia	1991-1997	The pearl millet variety Okashana 1, developed jointly by ICRISAT and the Namibian national program, was grown on almost 50% of the national pearl millet area. ICRISAT and the Government of Namibia jointly obtained a 50% IRR to public investments in the development and dissemination of this variety. The NPV of this return was more than US$11 million in 1998.
5	Bantilan and Parthasarathy 1999	Efficiency and Sustainability Gains from Adoption of Short-duration Pigeonpea in Non-legume based	1986-1994	Wide spread adoption of short-duration pigeonpea has made farming profitable in the short term-via cultivation of a second crop in the post rainy season - and farmers expect to sustain productivity in the long run via crop rotation to maintain soil fertility.

		Cropping Systems		
6	Yapi, Dehala, Ngawara and Issaka 1999	Assessment of the Economic Impact of Sorghum Variety S35 in Chad	1986-1996	Between 1990 and 1995, the percentage of adopting farmers grew from 14% to 80%. In 1990, 7% of the total sorghum area (13 000 ha) was sown to the S 35 variety. By 1995, the area under S 35 had increased to 27% (66 000 ha).
7	Ramasamy, Bantilan, Elangova and Asokan 2000	Improved Cultivars of Pearl Millet in Tamil Nadu: Adoption, Impact, and Returns to Research Investment	1985-1995	Farmers prefer improved cultivars because of their high yield, good grain size, pest and disease tolerance, and short duration. The increased production on account of adoption of improved cultivars largely goes to the animal feed industry for use as raw material. But, consumption of pearl millet has sharply declined in Tamil Nadu. An analysis of farm level efficiency of pearl millet production shows some degree of inefficiency.
8	Yapi, Kergna, Debrah, Sidibe and Sanogo 2000	Analysis of the Economic Impact of Sorghum and Millet Research in Mali	1990-1995	The results indicate that by 1995, 30% of the sorghum and 37% of the millet areas were sown to improved varieties. The estimated benefits (NPV) from research and extension efforts range from US$ 16 million (for sorghum) to US$ 25 million (for pearl millet). These represent IRR of 69% and 50%, respectively.
9	SHiyani, Joshi and Bantilan 2001	Impact of Chickpea Research in Gujarat	1987-1996	Results show that improved chickpea varieties showed distinctly superior performance over local cultivars in terms of yield, net income, and per unit cost of reduction, proving their cost- and profit-maximizing characteristics.
10	Joshi, SHiyani, Bantilan, Pathak and Nageswara Rao 2002	Impact of Vertisol Technology in India	1974-1996	This study assesses the extent of adoption of the various components of vertisol technology, identifies the constraints to their adoption, examines farmers' perceptions of the sustainability benefits from it, estimates the on-farm benefits, and details the relative significance of the various components.
11	Brennan, Bantilan, Sharma and Reddy 2004	Impact of ICRISAT research on Sorghum Midge on Australian Agriculture	1988-1997	The price effects resulting from successful ICRISAT research were found to be significant. The lower prices for sorghum, as a result of increased production led to income reductions for Australian producers, and these were partly offset by the increased yields. The gains for the Australian consumers of these grains (ie, the Australian livestock sector) from the lower prices were significant, so that overall Australia made net gains from the impact of ICRISAT's sorghum research.
12	Padmaja, Bantilan, Parthasarathy and Gandhi 2006	Gender and Social Capital Mediated Technology Adoption	2002-2003	Findings show that women who are engaged in agriculture and allied activities develop bonding social capital. Men who are engaged in agriculture develop bridging social capital characterized by weaker, less dense but more crosscutting ties. Women's employment opportunities significantly improved with the introduction of technology.

Ex-post studies on impact assessment focused either on impacts of a particular crop cultivar (Deb, Bantilan, and Rai. 2005; Deb, Bantilan and Rai 2005; Deb, Bantilan and Reddy 2005; Deb, Joshi and Bantilan 1999; Joshi, Asokan and Bantilan 1999; Ramasamy, Bantilan, Elangovan and Asokan 1999; Shiyani, Joshi, Asokan and Bantilan 2000; Shiyani, Joshi, Asokan and Bantilan 2005) or a management technology (Bantilan, Anupama and Joshi 2005; Bantilan and Johansen 1994; Kolli and Bantilan 1997) in a specified geographical region. These studies have conducted primary surveys, rapid appraisals and focus group discussions with scientists, extension professionals and other experts who have knowledge about the technology development, adoption and diffusion process of the improved technology. Information on adoption level, preferred traits of the adopted technology, reasons for adoption, benefits received from the technology in terms of yield gain, income, etc. were gathered in a systematic manner. Considering the possibility of limited or no adoption of some technologies, underlying reasons for such occurrences were fully documented and reported as “lessons learnt”. Impacts were reported as joint impacts of all partners. This way, it was possible to gather and provide feedback for technology refinement and shifting in research focus. Articulation style and reporting mechanism provided enough confidence to the all stakeholders to reveal all related information, insights and understanding regarding research focus, dissemination process, adoption, performance at the farm level and attendant impacts.

Data on adoption of improved cultivars in different countries of Asia and Africa were complemented by identification of the critical factors influencing the uptake process. Impact studies also reported on farmers' perceptions on adoption constraints. These studies showed that adoption level of improved cultivars was related to the existence of preferred traits in the new cultivars, the options (number of cultivars) and the availability of seeds and profitability of new cultivars. Various dimensions impacts such as productivity impacts, genetic diversity and yield stability, were quantified. The productivity impacts were measured in terms of increase in yields, reduction in per unit cost of product ion and increase in stability of yield.

Some studies (Bantilan et al. 2004; Bantilan, Deb and Nigam. 2003; Bantilan and Deb. 2003; Deb and Bantilan. 2003) have detailed documentation of evolution of research process and priority areas for research focus for sorghum, pearl millet and groundnut which has continuously being evolved at ICRISAT. For example, there have been six phases in the evolution of sorghum enhancement research: (1) 1972-75: breeding for wide adaptability and higher grain yield; (2) 1976-79: breeding for wide adaptability and screening techniques; (3) 1980-84: regional adaptation and resistance breeding; (4) 1985-89: specific adaptation and resistance breeding; (5) 1990-94: trait-based breeding and sustainable productivity; (6) 1995 onwards: intermediate products and upstream research. Recent research thrusts included the development of suitable materials for resistance and tolerance to abiotic (drought, low temperature, acidic soils) and biotic (Striga, diseases, insect pests) constraints, yield enhancement, yield stabilization and genetic diversification. Thus, focus of ICRISAT’s crop improvement moved from developing improved cultivars to development of intermediate products to cater the need of partners with a view to generate higher level of impacts. To incorporate this reality, impacts studies developed and adapted appropriate methodologies to assess the impacts of crop improvement research on the efficiency of NARS breeding programs, crop productivity, genetic diversity and yield stability and also on technology spillover. They have documented research partnership, technology exchange and ICRISAT's partnership with the NARS, Advanced Research Institutes (ARIs), private sector organizations and Non-Governmental Organizations (NGOs).

Impacts studies generally tried to suggest implications of their research findings for future directions for research and partnership. They have identified the range of uses of different crops such as sorghum and emphasized the importance of breeding for end use that farmer-preferred traits vary with location and season and change over time suggests the need to respond to farmers' changing needs in a crop improvement endeavor. Collaboration with the NARS takes the form of seed exchange, a two-way street where the NARS receive and contribute to regional trials and nurseries and to specific requests. Stress was laid on collaboration with private companies, providing them with useful breeding materials, hybrid parents and cultivars and encouraging them to contribute. The importance of increasing participation across agencies was highlighted. Impact studies with evidence suggested meeting the needs of NARS with varying capacities through building and strengthening partnerships among all players (ICRISAT, ARIs, public and private sector NARS and NGOs) for enhancing the impacts in farmers' fields and increasing the efficiency and effectiveness of research for development.

Current agenda: selecting research projects for ex-post impact assessment at ICRISAT

The process of identifying research projects for ex-post impact studies is guided by the institute's protocol on impact assessment. The process led by the IAO Head in consultation with Research Program Directors with significant input from scientists. The identification process of studies is guided by a set of criteria to enable screening different research projects for priority ex-post impact assessment studies.

The criteria include the following:

1. *Is the research developed or attributed to ICRISAT?* If this is partly attributable to ICRISAT, the extend needs to be qualified and further justification provided for prioritizing such a study.
2. *Has intervention taken off in terms of adoption?* Adoption is a condition for impact. In fact, the single, most influential variable on the payoff to research investment is the level of farmer adoption of a new technology innovation. There is therefore need for adequate time after research completion to enable quantification of scale of adoption.
3. *Relative size of potential benefit of adoption of the technology.* Need to define who, and how many, are the potential beneficiaries of the project to better defining scope and potential impact.
4. *Uniqueness of the impact assessment study.* It is important to know whether a similar ex-post impact assessment study has not been done, particularly within ICRISAT.
5. *Geographic coverage of the research project*. Is the impact assessment study going to be spread across several countries, or multi-locations within a single country? This is important, other than for budgeting purposes, but also for strategic marketing. Some

donors target specific geographical regions for funding and it is important to have documented impacts of past research efforts in that region.

6. *Are there any prospects for documenting impacts along the impact pathway?* One of the major task of impact assessment is to establish highly plausible links between a research effort and the observed changes along the impact pathway.

Describing Plausible Impact Pathway

One major task in ex-post impact assessment studies is to establish highly plausible links between research a research effort and other observed changes along the impact pathway. It has further been argued as a principle of good practice for ex-post impact assessment is to enhance the rigor of establishing the links along the input-output-outcome-impact pathway

Box 1. Quantitative Description of Impacts of HHB 67 and HHB 67 Improved in India

The pearl millet hybrid HHB 67 was developed at CCS Haryana Agricultural University, Hisar based on the seed parent, 843A from ICRISAT and the restorer parent, H 77/833-2 from CCSHAU. Released in 1989-90, HHB 67 entered cultivation in 1991. Expecting that it would become vulnerable to downy mildew like other released hybrids, efforts were directed to incorporate downy mildew resistant genes into the seed parent through backcross breeding at ICRISAT, Patancheru. The downy mildew restorer parent was developed through marker-assisted backcross breeding. Selected seed parent (843-22A), and restorer parent (H 77/833-2-202) resembling the original parents were crossed to produce an essentially a similar, but downy mildew resistant hybrid, HHB 67 Improved.

Starting with 81 tonnes (t) of certified seed production in 1991, the production of HHB 67 seed peaked to 2,835t by 1999. Starting with 80t of certified seed production in 2006, HHB 67 Improved seed production peaked to 3,491t in 2011.

In Rajasthan, the productivity of HHB 67 Improved ranged from 589 kg/ha (57 % over the local variety) to 600kg/ha (60% over the local variety) on marginal and small farms. Medium and large farmers harvested marginally more grain yield (621 kg/ha) but the gain has been lower at 38 % over the local variety (449 kg/ha) under rainfed situation in a normal year. Still, there has been marginal improvement in the productivity of fodder (9 %). In the case of Haryana, since local varieties are not in vogue, HHB 67 Improved productivity was compared with HHB 67 as the control. This comparison showed that the productivity difference is 14 %. Due to protective irrigation coupled with high fertility of the soils in Haryana, the productivity of HHB 67 Improved is 300 % higher than in Rajasthan.

Grain farmers' surveys indicated that the cost of cultivation in Haryana was Rs 15,000/ha, which is 200% more than in Rajasthan (Rs. 5,000/ha) owing to less input use. In both the states, human labour cost forms 50% of the variable cost and with the inclusion of machinery costs, it accounts to 70% of the cost. The proportion of labor cost exceeded the value of material input cost. After deducting the paid out cost, farmers reaped a net income of Rs 3,494/ha in Rajasthan with a cost benefit ratio of 2.32 as against Rs. 6,820/ha in Haryana with a cost benefit ratio of 1.79, without considering family labour.

Economic analysis revealed that the farming community of Rajasthan accrued net returns of Rs 399 million, averaging Rs. 3.99 million per year from the cultivation of HHB 67 Improved. The IRR was 35 % indicating an impressive rate of returns to the investment. Similarly, in Haryana, the net present value of benefits accrued to the farming community was Rs. 123 million or Rs 1.23 million per annum and an IRR of 46 % implying an appreciable rate of returns to the investment.

beyond ‘plausibility’ to ‘substantially demonstrated’ impacts (Maredia and Raitzer 2006, Raitzer and Kelley 2008).

The planned CRP projects all include brief description of the most plausible impact pathway – from problem identification to intended institutional goals. This ex-ante (predicted) impact pathway descriptions are specific to the research proposed and provide a description of the planned outputs, intended users, expected outcomes and likely impacts. On the other hand, the task of the ex-post impact assessment is to map out, based on evidence, the links between a specific intervention and the relevant outputs, outcomes and realized impacts, by identifying the cause-effects relationships between the different partners. Based on outcomes of the impact assessment study of HHB 67 and HHB 67 Improved Figure 1 illustrate the ex-post impact pathway of the project.

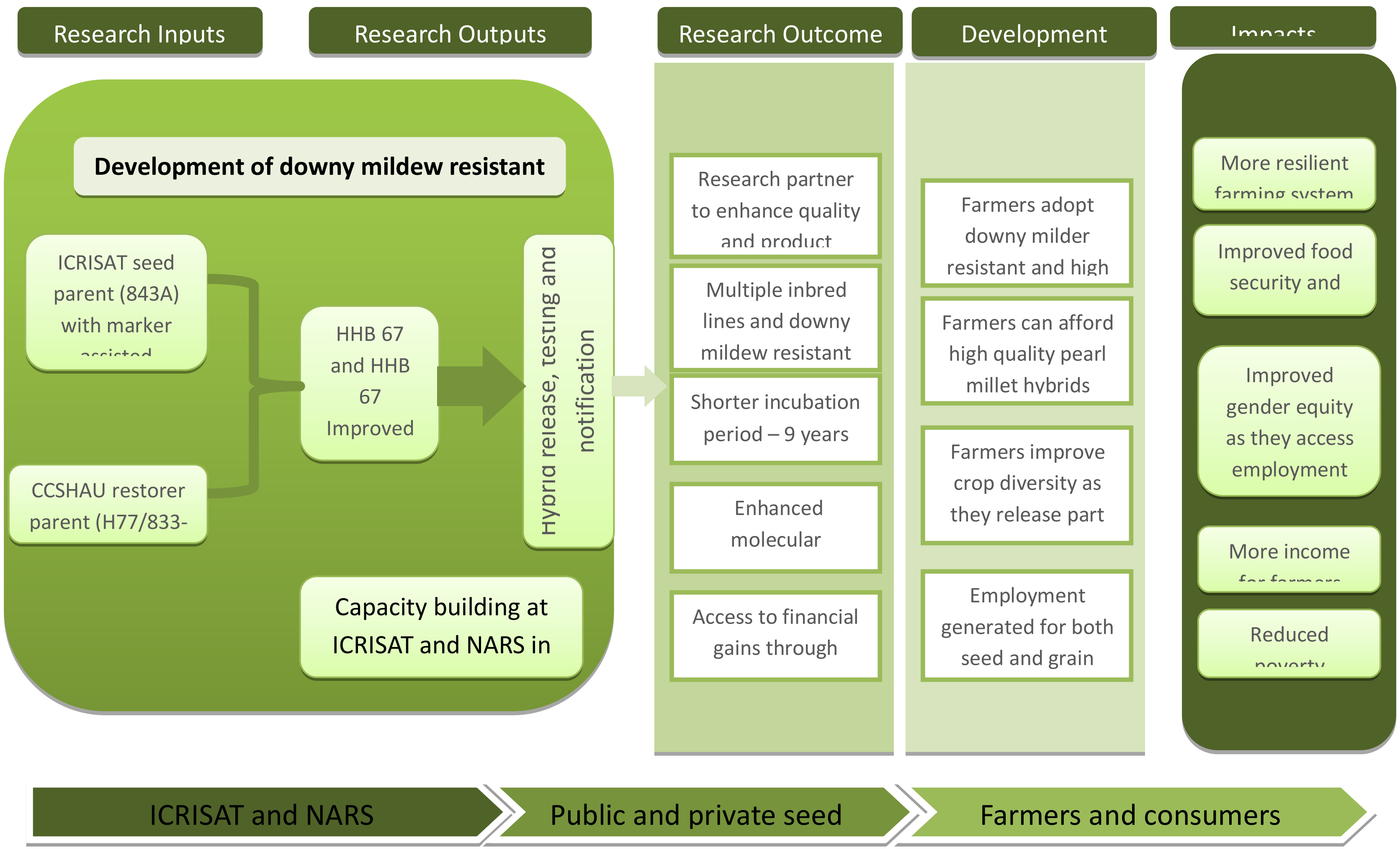

Figure 1. Impact Pathway for Pearl Millet Hybrids, HHB 67 and HHB 67 Improved

Monitoring on-going Impact Assessment Studies

The 12 planned impact assessment studies are at different levels of implementation. The Groundnut Impact Study in Nigeria has the final report under review. The Seed Systems Impact Study in WCA was suspended in 2012, and is to resume in early 2013 under new consultants and modified terms of references. Three studies are currently underway at various stages of data collection and analysis. The three studies are: a) Pigeonpea in Tanzania, b) Fertilizer Microdosing in Zimbabwe, and Chickpea in Andhra Pradesh. Finally, the Groundnut Impact study in Malawi will start in February 2013.

Six studies were identified for Set 2, and these will be implemented at various stages in 2013. Preparation of studies terms of reference we led by the selected focal points (Table 1). There are three studies that are likely to start off in the 1st quarter of 2013, due to readily availability of impact assessment funding. The three studies are; a) Impacts of Agri-Business Incubation, b) Impacts of Sorghum in Tanzania, and c) Impacts of Lucheba Watershed work in China.

Table 1. Set 1 Studies under implementation

Impact Assessment Studies		Region/ Country	CRP
Set 1	Impact of seed systems development in Western and Central Africa (WCA)	WCA	Markets, Institutes and Policies / Grain Legumes / Dryland Cereals
	Impact of groundnut research in Malawi	Malawi	Grain Legumes
	Impact of pigeonpea research in Tanzania	Tanzania	Grain Legumes
	Impact of improved chickpea varieties in India	India	Grain Legumes / Markets, Institutes and Policies
	Impact of groundnut research in Nigeria	Nigeria	Grain Legumes
	Impact of ICRISAT research and development for fertilizer micro-dosing in Zimbabwe	Zimbabwe	Resilient Dryland Systems
Set 2	Impacts of chickpea improved research in Central Dry Zone of Myanmar	Myanmar	Grain Legumes
	Impacts of Lucheba watershed work in China	China	Resilient Dryland Systems
	Impact assessment of the Agri- Business Incubation (ABI) program at ICRISAT	India	Markets, Institutes and Policies
	Impacts of sorghum research and development in Mali	Mali	Dryland Cereals
	Impact assessment of sorghum variety development in central Tanzania	Tanzania	Dryland Cereals
	Impact assessment of Village Level Studies in Asia	India and Bangladesh	Markets, Institutes and Policies

Lessons Learnt from ICRISAT's on-going Ex-Post Impact Assessment Studies

In pursuing the objectives of the IAO, there has been some lessons learnt, and some providing challenges based on the fact that assessing the effects of agricultural research is complex and costly.

Measurement of Impact Indicators

It is quite difficult to measure changes in yield, production, nutritional status, and erosion, and it requires costly fieldwork and analysis. At times dedicated funding for such activity is not available, especially when several growing seasons are required for changes to be measured in most yield and production systems. Trends in dryland agriculture, for example, cannot be measured in fewer than eight cropping seasons.

Dealing with Attribution

Ex-post impact assessment can measure change, but it is difficult to attribute it to specific research activities. For example, in an area where sorghum yields has increased, how can the contribution of research versus that of extension, credit programs and improvements in market conditions be estimated?

Realistic Timing of Ex-Post Impact Assessment

Research management, policymakers, donors, and the public all tend to be impatient and to want impact estimates when research is still underway or has just recently been completed. This is neither realistic nor possible. There is often a considerable time lag between the time research is started, a new technology is released, and impacts can be measured – often as long as 10 to 15 years.

Dealing with Economic Approaches

More than other types of evaluation, impact assessments tend to be carried out as research studies leading to formal publications. They generally employ scientific methods drawn from economics and the social sciences and often use indirect measures or indicators of impact because the effects of technology on farm-level production, nutritional status, and environment cannot be directly measured. To cope with this problem, production-function models are often used to estimate the effects of research or technology on production, incomes and associated variables. Numerous assumptions are also often made to overcome data limitations and to simplify economic models.

Appropriate Packaging of Ex-Post Impact Assessment Results

At times the targeted audiences tend to be skeptical of the data and methods used in impact assessment; they may also find the reports difficult to understand, interpret, and apply. This highlights the need to plan impact studies in terms of real information needs, to pay close attention to data quality, and to make special efforts to summarize the findings. It is extremely important for results and recommendations to be presented in terms that are meaningful to donors, policymakers, ICRISAT management and scientists.

Estimating Research Costs

Most ex-post impact assessment studies have been unable to effectively separate components of research costs. It is generally assumed that education and extension is part of research costs. The few studies that have sought to separate these activities have had to do so subjectively. Because of the lack of sufficient theoretical instruments, these studies have generally attributed most of the benefits to research alone, and in some cases this may have resulted in erroneously high rates of return being attributed to investments in research.

Dealing with Human Capacity as Inputs

Problems of measurement can also apply to inputs, although many of these can be defined. However, inputs of highly skilled manpower may be hard to quantify. The pricing and measurement of previous research also represents an input problem unless prior research endeavours are treated as free goods. But this ignores the fact that someone paid for the prior research, and if this cost is not taken into account it can again give a result which places an unduly high social rate of return on the research.

Appendix 2

More questions sought to support priority setting decisions

ICRISAT core team renewed their efforts on a forward-looking trend analysis to add to the essential inputs to effective research prioritization. This was in response to research management queries as follows:

- Whereas sorghum area in India decreased by 22% and sorghum yields were essentially unchanged from 1996-2006, both yield and area increased by 18% in WCA, which combined to give a 39% increase in total sorghum production. Did the reduction in sorghum area in India result from displacement of sorghum in the moist SAT by higher value crops such that average yields remained stagnant or fell slightly because a larger proportion of the remaining sorghum was produced in the drier SAT with lower and more variable yield potential? If so, did this trend mask the positive impact of ICRISAT's work on sorghum drought and disease resistances and watershed management to improve water productivity?
- What was the reason for both the expansion of sorghum area in WCA and also the large increase in average yields? It seems that WCA has achieved a significant increase in sorghum yields and total production that deserves recognition and possible replication elsewhere.
- Did the increase in sorghum production contribute to a reduction in poverty and greater food security? Is there anything in the WCA sorghum research experience that could be replicated in ESA where increases in sorghum yield and production area has been much slower?
- Perhaps the data for SSA crop production are not reliable, and if so, it seems a concerted effort is needed to obtain a reliable source of data for crop production trends in SSA. The Panel notes other trends in area and yield of the mandate crops that deserve attention as input to priority setting.

ICRISAT's strategic planning would be greatly enhanced with a more thorough analysis and understanding of mandate crop production trends, use of geospatial and simulation scenario analysis, and an economic analysis framework with explicit prioritization criteria to quantify the magnitude and extent of impact on food security and poverty alleviation consistent with the Center's mission and goals. Drawing from its own impact assessment and adoption studies, the Center seeks to better understand the factors responsible for these trends and the degree to which ICRISAT's research products contributed to them. Understanding the distribution of benefits among different regions and different segments of the population has also been increasingly critically sought for prioritization, including benefits to urban and rural poor, women and children, and minority ethnic groups.

Development of a set of hypotheses that determine the international public good (IPG) potential of ICRISAT's downstream work on technology development, testing and adaptation

An area frequently debated in the Governing Board and Management for years relates to the IPG potential of ICRISAT's downstream work, e.g. producing IPGs about the scaling up process. This question has been posed to the social science group with a challenge to consider this issue as part of the priority setting exercise, i.e. inclusion of "IPG potential" in the set of criteria for research prioritization. One approach explored is framing an IPG in terms of 'proof of concept' hypothesis (eg do farmers adopt micro-dosing or not). Where the team has moved to conceptualize 'local level' technology adoption/impact within an IPG framework is with some of the seed systems work in Africa. With seed supply having been identified as a constraint, a set of research issues have been defined around the seed supply question, i.e. to identify where these opportunities lie and to follow up accordingly. Some of these issues, once resolved and documented, are legitimate IPGs. In this context, the research prioritization process entails consideration of the following:

- a conceptual framework to help identify the most important constraints, that if solved, would have the greatest potential impact with regard to ICRISAT's mandate;
- cost, timeframe, and probability of success in developing IPGs research that alleviate the identified constraints;
- ICRISAT's comparative advantages to address these constraints in relation to other potential research and development institutions, NARS, NGOs, and the private sector; and
- regional priorities, stakeholder needs and the strengths of key partners, and active involvement of partners and stakeholders in the priority setting process.

Demand by CGIAR external reviewers to include the estimation of global spillover in the CGIAR Research Program (CRP) proposal justification and priority setting "must haves"

More recent events in 2011-2012 during the proposal development of two CGIAR Research Programs (CRP) further stimulated the demand for rigorous priority setting with special consideration of the estimation of global research spillover benefits. In this instance, the external reviewers of the CRP on Grain Legumes (jointly proposed by ICRISAT, CIAT, IITA and ICARDA) and CRP on Dryland Cereals (by ICRISAT and ICARDA) specifically demanded as part of the proposal "must haves" a demonstration of the global spillover benefits in the priority setting process.

Appendix 3

Table 1 Ranking of capacity

Country	Kai final adjusted	Bantilan	# trials rank	releases rank	LSU training rank	ASTI spending rank	ASTI persons rank	Pardey (1989) Persons rank	Pardey (1989) spending rank	trials per ha rank	release s per ha rank	LSU train per ha rank	ASTI per ha spending rank	ASTI per ha persons rank	Pardey (1989) per ha persons rank	Pardey (1989) per ha spending rank
China	1.00	1.00	15	9	4	-	-	1	1	24	24	26	-	-	5	7
India	1.00	1.00	1	1	1	-	-	2	2	10	15	10	-	-	6	5
South Africa	1.00	1.00	16	6	23	2	4	4	5	20	22	29	6	15	12	10
Thailand	0.70	0.70	24	9	6	-	-	5	6	22	21	6	-	-	4	3
Viet Nam	0.70	0.70	3	6	5	-	-	-	-	4	6	4	-	-	-	-
Ghana	0.60	0.60	10	7	16	3	6	18	20	9	13	14	2	3	18	21
Pakistan	0.50	0.50	18	7	15	-	-	3	9	15	16	17	-	-	1	8
Indonesia	0.50	0.50	4	5	9	-	-	6	4	13	17	16	-	-	8	4
Bangladesh	0.50	0.50	12	7	12	-	-	7	8	8	8	7	-	-	2	2
Ethiopia	0.50	0.80	21	8	15	5	2	12	14	19	20	19	10	2	20	16
Zimbabwe	0.50	0.50	23	6	19	-	14	13	11	18	11	15	-	14	17	11
Senegal	0.50	0.50	11	10	13	8	13	15	12	7	25	8	7	12	9	9
Zambia	0.50	0.80	20	3	7	14	12	17	22	16	7	9	16	13	22	23
Burkina Faso	0.50	0.50	7	9	18	12	10	19	3	5	19	13	12	8	19	1
Myanmar	0.50	0.50	2	5	2	-	-	-	-	3	5	3	-	-	-	-
Nigeria	0.40	0.60	6	9	15	1	1	8	7	14	23	24	3	5	15	12
Cameroon	0.40	0.40	17	10	21	-	-	11	10	11	25	20	-	-	7	6
Uganda	0.40	0.90	25	6	16	-	8	14	-	25	9	12	-	7	14	-
Malawi	0.40	0.90	9	5	3	11	15	20	19	2	2	2	5	6	10	13
Sierra Leone	0.40	0.40	25	7	23	16	19	25	25	25	3	29	11	9	13	20
Chad	0.40	0.40	22	10	21	-	-	26	13	23	25	27	-	-	27	19
Ivory Coast	0.40	0.40	25	10	22	7	16	-	-	25	25	28	9	18	-	-
Mali	0.30	0.60	5	4	17	9	7	9	15	12	14	21	13	16	21	18
Benin	0.30	0.30	13	8	19	10	17	24	24	1	4	5	1	4	11	14
Tanzania	0.30	0.90	25	2	14	4	5	-	-	25	10	18	8	10	-	-
Guinea	0.20	0.20	8	7	11	17	11	16	18	6	12	11	17	11	16	17
Mozambique	0.20	0.80	25	7	10	13	9	21	17	25	20	17	15	19	26	22
Gambia	0.20	0.20	25	8	19	18	20	23	-	25	1	1	4	1	3	-
Sudan	0.10	0.20	14	10	8	6	3	10	16	21	25	22	14	17	24	24
Niger	0.10	0.20	19	5	20	15	18	22	23	17	16	25	18	20	25	25
Central African Republic	0.10	0.10	25	10	22	-	-	27	21	25	25	23	-	-	23	15
DRC	0.00	0.00	25	8	23	-	-	-	-	25	18	29	-	-	-	-

Table 2 Adoption rates and indicators used.

ADOPTION	FINAL Adjustments	GN area (05-07 mean)	Expert estimates	Group adjustments	DIVA based adjustments	ICRISAT releases	releases per ha (10000)	JN CRP estimates	1998 "DIVA"	2010 DIVA	Others
Bangladesh	0.20	32,430	0.20	0.20	0.20	3	0.93				
China	0.90	4,211,574	0.90	0.80	0.90	1	0.00		0.9		
India	0.65	5,974,000	0.70	0.60	0.65	26	0.04		0.56		
Indonesia	0.20	639,775	0.20	0.20	0.20	5	0.08				
Myanmar	0.40	803,500	0.40	0.40	0.40	5	0.06				
Pakistan	0.40	91,700	0.40	0.40	0.40	3	0.33				
Thailand	0.50	31,319	0.50	0.50	0.50	1	0.32				
Viet Nam	0.50	253,000	0.50	0.50	0.50	4	0.16		0.17		
Benin	0.10	124,783	0.10	0.10	0.10	2	0.16	0.10			
Burkina Faso	0.25	414,173	0.20	0.20	0.20	1	0.02	0.25			
Cameroon	0.13	325,519	0.30	0.30	0.15	0	0.00	0.13			
Angola	0.10	159,522	0.00	0.00	0.00	0	0.00	0.10			
Chad	0.15	485,168	0.30	0.30	0.15	0	0.00				
DR Congo	0.10	475,578	0.00	0.00	0.00	2	0.04	0.10			
Gambia	0.10	133,208	0.10	0.10	0.10	2	0.15	0.10			
Ghana	0.25	342,933	0.40	0.40	0.40	3	0.09	0.25			
Guinea	0.10	212,280	0.20	0.20	0.20	3	0.14	0.10			
Ivory Coast	0.10	71,049	0.30	0.30	0.15	0	0.00	0.10			
Mali	0.35	353,799	0.60	0.40	0.40	6	0.17	0.35			0.44
Niger	0.30	546,482	0.30	0.30	0.30	5	0.09	0.30			0.14
Nigeria	0.40	2,391,783	0.60	0.40	0.40	1	0.00	0.40			0.32
Senegal	0.35	834,376	0.30	0.30	0.15	0	0.00	0.35			
Sierra Leone	0.10	90,823	0.10	0.10	0.10	3	0.33	0.10			
Ethiopia	0.40	39,695	0.40	0.40	0.40	2	0.50				
Malawi	0.70	263,724	0.60	0.60	0.70	5	0.19		0.10	0.58	
Mozambique	0.40	295,000	0.60	0.30	0.40	3	0.10		0.75		
South Africa	0.85	49,840	0.90	0.60	0.85	4	0.80		0.75		
Sudan	0.10	832,372	0.10	0.10	0.10	0	0.00				
Uganda	0.60	244,000	0.60	0.40	0.60	4	0.16		0.10	0.55	0.59
Tanzania	0.50	548,333	0.40	0.40	0.50	9	0.16			0.35	
Zambia	0.65	150,009	0.40	0.40	0.65	8	0.53		0.20	0.57	
Zimbabwe	0.60	208,367	0.60	0.50	0.60	4	0.19		0.52		
WANA	0.15		0.15	0.15	0.15						
other Asia	0.10		0.10	0.10	0.10						
Latin America	0.35		0.35	0.35	0.35						
Other developing	0.10		0.10	0.10	0.10						
Australia	0.75	10,717	0.75	0.75	0.75						
other developed	0.75		0.75	0.75	0.75						

Table 3 Unit cost reduction and impacts of adoption of improved pearl millet cultivars

Country/Region	**Year**	**Cultivars**	**Yield gain (%)**		**Reduction in unit cost (%)**	**Increase in labour cost (%)**		**Per hectare net farm income (Rs.)**	**Remarks**
			Grain	Fodder		All	Female		
INDIA									
Eastern Rajasthan	1996	Improved	228	12	47	60	140	1134	
Haryana	1996	Improved	182	68	47	44	144	2062	
Gujarat (kharif)	1995	MH179	247	72	54	133	170	2818	Wide adaptability due to disease resistance, short duration ,high grain and fodder yield
Gujarat (summer)	1995	MH179	462	119	59	261	306	5557	
Maharashtra	1994	Improved	95	7	43	25	16		
Tamil Nadu	1994	ICMS 7703	108		18	59	45	3567	
MALI									
Segou	1995	Improved	63		38				Stable yield, improved food security. Generated NPV of US$35million with an IRR of 50%
Koulikore	1995	Improved	65						
Mopti	1995	Improved	52						
Namibia	1997	Okashana1	24						Broadly accepted for early maturity, bold grain for start of national seed industry. Provided NPV of US$11.7 million with an IRR of 50%
Zimbabwe	1996	SDMV	8904						Widely accepted for early maturity ad bold grain. Estimated IRR is 44%

Source: Bantilan and Deb (2003)

Appendix 4 Earlier efforts of ICRISAT's spillover estimation

There was continues effort at ICRISAT for refinement of empirical estimates and collection of relevant data from all possible sources. These efforts were related to analysis of experimental data and surveys of national research system to gather data on realize spillover across countries and location.

Technology spillover potential from enhanced sorghum germplasm was estimated using experimental data generated by (i) International Sorghum Varietal and Hybrid Adaptation Trial (ISVHAT), and (ii) All India Coordinated Sorghum Improvement Project (AICSIP). ISVHAT data included information on trial locations and cultivars (phonology, plant height, grain yield and response to important pests and diseases) for the period 1989 to 1992 which were conducted in 59 locations spanning 26 countries in Asia, Africa and Latin America. The trials comprised of about 25 cultivars common to all the locations (17 varieties and 8 hybrids, including a hybrid and a variety check). The AICSIP data generated through adaptive research trials conducted in 108 locations under 13 states of India, during 1975/76 to 1995/96, were utilized to quantify spillover impacts among different sorghum domains in India.

Sorghum research in different locations was conducted under eight research domains. A research domain was delineated as a homogeneous eco-region defined in terms of its soil and climatic conditions and spreading beyond the geographical boundary of a country. For example, the major problem in Sorghum Research Domain (SRD) 2 is grain mold; and in SRD3, stem borer and Striga. The eight sorghum research domains were: wide adaptability (SRD1), dual purpose with specific adaptability (SRD2), dual purpose with fodder emphasis (SRD3), forage sorghum (SRD4), early sowing postrainy-season sorghum (SRD5), late sowing postrainy-season sorghum (SRD6), irrigated sorghum (SRD7) and extreme altitude sorghum (SRD8) (for details, see Bantilan et al. 2004, Chapter 1).

To quantify spillover impacts (ie, estimation of the coefficients of sorghum spillover matrix), an econometric approach based on yield trial data, similar to that of Maredia et al.(1996) was used. The first step was to identify the origin domain and trial (test) domain of sorghum cultivars tested in AICSIP and ISVHAT trials. The final step was to quantify spillover matrices. Following Maredia et al. (1996), it was assumed that the performance of a variety is a function of environmental variables (location dummy, year dummy) and technology variables (vintage and origin of the variety). Technology variables were included to represent characteristics of varietal technology. The following regression model was used to estimate the spillover matrix.

Y_{hgt} = a + bh $DLOC_h$ + ct $DYEAR_t$ + v VINT + w.$DQRIG_i$ + r MR + E_{hgt} for j =1,2,..,n

where,
j is the test domain in which the yield data point is observed
Y_{hgt} is the observed yield (kg ha^{-1})of the g^{th} entry at the h^{th} trial location in environment j in the t^{th} trial year
$DLOC_h$ is a vector of dummy variables equal to 1 if the data point belongs to location h, and 0 otherwise
$DYEAR_t$ is a vector of dummy variables equal to 1 if the data point belongs to year t, and 0 otherwise
VINT is a variable to reflect the vintage of a variety approximated by the trial year in which the gth variety first appeared
$DORIG_i$ is a vector of dummy variables equal to 1 if the g^{th} variety belongs to the origin group i, and 0 otherwise
MR is the inverse Mill's ratio
E is the error term

ISVHAT panel data was used to estimate the model. Location and year dummies (DLOC and DYEAR) were included to factor out the site and time effects (such as different levels of management) on the observed trial. To correct probable selection bias related to the correlation between varietal attrition and experimental response (ie, yield) of non-randomly missing varieties in the trials conducted over a number of years, the variable MR (inverse Mill's ratio) was included. The model was estimated separately for each sorghum domain; therefore the coefficients for DORIG represent the performance of varieties of different environmental origins in a given sorghum domain relative to the 'home varieties'. The varietal group originating from the test domain was considered the benchmark variable (ie, the dummy variable $DORIG_j$ was dropped from the equation for each domain). Therefore, the coefficients of $DORIG_i$ are the differential yields defined as ($w^j_i = Y_{ij} - Y_{jj}$). These coefficients were used to estimate Y_{ij}/Y_{jj} to give the elements of the spillover matrix, C_{ij} based on the constant Y_{jj} (approximated by the arithmetic mean) for each domain.

The spillover coefficients are presented in Table 1 in terms of percentage coefficients based on average yields of the benchmark variables (i.e., $c_{ij} = Y_{ij}/Y_{jj}$). Off-diagonal values of less than one indicate that sorghum cultivars directly, introduced from other sorghum domains yielded less than those developed by local breeding programs in the test domain. Similarly, values greater than one (as in the case of ICRISAT-Patancheru-bred cultivars) indicate that sorghum cultivars directly introduced from these sources tended to yield more than those developed by local breeding programs in the test domain.

The significant yield advantages shown by varieties developed and evaluated in SRD7 and SRD 8.1 (implying less direct spillins of cultivars developed for other sorghum domains) can be explained by the fact that sorghum cultivars bred for rainfed environments cannot perform better in irrigated environments. 'Environmental distance' plays a role in explaining the significant yield advantage enjoyed by locally-bred cultivars in SRD7 (irrigated) and SRD8.1 (high altitude). The poor performance of all the cultivars developed for other sorghum research domains or bred for wide adaptability by ICRISAT-Patancheru in SRD8.1 (high altitude, ie, China) can be explained by the fact that the climate adaptation patterns are entirely different compared to other domains. Therefore, the best way ICRISAT can assist China's national program is by providing intermediate products (enhanced germplasm materials) rather than finished ones (varieties/hybrids). This argument is strengthened by the fact that of the 10 hybrids developed in China after 1987, 7 are derived from ICRISAT materials, but after incorporating genes for local adaptation. The implications for ICRISAT are that the focus should be on upstream (strategic) research to develop basic materials and provide NARS with strong research programs. ICRISAT moved in this direction in 1995.

Sorghum cultivars developed for irrigated environments (SRD7) showed 13% grain yield advantage in SRD2 (late maturing, dual purpose) but not vice versa. The asymmetry of these two domains explains the asymmetry in the spillover matrix (i.e. c # c). However, without comparing fodder yield it cannot be said that sorghums bred for irrigated environments (SRD7) were really performing better in SRD2. The major objective of dual-purpose sorghum (SRD2) is to provide high grain and fodder yield, while breeding of irrigated sorghum concentrates on increasing grain yield. Therefore, SRD7 cultivars may provide higher grain yield but not higher fodder (stalk) yield.

An analysis of the performance of ICRISAT-Patancheru-bred cultivars across sorghum domains using the regression analyses reveals wide adaptability and transferability to different sorghum growing domains. This points to the success of research in reducing G x E interactions and developing widely adaptive cultivars, especially in all types of rainfed cultivation and in low altitude areas, which account for a significant share of the sorghum growing area in developing countries.

Table 1. Estimated spillover matrix for sorghum improvement research at the Global Sorghum Research Domain level (computed from ISVHAT trial data, 1989-92).

Origin of cultivar	**Sorghum research domains where cultivars were tested**						
	SRD1	SRD2	SRD3	SRD4	SRD7	SRD8.1	SRD8.2
SRD1	1.00	0.95	0.84	1.50	0.73	0.36	1.16
SRD2	0.96	1.00	0.87	1.88	0.78	0.23	1.28
SRD3	0.88	1.05	1.00	1.68	0.85	0.42	1.21
SRD4				1.00			
SRD7	0.80	1.13	0.80	1.28	1.00		
SRD8.1						1.00	
SRD8.2							1.00
ICRISAT-Patancheru	1.15	1.13	1.07	2.17	0.83	0.33	1.27

Source: Deb et al. (2004), Table 11.7.

The AICSIP trial data for 1975-96 was used to estimate the spillover coefficient matrix for sorghum in India. It was computed for each of the eight sorghum domains for ICRISAT-derived¬cultivars (IDCs) and NARS-derived cultivars. IDCs are those varieties/hybrids developed through research partnership between ICRISAT and NARS using ICRISAT-derived germplasm or breeding material, while NARS-developed cultivars are cultivars developed solely by NARS.

The spillover coefficients are presented in Table 2 in terms of percentage coefficients based on average yields of the benchmark variables (ie, $c_{ij} = Y_{ij}/Y_{jj}$). Off-diagonal values of less than one indicate that sorghum cultivars directly introduced from other sorghum domains yield less than those developed in the test domain. Similarly, values greater than one (as in the case of IDCs) indicate that sorghum cultivars directly introduced from these sources yield more than those developed in the test domain.

A regression analysis of the performance of IDCs across sorghum domains shows their wide adaptability and transferability to different domains. The environmental specificity and associated selective environmental heterogeneity evident in the comparison of NARS-developed cultivars are minimized when IDCs are compared across different sorghum domains. This indicates the success of the collaboration between ICRISAT and Indian NARS in reducing G x E interactions and developing widely adaptive cultivars in India.

Table 2. Estimated spillover matrix for sorghum improvement research at the Sorghum Research Domain level (computed from AICSIP trial data, 1975-96).

Origin of cultivar	Sorghum research domains where cultivars were tested			
	SRD1	SRD2	SRD5	SRD6
SRD1	1.00	1.08	1.08	1.12
SRD2	0.94	1.00	1.09	1.65
SRD5	0.84	0.86	1.00	0.97
SRD6		1.00	0.92	1.00
ICRISAT-Derived Cultivar	1.08	1.11	1.23	1.12

Source: Deb et al. (2004), Table 11.10.

Survey of National Agricultural Research System (NARS) was conducted as part of ICRISAT's Impact Monitoring Survey to elicit information about realized spillover. Country specific studies were also conducted to know the research spillovers accrued to the specific country.

Brennan and Bantilan (1999) quantified the spillover impact of ICRISAT research on breeding programs and agricultural production in Australia. They identified ICRISAT germplasm lines released in Australia and grown by farmers there. In the case of sorghum, ICRISAT's most significant contribution to Australian agriculture has been the introduction of improved midge-resistant lines combined with desirable white grain and tan-colored plant (IC SV 745 and PM 13654). There are several advanced breeding lines that have incorporated midge resistance and a combination of other useful characteristics from ICRISAT-derived material. As a result, experts from the sorghum industry expect hybrids with midge resistance to be available in the near future, and that the resistance of such material will have a significant economic impact on the industry. Assuming that such resistance is likely to increase yield by 5% in 50% of the crop affected by midge each year, the expected yield gains to Australia are estimated at 2.5%. This translates into a cost reduction of \$4.02 ton $^{-1}$ or an annual cost saving of \$4.69 million at current average production levels.

Brennan and Bantilan (1999) also assessed the impact of ICRISAT's global research on Australia, via an impact on prices. ICRISAT's global research has increased production and decreased sorghum price. Given finite supply and demand elasticities, ICRISAT's research is likely to have a downward impact on prices for the predominantly export-oriented sorghum industries in Australia. Thus, Australian industries face lower prices and increase in yield. An economic analysis of those spillover impacts in an economic welfare framework revealed that the overall net effect for Australia was a reduction in benefits gained by producers. Australian sorghum producers will lose more through lower prices than through the benefits they gain from higher yields, resulting in an overall loss of A\$ 0.55 million per year. These losses occur because Australian producers are unable to make use of the productivity gains from ICRISAT's research as much as producers in the rest of the world. Hence, other producers experience greater cost reductions than do Australian producers. On the other hand, Australian consumers of sorghum (ie, primarily the livestock sector) will gain an average of A$1.69 million per year. Overall, the net gain to Australia as a result of ICRISAT's sorghum research effort averages A$1.14 million per year, or an aggregate of A$27.3 million (in 1996 dollars) over the period to 2022.

Actual spillover benefits have accrued in sorghum-growing countries. Macia, a variety released in Mozambique, was also later released in Botswana, Tanzania and Namibia (Table 3). Similarly, S 35 was developed in India and adopted by farmers of Cameroon and Chad. ICSV 111 was developed in India and released in Burkina Faso, Chad and Nigeria. ICSV 1079 BF was developed in Burkina Faso but is now cultivated by farmers in Mali. SPV 475 developed for India is now cultivated in Malawi, Swaziland and Zimbabwe. Seredo was developed for Uganda but also cultivated by farmers of Ethiopia, Kenya and Tanzania.

Table 3. Spillover of Sorghum Cultivars

Cultivar	Production System and country where originally selected	Spillover into
50 x 160	21 Uganda	21 Rwanda; 20, 21 Burundi
Dinkmash	8 India	19, 20 Ethiopia
Gambella 1107	20 Ethiopia	20, 21 Burundi
Ingazi	8 India	19, 20 Kenya
Macia	20 Mozambique	19 Botswana Tanzania, Namibia
Melkamash	8 India	20 Ethiopia
Seredo	21 Uganda	19 Ethiopia; 20, 21 Kenya; 20 Tanzania
SPV 475	8 India	20 Malawi; Swaziland, Zimbabwe
SRN 39	8 India; 19 Sudan	20 Kenya; 20 Ethiopia
Tegemeo	21 Uganda	19, 20 Tanzania; 20 Burundi
S 35	India	Cameroon, Chad
CE 151	Senegal	Mauritania
CE 145-66	Senegal	Mauritania
Malisor 84-1	Mali	Ivory Coast
BF 83-3/ 48-2-2	Burkina Faso	Senegal
IRAT	Niger	Burkina Faso, Chad
ICSV 111 IN	India	Benin, Ghana, Nigeria
ICSV 1079 BF	Burkina Faso	Mali
ICSV 1083 BF	Burkina Faso	Togo
ICSV 1089 BF	Burkina Faso	Senegal
ICSV 400	India	Nigeria

Note: Production system 8 (PS 8): tropical, low rainfall, primarily rainfed, postrainy season crops are sorghum/oilseed and includes the Western Deccan Plateau of India; Production system 19 (PS 19): lowland, rainfed, short season (less than 100 days) and suitable for sorghum/millet/rangeland and located in Sahelian Eastern Africa and the margins of the Kalahari Desert; Production system 20 (PS 20): covers semi-arid area, intermediate season (100-125 days), suitable for sorghum/maize/rangeland and located in Eastern Africa and parts of Southern Africa; and Production system 21 (PS 21): intermediate season (125-150 days), suitable for sorghum/maize/finger millet/legumes and located in Eastern and Southern Africa. The agroecological details of each PS are given in the ICRISAT Annual Report, 1993.
Source: Deb et al. 2004, Table 11.11.

These examples show that breeders were successful in generating technology with wide adaptability and technology spillover potential; and do not substantiate the 'location specificity' argument (at least in terms of yields). Sorghum cultivars originating from the collaborative ICRISAT-NARS international research system have proven to be highly transferable within sorghum domains and across different countries around the world.

Findings of the spillover study provided objective evidences that the international research system must considered research spillovers in priority setting. Currently, ICRISAT has been explicitly considering spillover potential for its research.