INDEPENDENT SCIENCE &
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CGIAR

A Stripe Review of Natural Resources Management Research in the CGIAR

September 2012

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Acronyms and abbreviations

ARI	advanced research institute
ASB	alternatives to slash and burn
CCAFS	Climate Change, Agriculture and Food Systems
CGIAR	CGIAR is a global research partnership for a food secure future.
CIAT	International Center for Tropical Agriculture
CIFOR	Center for International Forestry Research
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CRPs	CGIAR Research Programs
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EPMR	external program and management review
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GHG	greenhouse gas
IAA	integrated aquaculture–agriculture
IAR4D	integrated agricultural research for development
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	information and communication technology
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
INRM	integrated natural resources management
IPM	integrated pest management
IPs	integrated programs
IRRI	International Rice Research Institute
ISPC	Independent Science and Partnership Council
IWMI	International Water Management Institute
NARES	national agricultural research and extension system(s)
NARS	national agricultural research system(s)
NGO	non-governmental organization
NRM	natural resources management
NUE	nitrogen use efficiency
PMS	performance measurement system
R&D	research and development
REDD	reduced emissions from deforestation and forest degradation
REDD+	reducing emissions from deforestation and forest degradation and enhancing forest carbon stocks
SC	Science Council (now the ISPC)
SLOs	system-level outcomes
SPIA	Standing Panel on Impact Assessment
SRF	Strategy and Results Framework
TAC	Technical Advisory Committee
UN	United Nations
WANA	West Asia and North Africa
ZT	zero tillage

Preface

The *Stripe Review of NRM Research* was instigated by the ISPC at a crucial time for the CGIAR. The CGIAR is working through the design of several large programs in its transition to become a more strategy-led organization. Natural resources management (NRM) research is an essential underpinning of crop and animal improvement research, and natural resources are in their own right a focus of research – both to improve their benefits to humans and to enhance the sustainability of environmental services overall. The CGIAR has an increasing investment in natural resources research. Some of the new CGIAR programs focus directly on such subjects as land, water and ecosystems; forests and trees; and climate change. The scope of research can span from 'place-based' research to global resource measurements, and from microbial fauna to international policy and institutions. However, demonstrating the impact and return on investments in the overall area of NRM research has been challenging.

The Independent Science and Partnership Council (ISPC), as part of its mandated work on foresight and the provision of advice on the development of the future portfolio of CGIAR research, outlined the need for an NRM study in its 2011/2012 Work Plan. The design of the *Stripe Review of NRM Research* started in December 2010. The review was undertaken by a Panel of external experts under the guidance of ISPC Member, Prof. Jeffrey Sayer (School of Earth and Environmental Sciences, James Cook University, Cairns, Australia). The Panel was convened in March 2011 and consisted of Dr P. Caron (Director General, Research and Strategy, CIRAD), Dr J. Ghazoul (Professor of Ecosystem Management, ETH), Dr K. Giller (Professor of Plant Production Systems, University of Wageningen) and Dr B. Keating (Director, CSIRO Sustainable Agriculture Flagship). CGIAR Centers participated through a series of iterative consultations with Center focal points, including a face-to-face meeting at the Science Forum in Beijing in October 2011; these consultations ended in early March 2012. The panel members initiated the drafting of the final report in February 2012 with Serena Fortuna and Peter Gardiner of the ISPC Secretariat, and the report in its current form was endorsed by the ISPC in March 2012.

The **NRM Research Stripe Review** was designed to provide the Consortium leadership, CRP and Center management, and donors with insights that may facilitate the design and implementation of future successful NRM programs – programs that can produce international public goods and achieve impact at scale. The **present report, for which the ISPC developed the Executive Summary on the basis of the Panel's inputs**, seeks to identify conceptual and operational issues that still require attention from CRP leaders, CGIAR Centers, the Consortium and the Fund Council, in order to develop research that will meet CGIAR system-level outcomes.

Executive summary

The CGIAR reform process has moved the emphasis toward full inclusion of natural resource issues in the research agenda. Many CGIAR Research Programs (CRPs) embrace the ecosystem services approach that both underpins the livelihoods of the poor and serves as the foundation for sustainably increasing agricultural productivity in a resource-constrained world. Adoption of a new portfolio of global CRPs coincides with greater recognition of the challenges that must be overcome in order to feed a world of 9 billion people on a finite planet. These challenges were the major focus of attention at the Rio+20 World Summit on Environment and Sustainable Development held in Rio de Janeiro in June 2012. The CGIAR is responding to this challenge and is centrally placed to contribute to global efforts in managing the natural resource systems that will underpin food security.

The past decade has seen a major transformation of the CGIAR research agenda. A consensus has emerged that the **natural resource base upon which agriculture depends is a vital object of CGIAR research**. Many studies have argued for changes in the culture, incentives, structures and funding to enable the CGIAR to address natural resource management (NRM) issues more comprehensively and effectively. Much progress has been made, but impediments remain. This report is the result of a Systemwide review of NRM research in the CGIAR as it moves toward new modes of research. The Panel's report reviews the progress made and supports the view that there are still opportunities to improve the CGIAR's approaches to NRM research in support of the four system-level outcomes (SLOs): food security, poverty alleviation, improved nutrition and environmental protection. Improvements will come through the capture of **new science, better organization of science, stronger leadership, mobilizing new skill sets, adopting an impact culture and making longer-term investments**. The following are the key issues that emerged from the study:

- **The centrality of integrated natural resources management (INRM) to the CGIAR:** The renewed CGIAR has adopted a mission that places NRM firmly in the center of the System's agenda. Environmental sustainability is explicitly included among the SLOs as essential to underpin future agricultural production and sustainability of the food supply. Maintaining and building natural capital, and strengthening the institutions and policies needed to manage natural resources, are recognized as major global public goods that fall within the CGIAR mandate.

  Natural resource systems provide numerous benefits to the livelihoods of the poor beyond the boundaries of their farms. Degradation of these broader natural resource systems is one of the biggest threats to alleviating poverty. More productive and sustainable management of soils, water, forests, watersheds and living aquatic resources is fundamental to improving the livelihoods of the poor and to ensuring future food security at local to global scales. All indications are that the importance of NRM will continue to grow in the coming decades. Current trajectories of population growth, growing economies and changes in human diet will drive major changes in agriculture. Contested land, water, nutrient and energy resources, rates of land and water degradation, and climate change mitigation and adaptation all pose new challenges. While these resource challenges inevitably unfold at local levels, their aggregate effects lead to global impact and tradeoffs. Better NRM is essential if agriculture is to provide the full range of benefits to food and nutrition, health, incomes and adaptability.

  However, in many situations NRM continues to be the weak link in the world's agricultural, aquatic and forest systems. There are major inefficiencies in land allocation, nutrient or water use, soil husbandry and the management of forests, livestock and fisheries. Agricultural systems, broadly defined, continue to emit excessive greenhouse gases. Also, overharvesting of natural resources is rampant and biodiversity continues to be lost. These deficiencies threaten the sustainability of current agricultural yields and the potential to achieve yield increases with declining land resources and scarcity of inputs. Natural resources remain the foundation for agriculture, but there is also growing recognition of agriculture's central role in the health of multi-functional landscapes. Agricultural lands provide essential environmental services that go far beyond production functions. The CGIAR must be aware of these non-production values and also must be strategic in the extent to which it engages with these broader environmental issues.

- **The evolution of NRM in the CGIAR:** NRM has been part of the CGIAR portfolio from the outset. The early focus was on addressing biotic and abiotic constraints to realizing the genetic potential of new crop varieties. The Green Revolution came about through the combination of new genotypes with improved management of water, nutrients and pests. **The focus was on the management of natural resources *within* agriculture.** Over the years, the portfolio evolved within the original commodity Centers and through the addition of new Centers with broader mandates around crosscutting issues of policy, land and water resources, biological diversity and ecosystem management. In this sense the **CGIAR has evolved to consider NRM issues both *within and around* agriculture**. As a consequence **the distinction between INRM and crop germplasm improvement is starting to blur** and most research on agricultural issues today operates within an innovation system that links genetics to farmers' fields and to the broader environmental and socio-political landscape.

However, the historical development of the NRM research portfolio in the CGIAR has progressively added extra dimensions of natural resource systems, without an overarching strategy as to its role in relation to crop germplasm improvement, crop and livestock production practices, and socio-economic/institutional research. This is reflected in the outcome and impact stories that have been reviewed by the NRM research Stripe Review Panel. Assessments conducted by the Standing Panel on Impact Assessment (SPIA) and the external program and management reviews of the Centers have generally addressed NRM research within the context of yield improvements or pest and disease management, often treating other ecosystem impacts as externalities.

The CGIAR has clearly had success stories from its NRM research, but these have either been measured indirectly through crop germplasm improvement or have been local in scope. When assessments have been performed, they have largely failed to demonstrate that NRM research has produced true international public goods. Although there is a growing consensus that lack of evidence is in part an artifact of measurement and assessment methods, and while there is some progress in addressing this issue, the challenge of identifying robust impact metrics to assess NRM research remains unsolved.

Emerging CRPs aspire to convene, and provide inspirational leadership for large consortia of research partners spanning the full spectrum from basic to adaptive research, and outreach to farmers. They aspire to mobilize groups of scientists in interdisciplinary teams around the key 'Grand Challenges' facing agriculture. One grand challenge is to improve the management of the natural resource systems that support the production of food, feed and fiber, and that provide the ecosystem services essential to the livelihoods of the poor. **The CRPs are a major innovation in broadening and deepening the CGIAR research agenda, improving on partnerships, and fully embracing NRM issues.**

What will the CRPs need to address in their development and implementation?

- **The 'three pillar' CGIAR needs to be reconsidered:** The previous distinction or 'stove piping' of crop genetic improvement, NRM and socioeconomic/ institutional research no longer serves the CGIAR well. It inhibits scientific innovation and hence the impact of CGIAR research. Instead of thinking of these focus areas as independent endeavors, this report argues for **a new paradigm based on GxExM^I**. This is not a literal formula, but identifies the requirement to focus on more equal research efforts on genetics (G), environment (E) and management (M), all connected to their individual and overarching institutional (I) contexts. The reformed CGIAR recognizes the need for a more integrated research approach through adoption of a portfolio of large research-for-development programs. It is an approach in which crop germplasm improvement, NRM and socioeconomic research on institutions and policy are seen as interactive, intersecting and often co-dependent pathways for progress toward the SLOs. **This in turn requires a new organization of science** based upon the interactions of genetics, environment (including a changing environment) and management (done by and for people) with the most relevant institutional context.[1] Rather than blurring approaches, more attention is needed on how these interactions play out differently across spatial and temporal scales.

- **The CGIAR needs to play to its comparative advantages and those of its partners to meet its aspirations:** There are comparative advantages that can allow the CGIAR Consortium to play a global leadership role in addressing the major problems facing the agriculture–environment nexus:
  - The CGIAR Consortium has an *international* status and works to produce international public goods in the form of learning and the knowledge that lead to impacts.
  - It has scientists spread over the globe working in most of the major agro-ecological systems and grounded in the realities of developing countries.
  - Its scientists span a large continuum of expertise and thematic activities, in particular crop and agricultural product improvement, NRM and socioeconomic research, and this offers a unique opportunity for innovation across this continuum.
  - It has strong links with scientists working in diverse research and academic institutions – in both developing and developed countries – and is in a position to mobilize efforts that go far beyond its own staff through networks and partnerships.
  - The CGIAR Consortium has well-established financial systems that qualify it to operate large, complex research endeavors involving multiple partners in both public and private sectors.

However, although the CGIAR is charged with a major global responsibility in supporting international agricultural research, its total global budget approximates that of a medium-sized university in a developed country. **Therefore, what role can the CGIAR Consortium adopt for the System to become more than the sum of its parts?** This is a general question, but it is even more relevant to the NRM field because of the complexity of the issues to be addressed. It is important therefore to see clearly what the System should focus on, in terms of content, orientation and in how it relates to global scientific communities.

The Panel believes that the orientation of the CGIAR and the interface of its research portfolio should be to:

- Formulate and address emerging global concerns about NRM as they influence agricultural systems in developing countries, e.g. competing claims on natural resources and the issue of land sharing versus land sparing.

1 The term 'Institution' is used in the broadest sense of the word – often described in terms of efforts to 'reduce uncertainty in human interactions'. The term covers both the formal and informal 'rules of the game'. Policy and organizational structures are part of this broader notion of institutions. Institutions are the constraints that human beings impose on human interaction. They consist of formal rules (constitutions, statute law, common law and regulations) and informal constraints (conventions, cultural norms and self-enforced codes of conduct) and their enforcement characteristics. Those constraints, together with the standard constraints of economics, define the opportunity set in the economy. http://129.3.20.41/eps/eh/papers/9309/9309001.pdf

- Aim to achieve food security without the need for converting land currently in natural ecosystems, in tandem with substantial increases in water and nutrient use efficiencies, and with reduced negative environmental externalities.
- Address **inter-scaling** (and not only scaling up and out) **as a priority methodological challenge** that aims to provide a better understanding of impact pathways (e.g. Green Revolution technologies and fertilizer or land use impacts); addressing tradeoffs from one scale to the other (farm to landscape and back, trans-sectoral policy impacts, etc.); addressing gaps between local knowledge and global public good and providing an 'enabling environment' for interdisciplinary research that can support the GxExM^I concept.
- Develop **comparisons and learning processes**: Taking advantage of multi-site research outputs, networking, common methods and metrics, geospatial analyses and remote sensing, crop and ecosystem simulation models, and conducting syntheses or meta studies.

To promote and sustain a global effort, each **CRP needs strong intellectual leadership**. The CRPs must convene and provide coherence to large research endeavors. They need to put in place mechanisms for collaboration and networking, to bring together CGIAR Centers with universities, national agricultural research and extension systems (NARES), non-governmental organizations and other partners contributing to evaluation and management of environmental services at the nexus with agriculture and across scales. The CGIAR has a global presence and role, but it can only exercise its advantages by exploiting the strengths of others. This requires awareness and recognition of the strengths of other science and development providers. The success of such a posture relies on strategic leadership and sound management, and to inspire innovation and pursue learning processes. It depends on acquired legitimacy and a management culture that stresses complementarity rather than competition. In countries where the NARES are weak, particularly in integrated research capacity, the CGIAR should reclaim its former role of capacity building and training through active research collaboration with NARES and other organizations.

While the concept of the CRPs in the new CGIAR sets out the direction, many challenges to developing and implementing the CRPs – and the CRP portfolio as a whole – remain. These challenges are explored in later sections of this report. The NRM research Stripe Review Panel believes that the opportunities to match the vision with practice will depend on the following nine issues:

1. **A major scientific challenge for NRM research is to address the integrated nature of biological and landscape systems:** The concept of **multifunctionality** is contentious, but we use it here to recognize that NRM research encompasses diverse stakeholders and institutions, and multiple scales across which biophysical and human processes interact. **The development of crosscutting methodologies that address systems and scale interrelationships is a researchable constraint that should be afforded more targeted attention across the CGIAR.** The NRM-focused CRPs should collaborate in the development of 'systems'-based research frameworks, which recognize that functions are expressed in different ways at different scales. Up-scaling and down-scaling are non-linear; there are complex interdependencies, tradeoffs and feedbacks between and within scales. Factors that lie outside the normal realm of NRM research can have large impacts on system outcomes. Livelihoods themselves are diverse and dynamic, and short-term goals might be very different to long-term aspirations. The elaboration of impact pathways helps to conceptualize these challenges and focus research on the key issues. Yet the methodologies to address such issues (e.g. scaling, but also the coupling of economic, social and biophysical models) are not yet widely used in the CGIAR. Advances in up-scaling and down-scaling methodologies, and integration of modeling platforms would have crosscutting benefits across a wide range of research objectives, and would enhance the contribution of NRM research and evaluation of its impact.

2. **It is important to define the role of CGIAR research with respect to global environmental values. The Panel proposes that the principal role of the CGIAR is to understand how agricultural systems that can meet current and future human needs for food, fiber and fuel can be managed to minimize consumption and disturbance of ecosystem services, or even to enhance their availability.** The CGIAR's role is to work on NRM issues that have direct links to the alleviation of poverty and improved livelihoods in developing countries. A critical comparative advantage is the research on sustainable intensification, whereby environmental impacts of agricultural systems that strive for substantially greater levels of food output are understood and predicted to help guide research prioritization and policies. There are direct interactions between poor rural communities and the local natural resources they use – and on which the sustainability of their agricultural systems depend. There are also global influences that impinge on local systems and affect those communities. Changes in local natural resource use can in turn influence global values.
3. **New science for new opportunities – capturing emerging technologies:** New scientific and technological developments in plant physiology, materials science, remote sensing, and information and communication technologies are emerging from sectors that lie outside the usual agricultural and environment sphere. These provide opportunities to integrate natural resource concerns into the agricultural research agenda. Some of these new technologies are well developed but have yet to be adapted and applied to pro-poor contexts, while others still require considerable research investment. Ignoring such technologies might limit what is achieved by the CGIAR in the longer term. The scientific leadership of CRPs will need to stay abreast of emerging technologies and (through consortia of practice with other CRPs and their partners) seek to explore the potential application of these emerging applications within NRM and poverty contexts. This requires openness and flexible funding opportunities to develop new partnerships with academics and the private sector, as well as somewhat broader interpretations of the boundaries of CGIAR-based NRM research.
4. **In the development of CRPs over the next several years (as well as future horizons for their review and adjustment by the Consortium) emphasis should be given to clarifying the comparative advantages of the CGIAR and its partners to achieve complementary balances and responsibilities for NRM research and development activities.** The CGIAR might not be able to compete with universities or the private sector in some areas of emerging science, but it does have comparative advantages in exploring how new science and emerging technologies might be adapted to underpin pro-poor NRM challenges that are intimately linked to agriculture. Past CGIAR research activities have demonstrated the potential to catalyze new private enterprise initiatives although mostly for collaborative work in crop germplasm improvement, rather than for NRM. The CGIAR could be an effective bridge through which new scientific developments of all types arising in developed countries could meet the needs of developing countries.
5. **New approaches to the organization of consortia to address problems in an integrated manner:** The CGIAR has been edging toward the integration of its approaches with NRM; its ability to benefit from broader scientific partnerships is evident in earlier ecoregional approaches (including the Rice–Wheat Consortium and Alternatives to Slash and Burn) and the Challenge Programs that adressed NRM issues. New paradigms for integrated agricultural research for development (IAR4D) are being tested (e.g. through the Sub-Saharan African Challenge Program), and this will be relevant to the new CRPs. The CRP for Climate Change, Agriculture and Food Systems (CCAFS) embraces a new model for research implicit in the change process, with clear roles for a wide range of

partners including advanced research institutes (ARIs), NARES and **boundary organizations**. Other CRPs appear to revert more to traditional CGIAR research models and run the risk of not embracing the new culture of research for development, or of being able to make the social science links required for impact. No clear and unified model has yet emerged as to how the CRPs will be organized into effective and manageable research teams working on specific issues. Indeed, there may be different options for different subject matters and partner strengths. There will be a need for nested sets of scientific teams within the CRPs, with the autonomy needed to pursue their goals while contributing effectively to the 'Grand Challenge' that drives the CRPs. The CRPs will need to achieve global coherence while practicing subsidiarity, so as to reduce their transaction costs and free up their scientists to get on with their jobs.

6. **Improving monitoring, evaluation and impact assessment to value NRM research:** There is a paradox that must be addressed at the heart of the debate over NRM research. **Effective NRM is increasingly important to the attainment of the global goals for agriculture and sustainable development yet the evidence that the contributions of NRM research have had impacts at scale is patchy at best.** Impacts of the CGIAR's NRM research in the past, particularly enhanced agronomic practices, have been measured indirectly and incompletely through the adoption of, and improved yields from, new crop varieties. The lack of time series data for an array of indicators of system state and change and adoption has made it difficult to make the case for NRM research. This has been exacerbated by the perception that impacts from NRM research are intrinsically more difficult to measure or are 'more local' in scope. **The NRM community cannot opt out of the need for monitoring, evaluation and impact assessment on the grounds of complexity. It is necessary and legitimate to pursue research (in the CGIAR and working with international expertise) to develop new methods for research impact assessment that recognize the contribution of NRM research.** Impact assessment paradigms based simply on extension of approaches used for crop germplasm improvement will be insufficient. The NRM community needs to respond to this methodological challenge for impact assessment and to develop a culture where monitoring and evaluation are a central part of the research programs. **It will be necessary to plan impact measurement at the time of program design and it is understood that an *ex-ante* assessment of a 5-year-plus program should be treated as the best possible hypothesis at the time the program begins.**
7. **The need to invest in strategic leadership for NRM:** The CRPs present a radical new approach to science within the CGIAR. To allow the CRPs to realize their goals, a long-term vision and strong strategic leadership in this and crosscutting fields is required. **'Thought leadership' on both science and the pathways to impact from integrated NRM approaches need to be central to both CRP management and CRP advisory scientific bodies. A culture of openness to allow for partner input and innovation must be developed.** The CRP leaders must be vested with the leadership of the teams comprising staff from different CGIAR Centers and other partners and with the authority to drive them forward.
8. **Invest in hard and soft infrastructure:** Some areas of activity need to be strengthened to allow the CRPs to deliver against the ambitious goals the CGIAR has fixed for itself in the Strategy and Results Framework. Greater investment is needed in both soft and hard infrastructure. It will be necessary to invest in people. It will include setting up and managing eco-regional, benchmark, hub or sentinel sites and collecting, storing and analyzing an array of data over long time periods. Establishment of long-term data infrastructure will include retrieval and management of legacy data – traditionally a weak point in CGIAR research. This will help ensure meta-analysis through cross-site and cross-CRP comparison, and lead to the production

of international public goods. Consortium leadership will be required to manage this 'above the CRPs' and at the system level. Further, despite these issues being highlighted by earlier reviews, critical and analytical social science still needs further strengthening. **The CGIAR needs to appoint social scientists** who can steer research on complex rural livelihoods and institutions at all levels. Investment is needed in **establishing long-term monitoring and evaluation systems to benchmark and measure change. Monitoring also has to provide the key role of learning** from successes and obstacles as they are encountered and overcome.

9. **Donor commitment and discipline is needed to reap the rewards of changes in the CGIAR System, especially as it underpins NRM research.** Time and effort has been invested in restructuring the CGIAR and in the establishment and initiation of the CRPs. Donors were an important trigger – and remain a critical component – of this continuing reform. Now that the process of consultation and preparation is giving its first fruits, it is important that donors retain their commitment in order to achieve the development aims that have been agreed in the Strategy and Results Framework. Further refinement of the CRPs will occur as these global programs evolve, but if reflexive monitoring and evaluation systems are in place, the CRPs will continually learn and adapt to new challenges. **There is a mutual responsibility for the researchers to perform, and donors to sustain the work of the CRPs in the years to come;** there is thus a shared responsibility for the conduct of the NRM programs set in train by System restructuring.

CHAPTER 1. Introduction

Humanity is now facing the urgent challenge of feeding a potential 9 billion people while minimizing environmental harm – and allowing future generations to prosper. The challenge for agricultural research is also changing and becoming more nuanced as farmers are forced to deal with increased climate variability, among many other factors. The world needs a 21st Century Green Revolution, which will demand a new understanding of how rural development occurs, as well as a far more resource- and input-efficient agricultural system. New methodologies and approaches will be essential to ensure that increasing food production will not occur at great cost to the environment. The 'external' scientific world is gearing up to respond to this challenge. After 50 years of discovery and delivery towards global public good, the CGIAR also finds itself in a time of great challenge and transition. Its recently developed Strategy and Results Framework (SRF) and new CGIAR Research Programs (CRPs) are designed to simultaneously address productivity, poverty and environmental sustainability.

Natural resources management (NRM) research is certainly not a new field for the CGIAR; the importance of the conservation and sustainable management of natural resources has been recognized as a central concept since the late 1970s. However, NRM has meant different things to different people. As such, the focus of the CGIAR's involvement in the gamut of NRM research has drifted over time. The CGIAR portfolio of research evolved from a narrow focus on crop genetic improvement in the 1960s to its present scope, which encompasses a wide range of NRM issues. Initially, NRM work supported productivity – for example, CIMMYT's work on legume–cereal systems, ICRISAT's work on broad-bed furrow systems, IITA's work on alley cropping. In the 1980s and early 1990s these approaches were enhanced by the creation (or adoption into the System) of Centers with specific mandates for NRM. The concepts of agroecology and the ecosystem approach were also adopted until, by the 1980s, NRM research comprised roughly one-third of total CGIAR funding, not counting biodiversity and NRM policy research.

In the late 1990s, a CGIAR task force was formed to promote the integration of the several elements and approaches of natural resources research being undertaken across the System, and to consider how they might be applied to an integrated NRM (INRM). This task force was organized to share knowledge across the CGIAR System, bringing together Center scientists to work out approaches and methodologies for effective INRM. The task force produced three books and a number of papers on NRM research issues.[2] However, it failed to defuse issues concerning the continuing uncertainty about the CGIAR's comparative advantage in NRM, how to institutionalize an NRM research framework, and how to best measure impact. By recognizing the close link between agricultural productivity and environmental health and conservation, the CGIAR System is now accepting – at least in principle – that the prevailing dichotomy between the two was unfortunate. NRM, in fact, is not an alternative to commodity research. As this report argues, it provides a context and enables the impact of CGIAR research to be expressed over the long term. These concepts were already put forward by Uma Lele, who stated that, "improved resources management is, in most cases and over the longer term, a complement to development of improved germplasm" (2003: page 99) and by Alain de Janvry, who affirmed, "to convert improvements in genetic productivity into biological output requires the complementary enabling INRM production factor inputs and practices".[3]

2 E.g. INRM workshop I, Bilderberg, Netherlands, September 1999; INRM II, Penang, Malaysia, August 2002; INRM III, Cali, Colombia, August 2001; and INRM IV, Aleppo, Syria, September 2002.

3 In CGIAR interim Science Council and Center Directors Committee on Integrated Natural Resources Management (2003) *Research Towards Integrated Natural Resources Management - Examples of Research Problems, Approaches and Partnerships in Action in the CGIAR*. Harwood R.R. and Kassam A.H. (Eds). FAO, Rome.

The SRF describes these changes and provides a rationale for an emerging focus on INRM as a major component of the research portfolio (see Box 1.1). The sustainable management of natural resources is now explicitly included among the system-level outcomes (SLOs), which are: (i) reducing rural poverty; (ii) improving food security; (iii) improving nutrition and health; and (iv) sustainable management of natural resources. As described in the SRF: "*Agriculture demands better management of natural resources to ensure both sustainable food production and provision of ecosystem services to the poor, particularly in light of climate change*" (CGIAR, 2011).

Box 1.1. The CGIAR approach to integrated natural resource management

"Moreover, the problem structure of NRM is usually framed in terms of operation at different scales from production systems to communities to landscapes/watersheds to national policy frameworks and to global conventions. Sustainable management of natural resources such as water, forestry, grasslands, capture fisheries, and biodiversity has been framed within this hierarchy of interacting scales. This has facilitated the transition of NRM research into the areas of mitigation of climate change and the provision of ecosystem services. These are quite different objectives, and this difference hinders the specification of a clear development outcome around which to align NRM research within the CGIAR System, which would possibly be most clearly defined in terms of the intersection between productivity and ecosystem services. However, different objectives require quite different alignment of research activities and imply different accountability frameworks, as, for example, with the interacting roles of tropical forests, livestock, and land degradation in climate change mitigation."

Source: CGIAR (2011).

See Annex 5 for the complete Strategy and Results Framework text related to NRM.

These are important guidelines for the new CGIAR. Without clear considerations of what the System as a whole is trying to achieve from research categorized under the umbrella of NRM, it will be difficult to judge success or to apply successes to the wider aims of providing international public goods and contributing to global R&D. We still face a crucial paradox: on the one hand, the external reviews of the CGIAR and the more recent reform process and CRPs[4] consistently identify the need to invest more heavily in research on natural resource systems; on the other, there is little evidence of any widespread impacts of this research. A few assessments of CGIAR NRM research[5] have already been undertaken, reporting modest successes (mostly impacts at local level). Also, important influences have been demonstrated, but the assessments continue to voice uncertainty as to their large-scale impacts (Waibel and Zilberman, 2007). The identification of the most appropriate approaches to measure the impact of NRM research – especially considering that sustainable management of natural resources is one of the four SLOs – is one of the fundamental challenges for the CGIAR identified in this report.

The NRM research Stripe Review and this report

At this crucial time, therefore, the System needs to learn from its own research experience, as well as from cutting-edge international research from outside the System, and then lay out the strategic elements and priorities for an effective NRM research agenda within and across the CRP portfolio. With these considerations in mind, the CGIAR Independent Science and Partnership Council (ISPC), as

4 NRM research is embedded in most CRPs; special references are made in CRP 1.1, 1.3, 5, 6 and 7.

5 Barrett (2003); ICRISAT (2005); CGIAR Science Council (2006, 2009); Waibel and Zilberman (2007).

part of its mandated area on foresight and the provision of advice on the development of the future portfolio of CGIAR research, launched a study titled 'Natural resource management: challenges and way forward for the new CGIAR – A Stripe Review'. The *Stripe Review of NRM Research in the CGIAR* was inspired by the success of the 'Stripe Review of Social Science in the CGIAR' (CGIAR Science Council, 2009) and the important findings of the environmental impacts study undertaken by the Standing Panel on Impact Assessments (SPIA) (CGIAR ISPC, 2011). The concept of the *Stripe Review of NRM Research in the CGIAR* and its methodology are reported in more detail in Annex 1 and on the ISPC website.[6]

The report focuses on:

- the importance of NRM research within and around agriculture, amplified in an era of increasing population, diminishing resources and climate change
- past structures and frameworks of NRM research in the CGIAR, comparative advantage, the need to have impact at scale, including considerations of results from Centers' bibliometrics (see Annex 6)
- a potential new paradigm for research related to agriculture and a potentially new role for NRM research in the CGIAR
- the paradox in NRM research impact (i.e. the methodological challenge of measuring impact and the related need to pursue research on new methods in this field)
- emerging research approaches in light of the new 'sustainability science' concept
- operational and organizational issues of research, with suggestions for the Consortium leadership, CRP and Center management, and Donors.

While several key messages are highlighted in the report, they all underpin two main considerations:

1. the close linkage between agricultural productivity and environmental health, and thus the need to remove the barriers between NRM and crop genetic improvement
2. the need to move from the existing paradigm of NRM research to more appropriate methodologies, including those for impact assessment of NRM research in agriculture.

6 http://www.sciencecouncil.cgiar.org/sections/strategy-trends/en/ (accessed August 2012).

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CHAPTER 2.
Global challenges and the continuing importance of NRM research

After 50 years of discovery supporting the global public good, the CGIAR finds itself in a time of great challenge and transition. The global challenges of sustainable agriculture, food security, climate change, rural development and poverty alleviation are being seen as both inextricably linked and urgently in need of global solutions.

No consideration of NRM challenges and opportunities is possible without acknowledgement of agriculture's primary role in the provision of food. A reassessment of the security of global food supply is currently underway, stimulated in part by the food price peaks in 2007/08 and 2010/11 (FAO et al., 2011), but also by forward-looking analyses of food demand and supply trajectories.[7] Looking back 50 years, we see the success story of the Green Revolution. The world population grew by 117% from 1961 to 2008, and world food production (expressed in the conventional unit of calories) grew by 179% over this same period (see Figure 2.1a), largely from higher yields alongside relatively small increases in cultivated land area (Figure 2.1b).

Despite this impressive achievement, hunger and malnutrition have not been eliminated, and the recent food price spikes (since 2007) have reversed some of the earlier progress.

FAO (2009) estimated that there will be a 70% increase in food demand between 2000 and 2050. This assumes that prospects for demand will follow current trends. Yet, estimates of additional food demand by 2050 are very sensitive to several factors, including: assumptions around global population growth; shifts in consumption patterns driven largely by increased demand for animal protein in developing countries' diets; prospects to reduce levels of food waste along food chains; and the organization of exchanges and supply at the global level. In the Agrimonde scenarios developed by CIRAD and INRA, the increased food demand by 2050 relative to 2003 ranged from 30% to 85%, depending on these factors. One conclusion from this work is that only modest growth in food production would be needed over the next 40 years if waste could be significantly reduced. This would require developing country populations to not follow the dietary pathways of the developed world, particularly with respect to increased consumption of animal-based protein. While such trajectories of reduced demand would place less pressure on the natural resources, their feasibility remains uncertain.

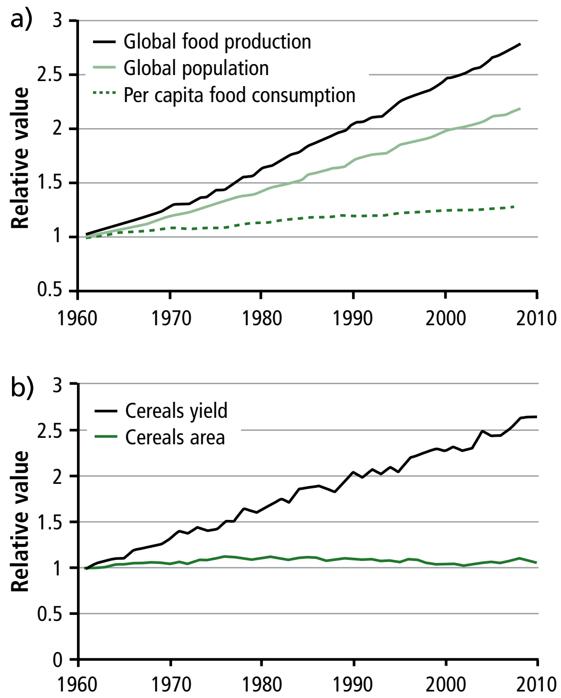

Figure 2.1. Global agricultural performance metrics (FAOSTAT, 2011): (a) Food production, population and per capita food available (b) Relative changes in cereal yields and areas harvested. (From Keating et al., in press.)

Keating and Carberry (2010) projected food demand to 2050 and estimated increases in

7 See for instance World Bank (2008); Chaumet et al. (2009); IAASTD (2009); Nelson et al. (2010); The Royal Society (2009); Hubert et al. (2010); Godfray et al. (2011); Keating and Carberry (2010); Foresight (2011); Schneider et al. (2011).

the order of 14–81%. The variation is dependent on assumptions made in relation to population growth, consumption increases, food wastage along the value chain, and diversion of arable land from food crops to biofuels (Figure 2.2). The most likely trajectories of food demand, based on current estimates of population and diet shifts, project increases of 64% to 81%. In terms of pressure on natural resources, these percentage changes are potentially misleading; that is, comparing the 179% increase in food produced (in calorific terms) between 1961 and 2008 (Figure 2.1a) with the projected demand increase of 64 to 81% from 2010 to 2050 (Figure 2.2). Modeling absolute calories of food that need to be produced for the same scenario translates to an additional 6.3 Exacal/year (Exacal=10^{18} calories) required in 2050 compared to 2010. The equivalent comparison between 2010 and 1970 was an increase of 5.0 Exacal/year in 2010.

The pressures on natural resources (land, water, atmosphere, nutrients, energy and biota) are more aligned to the absolute quantity of food that needs to be produced, so the pressures on resources in the future will be higher than they have ever been. The figures quoted above are global averages and they hide important regional differences. In many regions, food production has kept ahead of population growth by raising inputs (typically 3–5-fold) and raising yields (typically 2–3-fold) on the same land footprint. Sub-Saharan Africa is the exception: food production has barely kept up with population growth. The major force which has driven the increases that have been achieved is the increase in land area devoted to agriculture. The population of sub-Saharan Africa is likely to double between 2010 and 2050 (United Nations figures for 2006 as reported in UN 2010) against the backdrop of the lowest per capita food production of any region (Figure 2.3) and high rates of undernourishment (Von Grebmer et al., 2011). When considered as a whole, these data suggest that sub-Saharan Africa needs to aspire to more than a doubling of food production if it is not to become a bigger net importer of food than it is currently. This is not going to be possible without close attention to resource constraints.

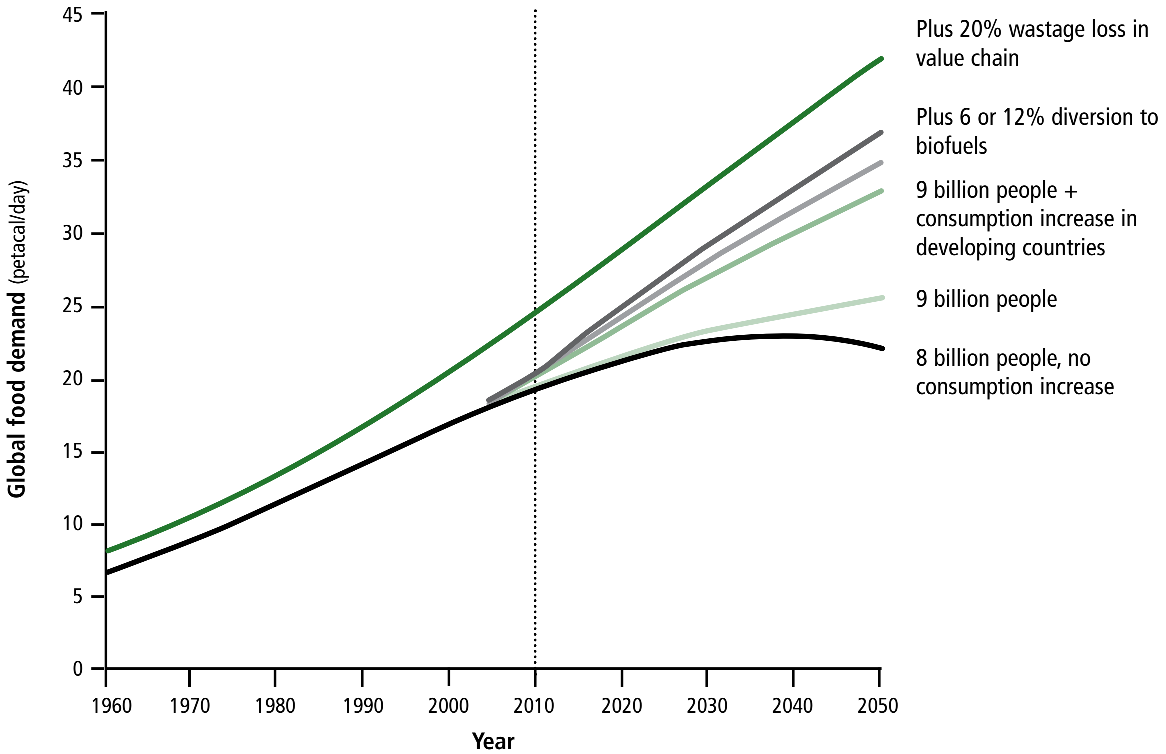

Figure 2.2. Modeled trajectories of global food demand (in Petacalories per day) from 1960 to 2050. (Adapted from Keating and Carberry, 2010.)

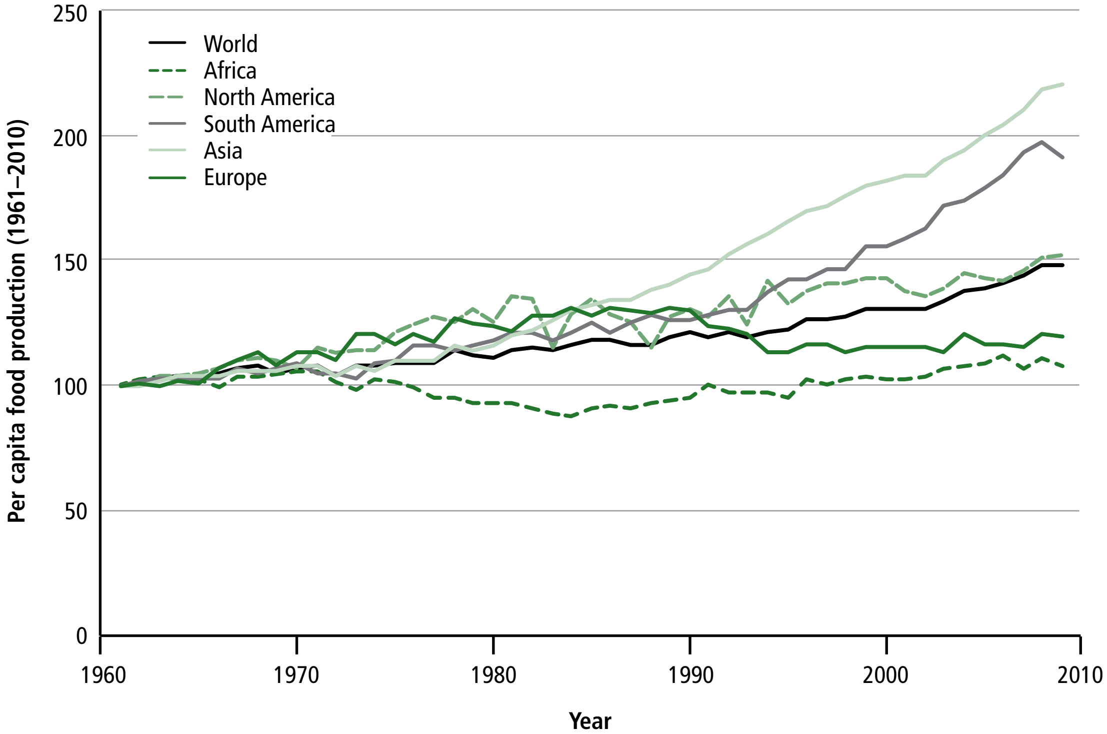

Figure 2.3. Trends in per capita agricultural production for different regions of the world, 1961–2010. (From Keating et al., in press; data from FAOSTAT, 2011.)

The global food production challenge outlined above has particular characteristics that confer greater significance to NRM issues than has been the case in the past. Key issues in this challenge include:

Unsustainable intensification practices deployed to date: While increases in input use have been fundamental to achieving the yield gains of the past 40 years, there is evidence that they are being used in excess or inefficiently in some regions and systems. For example, excess nitrogen fertilizer inputs in Chinese cereal production systems (Liu and Diamond, 2005; Ju et al., 2009) are well documented with nitrogen use efficiencies (NUEs) less than 20 kg grain per kg N applied (Zhu and Chen, 2002; Ju et al., 2009). The equivalent NUE for US corn is now in excess of 50 kg grain per kg N fertilizer applied (Cassman et al., 2002). These excess inputs are acidifying soil profiles, contaminating groundwater and rivers, and releasing greenhouse gases (GHGs) into the atmosphere. We point to this example because its scale confers global significance. Other cases of unsustainable intensification exist in both industrial and developing countries, and concern overuse of agro-chemicals, land degradation through acidification, or biodiversity loss.

Availability of new land resources is increasingly constrained: The area of land cultivated globally is now estimated at around 1.4 billion ha – or 11% of the earth's surface (Smith et al., 2010). Estimates for land used for food production rise to around 34%, including crop and pasture land (Godfray et al., 2011). The total area of agricultural land has increased from just under 4.5 billion ha in 1961 to just over 4.9 billion ha in 2007 (FAOSTAT, 2009). The potential for further cropland expansion has been estimated at between 6% and 30% (Smith et al., 2010). However, given the loss of land through urbanization, potential losses through climate change, and pressure to reduce GHG emissions associated with conversion of land to cropping, the amount of expansion likely to occur between now and 2050 is closer to 10% than 30%. Climate change remains a big unknown in this estimate – some cultivated land is likely to be lost to arable agriculture but large areas in higher latitudes may become arable due to longer growing seasons. See, for instance, the analysis of Zhu et al. (2011) on the extension of growing seasons.

New water resources and water availability are constrained: According to the Comprehensive Assessment of Water Management in Agriculture (CAWMA, 2007), the areas of irrigated agricultural land increased from around 160 Mha in 1960 to close to 300 Mha in 2005, but rates of expansion of irrigation have fallen away since 2000. There is considerable doubt over the prospects for implementing new irrigation developments sufficient to drive the necessary expansion of food production between now and 2050. The Assessment (CAWMA, 2007) has suggested that the greatest opportunity lies in improving agricultural productivity in existing irrigated areas, with only limited scope to expand areas of irrigation, except perhaps in sub-Saharan Africa. Any resource degradation in irrigation systems or on irrigated lands will further limit its ability to meet the projected food demand. Similarly, any negative climate change impacts on the quantity or reliability of irrigation supplies will have a large impact on food security.

The need to limit greenhouse gas emissions from agriculture: Agriculture, including fertilizer production, directly contributes 10–12% of GHG emissions; and this figure rises to 30% or more when land conversion and costs beyond the farm gate are added (Smith et al., 2007). The consensus of climate science is that global GHG emissions need to be reduced by something in the order of 80% by 2050 if dangerous (i.e. greater than 4°C) climate change is to be avoided. This mitigation challenge is an enormous one for agriculture. There are currently few options to reduce direct GHG emissions without reducing food production. Modest gains are likely to be achieved through improving efficiency in fertilizer use and livestock production. However, barring a major technological breakthrough, such efforts are more likely to achieve a 20% reduction in GHG intensity – not the 80% needed to maintain the global atmosphere. Under these circumstances, it is critical that emissions from land clearing cease and that productivity gains on existing land provide for food security. These gains must also be 'eco-efficient' (Keating et al., 2010) in terms of food output per unit input and GHG emissions per unit food.

The land is an increasingly attractive sink for carbon bio-sequestration: Given the scale of the greenhouse mitigation challenge across all sectors, not just agriculture, it is not surprising that land-based carbon bio-sequestration is being looked to as a short-term opportunity to slow the rise in atmospheric GHG levels and 'buy time' until other technological solutions are found, particularly in the energy sector. The key carbon sinks being examined are forest-based or soil-based. The establishment of forest-based carbon sinks on current agricultural land will make achieving the increases in food production required by 2050 that much harder. This prospect is controversial and the extent to which carbon forests could be competitive or complementary to existing agricultural activities remains unclear.

The second bio-sequestration target is via soil carbon stored in soil organic matter (Lal, 2007; Murray et al., 2007) or possibly biochar (Lehmann et al., 2006). Very significant quantities of the global carbon stocks that are found in soils and soil carbon levels in many agricultural systems have been depleted. Higher soil organic matter levels would deliver co-benefits in terms of soil physical, chemical and biological properties – so there are 'win–wins' here. However, the challenge is to find economically attractive farming practices that maximize soil carbon storage. Similarly, the economics of biochar as a source of stable carbon in soils and a soil ameliorant is far from certain.

Soil carbon offset incentives should not be ruled out entirely. While there are many practical obstacles, it is not going to be possible to raise agricultural productivity in sub-Saharan Africa without also raising soil organic matter (soil carbon) levels, given the current widespread limits in soil fertility and nutrient supply. The global atmosphere would benefit from storing additional carbon in Africa's soils. If this could be achieved securely, then there may be some logic in having the industrialized economies create incentives for African countries to build up carbon in their soils (Henry et al., 2009). However, this carbon offset would only exist until a new equilibrium level is reached in soil organic matter. Enhanced agricultural productivity and food security would be an additional co-benefit.

Already established climate change is generating additional pressures and great uncertainties: While there is logic in doing everything possible to reduce GHG emissions to avoid the prospect of dangerous climate change, some climate change is inevitable and in fact has already started. Estimates of the likely impacts of 2°C of climate change on food security vary. There are some studies which suggest yield reductions in the order of 10–20% in some regions, while others indicate that yields might increase in some situations (Easterling et al., 2007). Perhaps the greatest effect at the present time is the increased level of uncertainty that climate change generates in any future-looking analysis or investment.

Complex pathways in the tradeoffs between food demand and supply pathways: Changes in the food demand trajectories will also significantly influence the pressures on the expansion of land used for agriculture. However, these pressures are complex and at this stage there is no clear pathway forward that is firmly established and widely accepted. For example, the Agrimonde scenarios provide some insight into the complex tradeoffs between alternative trajectories of food demand and supply, and what these might mean in terms of the demand for increasing agricultural productivity on existing land; shifts in land use from livestock production to grain production – also within the existing agricultural land footprint; and pressures to expand agriculture onto new land, potentially forest or savannah. The Agrimonde 'global orchestration' scenario, adapted from the trend scenario of the Millennium Ecosystem Assessment (2005), is based on the following hypothesis: if food crop yields per hectare grow by more than 1% per year (increasing yields in 2050 by 45%) and if no major shifts occur in consumption patterns, an increase of arable land by 18% would be required. An alternative scenario, Agrimonde 1, adapted from Griffon (2006), based on average world and regional consumptions of 3,000 kcal/inhabitant/day (as opposed to current trends towards 3,600) and on a yield increase limited to 5.5% in 40 years, requires an increase of arable land of about 40% (Chaumet et al., 2009). However, in contrast to the 'global orchestration' scenario, the increase would occur by converting grazing lands and pastures into cropped areas. The encroachment on grazing lands, and not on forests, means that the total area under production would not increase. Effects of production on biodiversity and more broadly on the environment are of a different nature, whether one looks at the encroachment on forests or at the increase of productivity in areas of ordinary nature. It is certain, however, that the spatial worldwide organization of production will affect the environment in different ways, such as consumption and increasing scarcity of fossil fuel, biodiversity conservation or loss, GHG emissions and carbon sequestration, pollution and related damages from the use of large quantities of agricultural inputs. These are interconnected issues and cannot be addressed in isolation; they will be strongly affected by the model of agricultural transformation that will be pursued at the global level, and by its local manifestations.

The relationship between NRM research and the CGIAR's approach to agricultural research

NRM research is not tightly defined in scope. For some, it is focused on the use of natural resources *within* agriculture, while for others it is more broadly focused on the environment *around* agriculture. Both lenses are important and are duly considered in the scope of this report. NRM cannot be considered without reference to social, economic and institutional constraints and opportunities. All landscapes are ultimately ecosystems subject to various degrees of human intervention and management. Agriculture is a socio-ecological system with a spatial imprint extending from component technologies deployed in fields and farms, located in and connected into landscapes, regions and ultimately global systems. The temporal dimension of agriculture extends from day-to-day decision-making right through to the evolving state of natural resources that unfold over millennia.

Genetic improvement versus NRM research: Various authors have tried to attribute improvements in agricultural yields and productivity separately to genetic or management advances. One of the best-known case studies relates to wheat productivity in the Yaqui Valley in Mexico, a region with a long-term record of wheat yields achieved both on-farm (Figure 2.4) and in various research trials involving genetic and agronomic factors. Originally reported in the 1970s (Fisher and Wall, 1976), it has been revisited over the last 35 years (Bell et al., 1995; Fisher et al., 1998; Nally and Barkley, 2007; Sayre et al., 2008; Fisher and Edmeades, 2010, and many others).

Bell et al. (1995) focused on the 1968–1990 period of the data shown in Figure 2.4 (commencing near the initiation of the semi-dwarf cultivar phase). They concluded that, during this 22-year period, 28% of the weather-adjusted yield gain was attributed to genetic gains (0.5% yield increase per year), 48% was attributed to improved crop management, mainly increased application of N fertilizer (0.86% yield increase per year) and the remaining 24% could not be explained (0.43% yield increase per year). Sayre et al. (2008) suggest that some of this 'unexplained' category could be associated with an accelerated rate of farmer adoption of conventional tilled, raised-bed planting systems with furrow irrigation, replacing conventional tilled, solid-stand flat planting with flood irrigation over this time period.

A different approach with a greater focus on current agricultural development options involves experimental comparison of a set of varietal and management options, first separately and then in combination, under real-world farmer conditions. In situations where overall productivity levels are low, such as in many parts of sub-Saharan Africa, there are generally only modest gains being made with these interventions in isolation and a very significant positive interaction when they are used together. Figure 2.5 illustrates this point via on-farm trial data gathered by ICRISAT staff in Zimbabwe.

The dominance of the genetic improvement focus in the CGIAR is illustrated by the meta-analysis of the recent publication of 40 findings on the impact of the CGIAR from 1971 to 2011. It was possible to ascribe a research area to 30 of the 40 impact statements reported by the CGIAR (2011). Fifty-seven percent of these assigned impacts related directly to germplasm improvement, release and adoption (Figure 2.6). In contrast, 20% were associated with either management-related findings or management x genotype interactions. A further 20% related to findings where the impact was via enhanced institutional arrangements. Interestingly, only one of the 40 impact statements dealt with a technology other than germplasm-based ones.

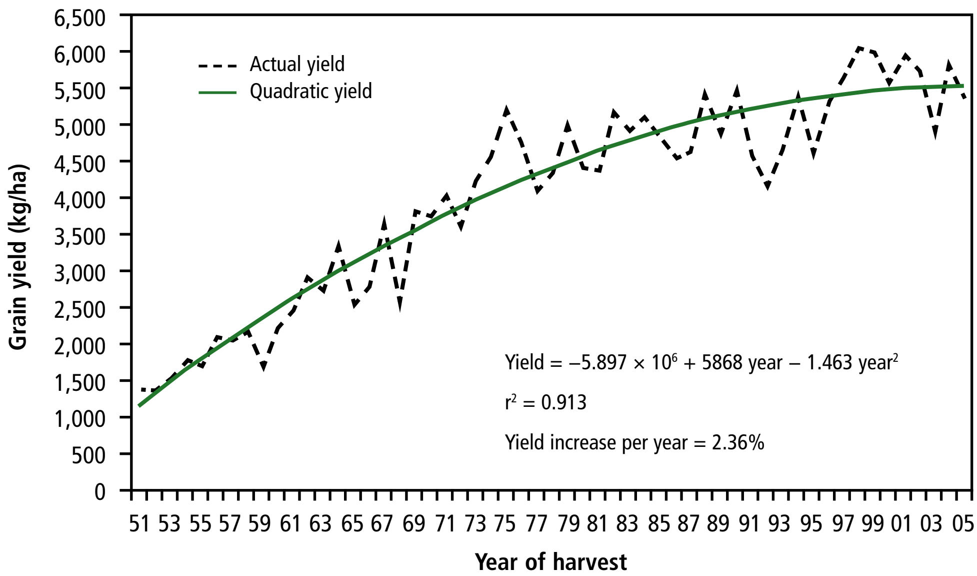

Figure 2.4. Wheat yield trend in farmer fields from 1951 to 2005 in the Yaqui Valley, Mexico. (Reproduced from Sayre et al., 2008.)

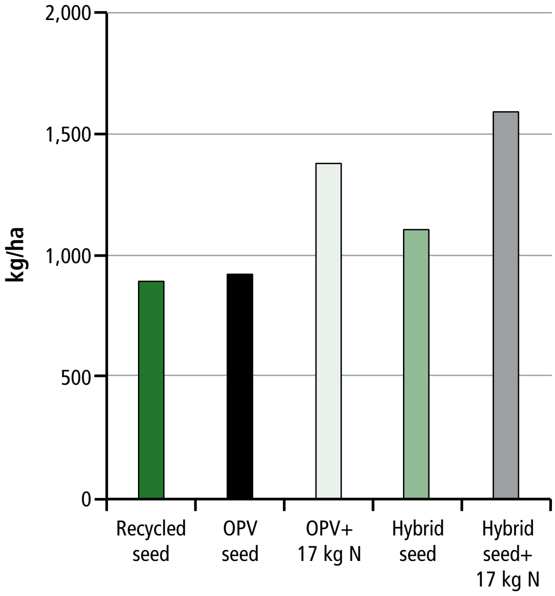

Figure 2.5. Maize yields obtained from individual and combined treatments of improved varieties and micro-doses of N fertilizer (17 kg N/ha) averaged from farmers' fields in Zimbabwe during the 2003/04 season (Twomlow and Rohrbach, 2006).

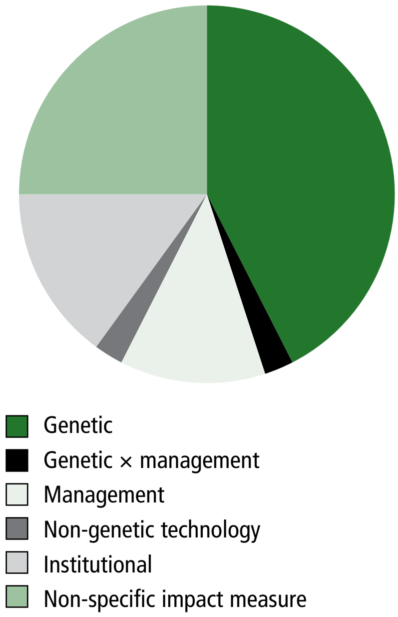

Figure 2.6. A breakdown of the 40 high-impact achievements of the CGIAR, 1971–2011. (CGIAR, 2011.)

The dominance of the genetic technologies in the CGIAR's sense of its achievements is further illustrated in a report produced on 'best bets' for Africa (Alliance of CGIAR, 2008). Of the 55 best bets proposed, 29 were solely focused on new varieties with claims of particular attributes. A further 11 proposed some mix of management and varietal intervention, and 15 were were solely management-focused. In contrast, following an estimation of the top 100 questions facing global agriculture (Pretty et al., 2010) the vast majority of the critical questions from this group of researchers and policy makers relate to: (a) the availability and sustainable use of natural resources for food production and related implications for environmental health, and (b) the institutional settings (including markets, trade, development policies, consumption issues) that can lead to better outcomes in resource use sustainability, food security, rural livelihoods and poverty alleviation (see Annex 4). Only seven of the 100 questions directly related to genetic improvement – a fact that seems at odds with the CGIAR's focus on genetic improvement.

Integration challenges within the NRM domain – agriculture and environment: Agronomic and environmental studies have long focused on providing the knowledge base for intensive food production and natural resource conservation, respectively (Brussaard et al., 2010). Throughout the 20th century these fields followed separate developments, stemming from the priority to increase production on the one hand, and the emergence (at the end of the century) of agriculture-related environmental concerns on the other. The interactions between agriculture and environment have therefore been to some extent polarized between and among scientific and political communities on the bases of ideological and epistemological differences. Many of the institutional and governance settings perpetuate the segregation of sectors, scales and issues between 'agriculture' and 'environment', turning NRM and environmental conservation into controversial issues. However, this dichotomy has reached its limits. The appreciation that resources are limited, and in some cases are becoming rare, will make mining behaviors impossible in the future. Second, there is an increasing acceptance of the concept that agriculture – crop and livestock farming, fisheries and forestry – can produce biological resources as well as using them. Current challenges call for a new paradigm for agriculture in which natural resources (and the ecosystem services they provide) would not only be used and depleted but also produced and managed; the production of ecosystem services would therefore be one of the functions of agriculture. The emergence of 'agroecology' and 'the ecological intensification of agriculture' aimed at purposely articulating multiple viewpoints on the links between agriculture and other activities and integrating ecological, economic and social outcomes (Giller et al., 1995; Altieri, 1999; Cassman, 1999) make it possible to embrace the new paradigm.

Technological *and* institutional solutions: With regard to institutional constraints and opportunities, CGIAR Centers have variously supported socioeconomic or policy research programs – and IFPRI is solely focused on such matters. The term 'institutional' research is used here with a broad meaning – covering the functioning of all human-related infrastructure that encompasses farm production, including infrastructure, the functioning of input and output markets, regulation across value chains, support for R&D and extension, education and training, finance and credit systems, trade, governance and security, and land/water tenure.

Hounkonnou et al. (2012) considered institutional barriers to progress on agricultural sector development in West Africa. They argue the case for persistent institutional bias against agriculture generally – and against smallholder agriculture more specifically – and conclude that progress in terms of agricultural productivity will not take place without an 'enabling institutional context'. By institutional context, they suggest the following for the West African situation of their case study: farmer representation; price formation processes; processes that finance rural development including credit markets; development of integrated value chains; provision of agri-input services; technology and capacity development; a public consultation and technical intervention program; policy formation capacity from a regulatory and governance perspective; facilitation at all systems levels; processes that encourage diversification of organizations; communication support mechanisms; adequate land and water tenure; and policy interventions that address long-term threats to smallholders, such as climate change and globalization.

The relevance of institutional matters to NRM research and, in fact, biophysical/technological research generally, is that the latter is unlikely to have any impact without the necessary institutions in place and functioning effectively. This is not just a matter for smallholder agricultural development in Africa. Hounkonnou et al. (2012) present a convincing argument that this has always been the case for agricultural development everywhere. They examine the advances made in US agriculture in the 1940s, Netherlands agriculture in the 1950s, and the Green Revolution in Asia and India in the 1960s and 1970s. The Stripe Review Panel is concerned that impact on CGIAR goals and the broader concerns of agriculture and the environment require simultaneous assessment of both technological and institutional dimensions in any target situation.

For this reason the Panel urges that the 'three pillar' CGIAR needs to be reconsidered: The previous distinction or 'stove piping' of crop genetic improvement, NRM and socioeconomic/institutional research no longer serves the CGIAR well. It may even inhibit scientific innovation and hence the impact of CGIAR research. Instead of thinking of crop genetic improvement, NRM and socioeconomic/institutional as independent endeavors, we make the case for a new paradigm based on GxExM^I. This is not a literal formula, but identifies the requirement to focus more equal research efforts on genetics (G), environment (E) and management (M), all connected to their individual and overarching institutional (I) contexts. The CGIAR Reform recognizes the need for a more integrated research approach through the adoption of a portfolio of large research-for-development programs. It is an approach in which crop genetic improvement, NRM and socioeconomic/institutional research are seen as interactive, intersecting and often co-dependent pathways for progress toward the system-level outcomes (SLOs). This in turn requires a new organization of science based on the interactions of genetics, environment (including a changing environment) and management (done by and for people) with the most relevant institutional context.[8] Rather than blurring approaches, more attention is needed on how these interactions play out differently across spatial and temporal scales.

Figure 2.7 deliberately depicts the technological and NRM elements as mounted on a platform of enabling institutions. As the CGIAR is focused on supporting development in terms of poverty alleviation and food security, all three elements will be critical components of any strategy for research and will be necessary for progress on these development goals.

The challenge of integration: The two big tensions throughout CGIAR's history, namely genetic solutions versus management solutions (e.g. Haefele et al., 2000) and a technology-push view of development versus an institutionally-enabled view (e.g. Raitzer and Maredia, 2012), will not disappear entirely. However, recognition of needs and possibilities can make an array of approaches a positive force as CGIAR undergoes its reform process. In many ways these arguments are perhaps more about power struggles within research institutions than they are about fundamental philosophical divides. If the view implicit in Figure 2.7 is accepted, the question becomes not one of 'what' but one of 'how' and 'when'. How much effort on each element? How best to achieve the necessary integration? When is it best to progress the technology development in technology-focused activities? And, particularly, as the CGIAR considers how to approach its system-level objectives, the critical question becomes: when is it essential that technology development is embedded in a program of institutional change?

8 The term 'institutions' is used in the broadest sense of the word – often described in terms of efforts to "reduce uncertainty in human interactions". The term covers both the formal and informal 'rules of the game'. Policy and organizational structures are part of this broader notion of institutions. Institutions are the constraints that human beings impose on human interaction. They consist of formal rules (constitutions, statute law, common law, regulations) and informal constraints (conventions, cultural norms and self-enforced codes of conduct) and their enforcement characteristics. Those constraints define (together with the standard constraints of economics) the opportunity set in the economy. See: http://129.3.20.41/eps/eh/papers/9309/9309001.pdf

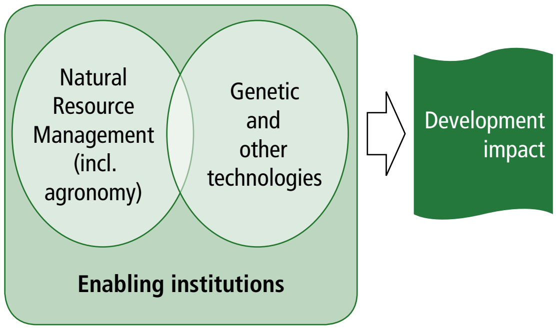

Figure 2.7. A schematic illustrating the co-dependencies of technologies, NRM and enabling institutions in achievement of development impact. (From Caron P., unpublished.)

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CHAPTER 3.
NRM in CGIAR research: History and projections

This chapter looks at the involvement of the CGIAR in NRM research, particularly with relation to its comparative advantage. Based on recent case studies provided by the Centers, we provide a classification of NRM research to help define its scope and highlight related issues. The chapter also reviews positive outcomes from the best cases of NRM research, as well as ongoing concerns and issues to consider in future planning.

The CGIAR's comparative advantage in NRM research

The CGIAR System provides unique opportunities for addressing NRM challenges in a systems-oriented approach. The CRPs provide unrivalled opportunities to address complex problems by drawing on the breadth of research expertise within the CGIAR System and its associated networks. CRPs are founded on an innovation systems structure (broadly defined), wherein interdisciplinarity and cross-scale interactions are explicitly recognized. Recognition of the importance of these approaches is, of course, not sufficient to deliver expected impacts; collaborative structures, data sharing platforms and analytical methodologies have yet to be fully developed. The CGIAR needs to do this to achieve the outputs expected from the CRPs; if achieved, it would be well positioned to make substantial contributions to other groups working on NRM issues globally. The CGIAR has a comparative advantage in responding to these challenges due to the following characteristics:

- **Ability to tackle the big picture in an integrated manner:** Collectively, CGIAR researchers have immense potential to address complex challenges from multiple perspectives and across several scales. This presupposes that interdisciplinary and transdisciplinary research is effective both across and within CGIAR Centers (see below).
- **Access to geographically diverse and long-term data sets:** Geographically extensive research investments in landscape-scale case studies, coupled with long-term research presence, has generated extremely valuable data sets[9] and provided a foundation for future research through CGIAR institutional recognition (and trust) across diverse stakeholder, government and partner organizations. This provides an effective springboard from which to launch new policy-relevant research that is available to other institutions only through partnerships with CGIAR Centers.
- **Access to networks:** CGIAR researchers have considerable opportunity to engage with international academic networks. They are also likely to have better access to corporations in the agriculture and forest sectors. Further, much CGIAR research engages directly with local and regional stakeholders. Engagement across these academic, corporate and stakeholder networks could foster serendipitous innovations in research and its application.
- **Access to policy processes:** CGIAR researchers have relatively good access to policy-making processes. Good access to national and international science and policy dialogues (relative to researchers in universities or non-governmental organizations), should provide more effective pathways for the uptake of research outputs. However, the challenges of doing so should not be underestimated.
- **Well-established financial systems:** CGIAR institutes have well-established and professional, audited financial systems that allow them to receive large grants without large financial risk, which makes the CGIAR attractive to donors.
- **Monitoring and evaluation possibilities:** Many new mega-grants have been awarded to CGIAR institutes across countries and locations within those countries that include substantial funds for base-

9 E.g. ICRISAT's Village Level Studies: these are considered an example of a valuable approach, although future CGIAR data gathering will have to seek more explicit natural resources measurement in tandem with long-term household and farming systems data.

line studies and monitoring and evaluation. Examples include Tropical Legumes (TLII), Harnessing Opportunities for Productivity Enhancement of Sorghum and Millets in Sub-Saharan Africa and South Asia (HOPE), and the Drought Tolerant Maize for Africa Initiative.

- **Long-term strategy and vision:** As opposed to direct bilateral collaborations between advanced research institutes and NARES, CGIAR institutes have the advantage of being able to develop a longer-term strategy and vision, i.e. not tied to the typical short-term (often 3-year) project cycle.

Track record and reframing

Given the wide-ranging means through which NRM research can underpin the CGIAR's goals, and the disparate ways in which CGIAR Centers have pursued their approaches to their commodities or resource sectors (see Box 3.1 and the following section), it is appropriate to establish the scope of the field of NRM and to identify entry points for research.

NRM has been part of the CGIAR portfolio from the outset. The early focus was on addressing biotic and abiotic constraints necessary for the genetic potential of new varieties to be expressed. The Green Revolution came about through the combination of new genotypes with improved management of water, nutrients and pests. The focus was on the management of natural resources within agriculture. Over the years, the portfolio evolved, both within the original commodity Centers and through the addition of new Centers with broader mandates around crosscutting issues of policy, land and water resources, biological diversity and ecosystems management. In this sense, the CGIAR evolved to consider NRM issues both within and around agriculture. Despite this long history of research effort, there is evidence that NRM continues to be deficient in many of the world's agricultural landscapes (including oceans and forests) given current states of soil degradation, GHG emissions, overharvesting, biodiversity loss, and inefficiencies in nutrient and water use. These deficiencies threaten the sustainability of current productivity levels as well as broader environmental resources. Beyond the direct considerations of natural resources as a foundation for agricultural productivity, there is wider recognition of the central role that agriculture plays in (i) multi-functional landscapes and (ii) the provision of environmental services.

To date, NRM research in the CGIAR System has evolved as a set of accumulating activities and Centers without an overarching strategy defining its place alongside crop genetic improvement and socioeconomic and institutional research. This has been reflected in the outcome and impact stories that were reviewed by the Panel, including assessments conducted by SPIA and the other independent assessments of other panels through the external program and management reviews (EPMRs) of the Centers' work and the Panel's own bibliometric assessment and evaluations (see following).

Although previous assessments (especially CGIAR TAC, 1996 and CGIAR TAC, 2001) noted the urgent need to develop a framework for NRM research in the CGIAR, the NRM research portfolio and structure within the CGIAR has not been developed to any particular 'master plan'. Instead it has evolved via two primary mechanisms. First, the commodity-focused Centers (CIAT, CIMMYT, CIP, ICARDA, ICRISAT, IITA, ILRI and IRRI) all developed NRM dimensions of their commodity-focused activities, extending from agronomic investigations of soil and water management to environmental considerations of agricultural practices. The agronomic aspects of these programs were present from the earliest days of crop genetic improvement, to enable the full expression of the new germplasm's potential. Over time, and to different degrees in different Centers, these 'NRM Programs' evolved to consider a wider set of environmental issues related to agriculture. Alongside these developments, new Centers emerged with a primary mandate focusing on NRM matters, for example, IWMI, with its focus on water management across scales and associated soil and landscape processes. Bioversity is a more recent Center, with a primary NRM mandate focused on the prevention of biodiversity loss. ICRAF and CIFOR clearly have strong

NRM foundations centered on agro-forestry and forestry, and WorldFish addresses fisheries, aquaculture and aquatic habitats. IFPRI, while not having a NRM focus per se, is highly relevant given the centrality of policy issues to the management of natural resources in numerous settings. Alongside these Center-level structural developments, important ideological debates have ebbed and flowed throughout the history of the CGIAR. One of these relates to the balance between genetic improvement and NRM research, another to the articulation of research in the agricultural and environmental fields, and a third to the balance between biophysical/technological solutions and institutional solutions. As discussed elsewhere, the development outcome approach adopted in the new CGIAR reduces the importance of such arguments and focuses more on how research, or combinations of research for development approaches, can produce the desired outcome.

A categorization of NRM approaches

While examining the historical performance of the CGIAR in this field, the Panel consulted the various outputs, outcomes and review statements available from former work (Annex 2). Based on this literature review, and through an iterative interaction with Centers on case study examples, the Panel used criteria[10] for large-scale impact to select a subset of examples (see Box 3.1 and Annexes 2 and 9). These examples serve as the main point of entry for this analysis of the nature and scope of NRM research in CGIAR.

The Panel believed that several typologies of NRM research could be constructed,[11] but chose a suggested typology to clarify the research elements that fall under the NRM umbrella. They also elucidated the relationships between different approaches underpinning farm-level production and other natural resources that sustain the livelihoods of the poor. Establishing the typology helped to identify priority actions for improving each of these fields, as well as ways

10 The description of methodology for the selection of the examples is reported in Annex 1.

11 An alternative potential typology is described in Annex 3.

Box 3.1. Examples of NRM studies conducted by CGIAR Research Centers

- Ex. 1. *Better beans in Africa: Towards valuing indirect and overlooked environmental impacts* – CIAT
- Ex. 2. *Financial due diligence for natural forest protection* – CIFOR
- Ex. 3. *The conservation agriculture hub in the cradle of the green revolution* – CIMMYT
- Ex. 4. *On-farm impacts of zero tillage wheat in South Asia's rice–wheat systems* – CIMMYT
- Ex. 5. *Returns to policy-oriented agricultural research: The case of barley fertilization in Syria* – ICARDA
- Ex. 6. *Water/land productivity in irrigated systems* – ICARDA
- Ex. 7. *A new protocol adopted by NARS for assessing soil health at watershed scale and recognition of widespread micronutrient deficiencies in Indian soil* – ICRISAT
- Ex. 8. *Collective Actions and Property Rights (CAPRi)* – IFPRI
- Ex. 9. *Sustainable Tree Crops Program* – IITA
- Ex. 10. *IPM Systemwide Program* – IITA
- Ex. 11. *Alternate wetting and drying is adopted by hundreds of thousands of farmers in South and Southeast Asia* – IRRI
- Ex. 12. *Co-management of electricity and groundwater in Gujarat, India* – IWMI
- Ex. 13. *Alternatives to slash and burn* – ICRAF
- Ex. 14. *Impact of the development and dissemination of integrated aquaculture–agriculture* – WorldFish Center.

See Annex 2 for details.

to address interactions between agriculture and the environment. The Panel found that some case studies targeted a specific issue, while others fostered a diversity of approaches. Studies differed in their main entry point to problems, either on the basis of different disciplinary research fields (e.g. conservation research, institutional research, agri-environment research, agri-sustainability research, agronomic research or technological research) or on their use of different types of tools to disseminate, scale up and scale out study results. For the purposes of this report the Panel established nine major types of study, which fall into three general categories representing different perspectives. Examples are provided for each (see Annex 2 for details).

From the resource point of view

1. **Status and dynamics of a resource**
   This research focuses on the evolution of one particular resource (soil, water, forage crops, etc.). Most frequently, the research qualifies and quantifies a degradation process and considers agriculture as one of the responsible factors. Different 'hard science' disciplines are involved, such as ecology, soil sciences, forestry sciences, hydrology.
   Example 7: *A new protocol adopted by NARS for assessing soil health at watershed scale and recognition of widespread micronutrient deficiencies in India soil* – ICRISAT
2. **Management of one particular resource**
   These studies characterize the individual and collective behaviors of stakeholders when dealing with the ownership and uses of (a) resource(s). The studies demonstrate an attempt to understand and/or model stakeholders' practices. Farming system research has been instrumental in providing methods. Human and social sciences are particularly represented in this category.
   Example 6: *Water/land productivity in irrigated systems* – ICARDA, and Example 12: *Co-management of electricity and groundwater in Gujarat, India* – IWMI
3. **Ecosystem management**
   This category includes the interactive study of behaviors and the characterization of the dynamics of resources, but in contrast to the previous categories it is conducted at the ecosystem level (landscape, watershed, forest, etc.). Studies are usually undertaken by ecologists.
   Example 13: *Alternatives to slash and burn* – ICRAF
4. **Institutional arrangements for NRM**
   Research in this category looks at the definition of norms and rules for appropriation, ownership and uses of resources or territories, through governance, coordination and regulation processes. The main focus is the understanding of collective action and conflicts around NRM. This is very often referred to as part of an 'enabling environment'[12] by life scientists, although this is an important research area for anthropologists and social scientists. Life scientists can be associated with social scientists (e.g. geographers, economists and sociologists) to study the evolution of ecosystems and/or resources in the light of changing institutional arrangements.
   Example 8: *Collective Actions and Property Right (CAPRi)* – IFPRI
5. **Policy for NRM**
   This field encompasses political, social and economic sciences. It includes the study of the processes through which NRM policies are designed, their characteristics, the tools and instruments upon which they rely, and their effectiveness and ultimate impact. This objective is sometimes associated with the one on institutional arrangements when the articulation of collective action with policy change is considered.
   Examples 5: *Returns to policy-oriented agricultural research: The case of barley fertilization in Syria* – ICARDA

12 What is referred to as the 'enabling environment', the 'institutions' or 'institutional capacity' often provides an easy justification for the failure of technological inventions to be taken up or properly diffused. However, considering all these as parts of the innovation process means that they could be addressed through a specific research effort when it is appropriate for the CGIAR to do so. This review suggests following the main challenges identified by Zander et al. (2007): Rethinking the assessment and evaluation of agriculture; accounting for multi- and cross-scale processes to promote innovation; and addressing the governance issues of agricultural development by facilitating a science–policy interface through the development of boundary works and through the association of socio-political sciences with agricultural research.

From the agricultural production perspective

6. **Adaptation of agriculture because of an environmental constraint or for resource optimization**
   This category of NRM research aims to design new material, technology or methods in response to an environmental constraint. It looks in particular at the challenges and tradeoffs of producing more (quality or quantity) through ecological intensification. The environmental constraints can be diverse, including: changes in the environment and physiology, which may or may not relate to climate change; depletion of or difficulty in accessing a chemical input, or attempts to reduce its use; emergence or spread of a pest or pathology; or the application of new norms through policy and trade regulation and tools. This type of research brings together different disciplines such as agronomy, ecophysiology, phytopathology and veterinary sciences. It often refers to a 'movement' that has both scientific and ideological dimensions, e.g. conservation agriculture, eco-agriculture, agroecology and integrated pest management.
   Example 3: *The Conservation Agriculture hub in the cradle of the green revolution* – CIMMYT, Example 4: *On-farm impacts of zero tillage wheat in South Asia's rice–wheat systems* – CIMMYT, Example 10: *IPM Systemwide Program* – IITA, and Example 11: *Alternate wetting and drying is adopted by hundreds of thousands of farmers in South and Southeast Asia* – IRRI

From the perspective of interaction between agriculture and ecosystem services

7. **'Production of natural resources' by agriculture**
   This category reconsiders the role of agriculture in 'producing natural resources' within a context of acknowledged multi-functionality. It mainly refers to the study of environmental benefits and services provided by agriculture, e.g. soil fertility, water quality, biodiversity conservation and climate change mitigation. This area brings together agronomists and ecologists for the characterization of such production. It allows review of the 'natural' dimension of the resource base and reversal of the way of looking at NRM. Natural resources are no longer no-cost assets to use (and potentially deplete) through extractive and pioneer behaviors. Rather, research establishes the roles played by essential resources, with commensurate values to be taken into account. Strategies for renewing resources are addressed through social, economic and technical means with specific tools and explicit policies.
   Example 1: *Better beans in Africa: Towards valuing indirect and overlooked environmental impacts* – CIAT, Example 3: *The Conservation Agriculture hub in the cradle of the green revolution* – CIMMYT, Example 4: *On-farm impacts of zero tillage wheat in South Asia's rice–wheat systems* – CIMMYT, Example 9: *Sustainable Tree Crops Program* – IITA, Example 11: *Alternate wetting and drying is adopted by hundreds of thousands of farmers in South and Southeast Asia* – IRRI, Example 14: *Impact of the development and dissemination of integrated aquaculture–agriculture* – WorldFish Center
8. **Payment for the provision of natural resource services produced by agriculture**
   This field developed very quickly in the early 2000s as studies began to involve economists seeking to assign values to ecosystem services. Other human sciences have been involved in the design and assessment of tools and policies to promote payment schemes. Various fields in the life sciences may collaborate to monitor the results of such research through the estimation of resource quality and quantity.
9. **Land use at the global level**
   This is an emerging multidisciplinary field of research, addressing the tradeoffs between environment conservation and production at the global level. It addresses, on the one hand, the question of the agrarian frontier at both local and global scales (land sparing and the processes and impacts of forest use) and, on the other hand, the question of ecological intensification and land sharing.
   Example 2: *Financial due diligence for natural forest protection* – CIFOR.

Measures of success: Reviews and impact assessments

As will be discussed further in Chapter 6, the CGIAR System can certainly offer several examples of successful NRM research. Some examples were also mentioned in Centers' EPMRs or within the framework of the 2005–2009 performance measurement system, as "successful, mature or proven research" (Box 3.2).

Note that the judgments from earlier reviewer groups range from congratulations on the excellence of the science or on the approach to an important field to research, to research which has great potential for successful NRM outcomes. However, when evaluation was entrusted to more standard assessments of impact scientists CGIAR research fared less well.

Working on an earlier selected set of CGIAR case studies on NRM research, which represented only a small fraction of the NRM research portfolio of the System,[13] Waibel and Zilberman (2007) deliberated on the state of impact assessment of NRM research in the CGIAR and on how to potentially improve the design of future impact assessment studies. They essentially considered rates of return on investment, as had been done with crop genetic improvement research. Even if the rate of return in some of the cases appeared lower than other research categories, overall the authors considered that the seven case studies provided good examples of investments in NRM research projects that have paid off. The study also suggested that the overall returns from this type of research might be underestimated. It became clear that a general problem with NRM impact assessments has to do with attribution, and sometimes with valuation. Waibel and Zilberman also showed that successful NRM research may lead to increases in productivity, resource conservation and environmental services, as well as a reduction in risk.

13 It is also true that a rather small selection of adequate impact assessments or feasible stories was available to the Waibel panel, and this reflects the need to structure and strengthen NRM data collection and assessment more broadly, as discussed in Chapter 5.

This study also recognized that "*impact assessments cannot be avoided*" and that one of the major challenges for undertaking impact assessments of NRM research is to "*organize research projects from the start with an eye on assessment of impacts, and to document costs, as well as benefits, as part of the ongoing activities of the projects*" – not as an add-on at the end of the research project. The present report underlines this finding and deems it a necessity for the CGIAR to plan CRPs adequately, collect impact-relevant data, and measure and report on impacts.

Another recent study (Renkow, 2011) was commissioned by SPIA to review and assess available documented evidence of impacts on the environment from agricultural technologies and policies derived at least in part from CGIAR research (CGIAR ISPC, 2011). The study revealed a very thin record of accomplishment in documented environmental impact assessments in the System. The limited available evidence focused on on-farm environmental production effects, leaving the off-site environmental impacts of research largely overlooked. Not counting the notable exception of the work on timber harvesting policies and deforestation, there was only a small number of cases in which more than a partial analysis had been carried out. In Renkow's words, "*there has been no work carried out to date that has successfully traced the entire impact assessment pathway from research investment through to measurement of off-site biophysical effects on ecosystem services, and on to the ultimate economic impacts on agents located in receiving sites*". However, the integration of environmental impacts in cost–benefit analysis of crop genetic improvement, as Bennet (2011) has emphasized, is "*practical and capable of application*."

This Stripe Review Panel therefore urges the CGIAR and the key groups currently planning CRP development to grasp this chance to establish viable impact pathways for new research programs, determine the requirements for the organization of science, and to analyze how the contribution of NRM programs will be adequately measured (see Chapter 6).

Box 3.2. Examples of successful NRM research cited in past EPMRs or in the performance measurement system database

The examples of NRM research cited below have been highlighted as "successful, mature or proven" in past external program and management reviews (EPMRs) of the Centers or within the framework of the 2005–2009 performance measurement system (PMS).

Zero tillage – CIMMYT: "*Zero tillage (ZT) in the rice–wheat farming systems of the Indo-Gangetic plains represent the most profoundly influential natural resource management activity to date within the CGIAR in terms of the geographic scope of diffusion and the number of farmers affected.*" – Renkow, 2011

Alternatives to Slash and Burn (ASB) – World Agroforestry Center: "*The Panel concludes that the ASB Program has played a significant role in transforming the way that decision makers think about the factors shaping land use at forest–agriculture interfaces in the humid tropics. In so doing, it has created the world's pre-eminent system for use-driven, comparative scientific investigation of human–environment interactions at the forest margin across the pan tropic domain. ... The uptake of ASB products by independent publishers and by users of the Program's world wide website is substantial and, suitably normalized, on a par with or somewhat greater than levels achieved by other CGIAR units. ... ASB results are treated as influential outputs by communities specializing in the ASB domain around the world. ... In the action realm, ASB is widely acknowledged to have contributed directly to the design of innovative policies, legislation and institutions across its pan-tropic domain.*" – CGIAR Science Council, 2006b (ASB EPMR)

Collective Action and Property Rights Systemwide Initiative (CAPRi) – IFPRI: "*The CAPRi work won the CGIAR's Excellence in Science Award in 2002 for Outstanding Partnership. At the same time, they have also participated in other global events such as the Millennium Ecosystem Assessment. ... EPTD's [Environment and Production Techonology Division, under which CAPRi was implemented] relatively long standing in the areas of property rights, sustainable development of less-favoured areas and water resource allocation research has provided the Division with opportunities for establishing itself as a leader within research communities and having influence in policy-making circles within developing countries. The Panel commends EPTD for its outstanding work in these areas.*" – CGIAR Science Council, 2006a (4th IFPRI EPMR)

Systemwide Program on Integrated Pest Management (SPIPM): Whitefly collaborative project – IITA/CIAT: "*The panel also noted that some individual taskforces (the operational components of the SPIPM) are operating well and was particularly impressed with the whitefly taskforce, citing this as an example of a model programme to achieve inter-Center leverage in tackling serious global pest problems. ... The panel considered this a model project.*" CGIAR Science Council, 2008b (6th IITA EPMR)

Assessing the impact of CIFOR's Influence on policy and practice in the Indonesian pulp and paper sector. Impact assessment paper: "*Raitzer (2008) is one of the most successfully executed policy research* ex-post *impact assessment (epIA) studies to have been conducted within the CGIAR.*" – Renkow, 2011

Alternate wetting and drying – IRRI: "*Alternate wetting and drying [AWD] is now considered a mature and proven technology. ... Research results have given an average water saving of 20% for both deep and shallow tubewell systems, with no yield loss compared with conventional systems. ... These innovations present some exciting possibilities of obtaining really significant water savings without losing the yield benefits of current irrigated rice systems. ... AWD is providing better economic returns than full irrigation to farmers on the very large irrigated areas in China and in areas where pumping from tube-wells provides irrigation water, so reductions in pumping provide a significant saving in energy costs to farmer. ... The Panel considers that AWD, other*

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water saving technologies and systems of aerobic rice production have wide implications both for farmer profits and for the governments of partner countries who are facing potential water crises in their urban supplies. However, they will clearly need a larger network of ARI scientists and water specialists to realize the opportunities offered." – CGIAR Science Council, 2004 (6th IRRI EPMR)

People and agroecosystems Research for Development Challenge: Integrated soil fertility management (project line PA2) – CIAT: "*It is clear that TSBF-CIAT has a well-developed research strategy based on integrated multi-disciplinary teams to undertake system-based action research and innovation that is targeted at priority development outcomes. ... The quality of outputs and achievements at TSBF is among the highest within CIAT and a direct reflection of its historical institutional culture of collaboration (South-North and South-South), competitiveness for international funding, and excellent scientific guidance.*" CGIAR Science Council, 2008a (6th CIAT EPMR)

Enhancing productivity and sustainability of favourable environment programme, Managing Resources in Intensive Rice, Irrigated Rice Research Consortium – IRRI: "*The Consortium has been outstandingly successful in developing more sustainable production systems that will be of benefit to many of the 1.2 billion people who live on the Indo-Gangetic Plain.*" CGIAR Science Council, 2004 (6th IRRI EPMR)

Sustainable management of wetlands (project) in Water management and environment: Balancing water for food and nature (theme) – IWMI: "*A number of the projects show strong potential to provide research outcomes that will not only be innovative but also be policy relevant. In particular, 'Sustainable Management of Wetlands' is a well structured project. It has an appropriate focus on the modeling of causes and effects in the hydrology side of the research and follows that through in the analysis of social and economic impacts. The emphasis on trade-off analysis provides a useful step toward making this research policy-relevant.*" CGIAR Science Council, 2008c (3rd IWMI EPMR)

Uptake of methods and tools for the analysis of environmental vulnerability by NARS – CIP: During the evaluation of the outcomes submitted by the Centers in the framework of the PMS for the year 2009, the Science Council considered this research "good and innovative" and gave it a score of 9.1 out of 10.

Use for research purposes of IWMI's data in the IWMI Data Storage Pathway – IWMI: During the evaluation of the outcomes submitted by the Centers in the framework of the PMS for the year 2007, the Science Council considered this research "very relevant, clearly documented" and gave it a score of 10 out of 10.

Using African climate vulnerability and poverty maps to inform national, regional and global decision-making – ILRI: During the evaluation of the outcomes submitted by the Centers in the framework of the PMS for the year 2008, the Science Council considered this research "novel", with "significant outcomes" and gave it a score of 9.6 out of 10.

Other measures of success: CGIAR publications in the field of NRM

Bibliometrics around scientific publications are not the 'be all and end all' of the CGIAR's impact – there are many more important dimensions of what the CGIAR does. However, CGIAR Centers are in the business of science that requires peer review through scientific publication. Therefore, the CGIAR has to achieve a minimum standard of scientific output to be a credible part of the global innovation system. There are ancillary benefits of fostering a scientific publication culture in the CGIAR – including communication across the Centers and enhancing the attractiveness of the CGIAR as an employer of scientists. The Panel's aim was to evaluate how the CGIAR might be judged on past publication history and how it could maximize the influence of its publications in the future. We consider this approach therefore to be an indicative – but not an exhaustive – analysis.

For this study, a total of 10,455 CGIAR publications[14] were found for the period 2000–2010 (Table 3.1). We checked with the Centers and found that small numbers were missed, largely because of inconsistencies in the naming of Centers on publications. All Centers were given time to verify and correct the documents, and we are confident that this is a valid sample of CGIAR publications.

It was difficult to classify publications precisely into NRM and non-NRM research areas. We thus took all publications with more than 20 citations (a somewhat arbitrary cut-off point) and created ten classes[15] of which five (animal nutrition, AN; conservation, C; climate change, CC; ecology, E; natural resources management, NRM) were considered to fall within the general area of NRM research. Out of the total 10,455 publications captured in the search, 1,036 had 20 or more citations (with a total of 40,876 citations), of which 475 were classified as AN, C, CC, E or NRM (total citations: 20,156). Using this group of articles, the Panel calculated the 'H index' for each of the Centers (Table 3.2). Due to the choice of methodology (i.e. focusing only on publications with 20 or more citations) this report cannot give precise H indices for Centers with citation values of less than 20.

The information analyzed led to the conclusion that the CGIAR's scientific publication and citation record is not as strong as

Table 3.1. Cumulative number of publications and citation data for all CGIAR Centers[16]

Center	2000–2002			2003–2005			2006–2008			2009–2010			
	all pubs	ctns	ctn index	all pubs	ctns	ctn index	all pubs	ctns	ctn index	all pubs	ctns	ctn index	total ctns
AfricaRice*	55	55	1.0	104	287	2.8	176	634	3.6	260	825	3.2	1801
Bioversity*	29	14	0.5	70	138	2.0	210	737	3.5	320	1438	4.5	2327
CIAT*	162	186	1.1	361	1038	2.9	656	3036	4.6	918	4262	4.6	8522
CIFOR	83	90	1.1	214	632	3.0	509	2121	4.2	747	3519	4.7	6362
CIMMYT*	152	167	1.1	339	1011	3.0	771	3742	4.9	1099	4979	4.5	9899
CIP	97	172	1.8	230	508	2.2	479	1520	3.2	650	1873	2.9	4073
ICARDA*	53	57	1.1	125	339	2.7	215	858	4.0	462	1377	3.0	2631
ICRAF*	135	260	1.9	311	893	2.9	472	1818	3.9	700	2954	4.2	6685
ICRISAT*	167	147	0.9	297	573	1.9	479	1661	3.5	836	2736	3.3	5117
IFPRI	86	112	1.3	194	444	2.3	483	1345	2.8	681	2175	3.2	4076
IITA	212	192	0.9	401	881	2.2	877	1983	2.3	1188	2404	2.0	5460
ILRI	190	192	1.0	307	956	3.1	567	2024	3.6	816	2480	3.0	5652
IRRI	224	421	1.9	356	1627	4.6	741	4136	5.6	1037	7622	7.4	13806
IWMI*	51	34	0.7	170	292	1.7	430	1252	2.9	667	2455	3.7	4033
WorldFish	20	56	2.8	41	224	5.5	63	385	6.1	74	382	5.2	1047
Total	**1716**	**2155**	**1.3**	**3520**	**9843**	**2.8**	**7128**	**27252**	**3.8**	**10455**	**41481**	**4.0**	**81491**

Table extracted from Petrokofsky, G. final consultancy report to the NRM research Stripe Review.
Note: The number of publications resulted from the bibliometric search contains a margin of error due to a limited percentage of double accounting of articles published by more than one Center.

14 The search was made using the bibliographic database Scopus and for three document types: (i) journal articles; (ii) reviews; (iii) conference papers. Full description of the methodology and the various steps in the exercise are reported in Annex 6.

15 NRM = natural resources management; CC = climate change; C = conservation; E = ecology; SEI = socioeconomic/institutional research; HN = human nutrition; AD = animal diseases; G = genetics; AN = animal nutrition; IPM = integrated pest management.

16 The list of publications found was shared with each Center in February 2012. In their feedback, some of the Centers noted that publications were missing from their list. In the case of those Centers (indicated with an asterisk in the table, the bibliometric search was therefore revised to add potential affiliations that were not previously included in the searchable items). Further details on the bibliometric component methodology are available in Annex 6.

Table 3.2. H index* of CGIAR Centers

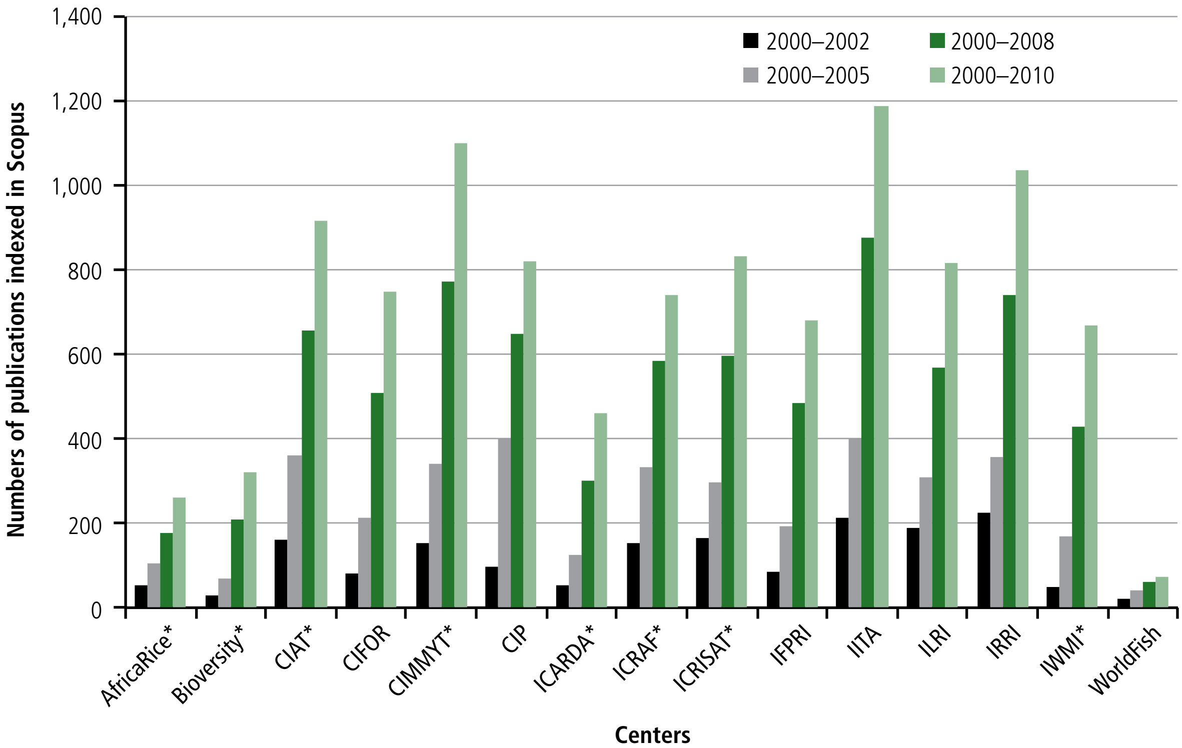
Centre	H index
AfricaRice	<20
Bioversity	<20
CIAT	33
CIFOR	25
CIMMYT	28
CIP	<20
ICARDA	<20
ICRAF	31
ICRISAT	<20
IFPRI	<20
IITA	21
ILRI	21
IMMI	25
IRRI	37
WorldFish	<20

* Only articles with 20 or more citations in the field of NRM (loosely defined to include animal nutrition, conservation, climate change and ecology), were considered in the calculation of the H index.

desired. Eight Centers have an H index in the range of 21–37 for their NRM research output over the last 10 years. That is, 21 to 37 papers cited more than 20 times. Seven Centers registered H indices of less than 20 (although given we used 20 as a threshold for the analysis of highly cited papers, further analysis would be needed to define precisely how far they fell below 20). These metrics would be an excellent publication record for a small team, but fall well short of what might be expected for the entire group of Centers with their large numbers of professional staff. Even if team outputs were directed at both publication and implementation targets to date, Centers need to look into how they can improve their publication performance.

Opportunities for improvement

The good news is that CGIAR research is widely cited – with over 81,000 citations over the 10-year period from 2000 to 2010. However, the larger Centers – IRRI and CIMMYT – have the most cumulative



* Centers which indicated that the Scopus search was incomplete: the bibliometric search was revised to add potential affiliations that were not previously included in the searchable items.

Figure 3.1. Number of publications for each CGIAR Center, 2000–2010

citations (13,806 and 9,899, respectively) based on around 1,000 journal articles. IITA had roughly half the number of citations (5,460) yet it produced the largest total number of papers (1,188). Smaller Centers had fewer publications. WorldFish emerged with the highest impact factor on a citations-per-article basis, despite having produced only 74 articles that were included in the analysis.

The differences among the Centers in the number of publication and citation records can be seen in the detailed report, which the Centers are encouraged to review for reflection on how to improve performance. The inter-institute comparison in Annex 6 perhaps reveals as much the shortcomings of such comparisons as it gives insights into relative performance of the institutes. Therefore, we caution against a direct comparison between Centers, as they have different numbers of staff and different histories. It was not possible to correct the analysis for numbers of staff or amount of income due to lack of information.

Evidently, the number of citations increases with the age of an article, so our analysis was broken down according to age class to avoid bias in favor of older publications. This is of particular importance for NRM fields where the number of citations tends to peak after 3–4 years, as opposed to, e.g. biotechnology, where citations peak closer to the publication date.

The CGIAR System has a specific mission for strategic and applied research, and this is outlined in the SRF and system-level outcomes: the institutes and scientists should strive toward excellence in their science. Hence, although CGIAR institutes should not be measured alongside universities or agricultural research institutes, it is clear that many articles derived from research at CGIAR Centers are widely read and highly cited.

The full citation analysis is available for use by the Centers, and the Centers are encouraged to build some form of citation analysis into their internal staff appraisal systems. Given that many CGIAR staff are full-time researchers, it is not unreasonable to expect that they should be publishing at least two articles each year in refereed journals, one as first author.[17] If this norm were to be applied to the Centers, the number of publications would increase substantially. Given the exciting research going on in many of the Centers, the panel concludes that the Centers could do a much better job of communicating the results of their work to the broader science community. This will provide impetus for future partnerships and demonstrate the importance of NRM research to the CGIAR's contributions to reseach for development.

Our suggestions for improving performance in terms of scientific publications in CGIAR Centers include: incentive schemes; setting clear targets and expectations in staff appraisals; increasing joint appointments with agricultural reseach institutions and joint postgraduate student supervision; including time for writing in work load planning; and offering scientific paper writing courses to junior staff.

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17 Why at least two papers per researcher as an indicative output? This is often used as the minimum norm for basic performance of academics, assuming that 40–50% of their time is devoted to research and the other 50–60% to acquisition of funds, management and teaching. Thus this appears to be a reasonable norm for the CGIAR, but could be raised or qualified by CRP managers or system evaluators.

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CHAPTER 4.
A changing role for the CGIAR: Organizing the approach to sustainability

Since the late 1980s the focus of the CGIAR has shifted toward issues of sustainability, ecological efficiency and the maintenance of the natural resource base on which agriculture and the livelihoods of the poor depend. This has occurred in parallel with the growing international attention to these same issues, manifested by international and intergovernmental processes such as the World Conference on Environment and Sustainable Development in Rio de Janeiro in 1992 and follow-up processes.

At various times in the past, the CGIAR allocated its research agenda and funding to different 'pillars' – for instance 'crop genetic improvement', 'natural resources management' and 'institutions and policy'. This segregation was often reflected in the organizational structures of the Centers, where natural resource, genetic improvement and policy scientists were segregated into respective administrative units.
Over the years there has been increasing recognition of the need for integrated and interdisciplinary approaches to NRM and Centers have increasingly grouped staff into research teams focused on multidimensional problems or specific geographic spaces. This tendency has culminated in the high degree of interdisciplinarity and problem- or place-focused teams in the emerging CRPs.

It is noteworthy that the concepts of working at the scale of eco-regions or farming systems were widely promoted as early as the 1980s, and repeated evaluations and commentaries have argued for these integrated organizational frameworks for CGIAR research. However, in general they failed to achieve traction at an operational level and came to be discredited. With hindsight, many would now agree that the concepts were sound but that the incentives, organizational structures and research cultures within the Centers did not favor such integrated organizational frameworks. The emergence once more of geographically-based organizational frameworks envisaged in the CRPs goes some way to vindicating the original concepts for eco-regional research.

Farming systems research did not meet the expectations of its original advocates and thus fell out of favor. The emergence of better scientific tools for working across scales, from plot to farm to landscape and eco-region, is now leading to greater interest in farming systems. Advances in information and communication technologies may enable researchers to deal with large volumes of data from farming systems, to detect patterns in such data, and to conduct meta-studies across scales and eco-regions.

The food price peaks in 2007/08 and 2012 have focused attention on food security issues, including on the resource limitations that increasingly threaten the growth in agricultural production needed to meet global food demand. The issue of the environmental limitations to agriculture and, conversely, of the impacts of agriculture on the environment, have risen to prominence in international policy discourse. They commanded international attention at the highest political levels in the Rio+20 Conference in June 2012. The renewed CGIAR and its emerging CRPs represent the largest and most coherent response to this challenge, and the CGIAR is well positioned to be a major player in post-Rio+20 processes.

The CGIAR Science Forum in October 2011 in Beijing brought together a wide range of scientists and decision makers concerned with the agriculture–environment nexus, and provided a great deal of scientific input on the debate over how to feed the world without degrading the environment. The Forum helped to clarify concepts, identified new areas for research collaboration, and provided the beginnings of a community of practice dealing with the agriculture–environment nexus, both within the CGIAR System and in partnership with it (CGIAR ISPC, 2011, 2012).

A new science culture is emerging in the CGIAR and this is evident in the proposals for CRPs. Several CRPs have used the term 'sustainability science' (Box 4.1) to describe the organizational framework for their activities.

Understanding processes of change and the feedbacks and synergies associated with such changes has a central importance in managing human–environment systems. This has ushered in new ways of conceptualizing NRM research as 'sustainability science' (Clark, 2007). Such research is: (i) interdisciplinary across social, economic, political and natural sciences; (ii) integrative of traditional, technical and natural science knowledge; and (iii) multi-scale with particular attention paid to linkages across scales. Accepting the validity of this approach to NRM does not easily translate to the effective implementation of its principles. While sustainable science concepts have contributed greatly to the theoretical development of integrated socio-ecological research frameworks, there has, in general, been less success in translating theoretical research into successful practice for the ultimate purposes of sustainable NRM, food production, livelihood security and poverty alleviation. Proof of concept is urgently needed.

Nevertheless, terms such as sustainability science are increasingly being used within the CGIAR to describe science that is inspired by the needs of beneficiaries. The approach is well represented in the CRP proposals and was debated by representatives of most CGIAR Centers during the Beijing Science Forum in 2011. Sustainability science seeks to draw upon different disciplinary skills and tools and to operate at multiple scales, in order to achieve impacts on the lives of the rural poor and on their environment. Recognizing that 'sustainability' is a moving target, and that new arrangements might be needed for scientific partnership to address integrated NRM targets within and outside the CGIAR, a number of principles were developed at the Sustainability Science sessions. The Panel believes these principles should apply to future CGIAR research, particularly to the CRPs:

- Measuring the impact of large-scale sustainability science endeavors will require that long-term data sets are maintained for large natural resource, cropping or farming systems. Data sets need to be established and maintained efficiently and cost effectively. There are opportunities for the different CRPs to combine their monitoring and evaluation activities around eco-regional poles.
- The emphasis on *ex-ante* and *ex-post* evaluation of impacts on crop yields needs to shift toward the examination of impacts on the livelihoods of the poor and on the environmental attributes that will sustain their livelihood gains. The motivation for impact studies needs to shift away from justification of research investments to donors, focusing more on learning and adaptation in an integrated agricultural research for development (IAR4D) context.
- IAR4D requires new partnerships and alliances. However, pragmatism is needed to determine the optimal sizes of teams and to limit the the size of IAR4D teams accordingly. Large teams are unwieldy and have proven to be a handicap. The transactions costs of very large-scale research for development endeavors are great. CRPs will need to function on the basis of nested hierarchies of teams, with provision for metaănalysis of findings to generate public goods and allow for scaling up.

Box 4.1. Definition of 'sustainability science'

Research to address the agriculture–environment nexus must make sense of dynamic linkages between biophysical and social drivers that determine trends in food security and environmental consequences. The term 'sustainability science' provides a framework to facilitate the required integration of scientific disciplines. It has been defined as 'an emerging field of research dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems'.

Source: Proceedings of the National Academy of Sciences. (no date). Online: www.pnas.org/site/misc/sustainability.shtml

- Changes are needed in science management to allow for – and encourage – participatory, integrative, inclusive, trans-disciplinary and multi-scale research endeavors. New information and communications technologies, geographic information systems, remote sensing and simulation modeling provide valuable tools to support sustainability science. However, these technologies should be used as tools, and should not become ends in themselves. Ecological and social systems are complex, dynamic and unpredictable; complexities should be communicated rather than reduced. Researchers must strive to see 'simplicity beyond complexity'.
- The constraints imposed on agriculture by increasing costs and the diminishing availability of inputs such as land, water, fossil fuels and fertilizers will make ecological efficiency and intensification more important in the future. This implies that sustainability science will become more important over time.
- It is becoming more important to use a food system approach and, considering the value chain from farm to fork, issues of post harvest losses and waste should also be assessed. Food security means much more than food availability – all dimensions of livelihoods come into play. Collaboration with the private sector should be recognized as highly valuable, not only in terms of funding, but also to help frame problems and provide information.
- There are major new challenges emerging for sustainability science. Some of these relate to:
  - Scientists can operate on long-term scales (10–100 years) but politicians deal in shorter periods of 1–10 years, while farmers can rarely enjoy the security of looking beyond their next harvest.
  - Research could operate on the 'three thirds' model: one-third for stakeholder engagement, one-third for the research per se, and one-third for delivery and scaling up. Under the IAR4D model all three of these activities are linked to learning and innovation systems.
  - Many of the problems facing the rural poor are 'wicked problems' – where all solutions lead to new problems. This also includes the global issue of feeding the world, reducing poverty and protecting the environment. We have to deal with cascading sets of issues, opportunities and challenges. It should be recognized that in addressing these problems, there are rarely win–win possibilities: in practice, critical tradeoffs between food security, livelihoods and environmental protection exist.
  - In general, scientists are not trained to operate within complex adaptive systems. Also, current incentive structures for science are not necessarily well aligned with the kind of innovative science required to address these complex emerging problems. Scientists must receive more recognition and support for working in inter-disciplinary teams in a 'sustainability science' mode.

In summary, the use of a sustainability science perspective is motivated by the observation that crop genetic improvement, NRM and social and institutional sciences cannot achieve their optimal impacts in isolation. The most significant impacts of CGIAR science are likely to be achieved when these three major branches of science are combined in inter-disciplinary research programs. The concept of IAR4D is one manifestation of the move toward more integrative approaches to addressing the CGIAR mission.

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CHAPTER 5.
Impact assessment and NRM research

Underlying the discussion in the previous chapters is a paradox: effective NRM seems to be more and more important to the attainment of global goals for both agriculture and development, yet the evidence for impact from NRM research at scale is patchy at best (Box 5.1). Good NRM research has proved excellent at diagnosis, providing evidence for many of the challenges that we are currently confronting (water shortages, depletion of soil nutrients, loss of capture fisheries and forests, GHG emissions, and scenarios for climate change). However, the pathway to solutions is much more complex than crop germplasm improvement and is conditional on the broader enabling environment.

That the majority of impacts from CGIAR's NRM research, particularly enhanced agronomic practices, have been measured (indirectly) through the adoption and improved yield of new crop varieties is illustrative of the difficulty to date in providing alternative indicators. Frameworks for measuring advances in NRM research, effects of new practices or policy, and outcomes and impacts within and across different sectors have not been easy to develop. The lack of availability of consistent adoption and time series data for other indicators, and the more local scale of impacts from NRM research generally documented to date, have exacerbated the perception that impacts from NRM research are intrinsically more difficult to obtain or are 'more local' in scope. Some observers have gone as far to suggest that, because NRM research has not shown impacts on the scale of crop genetic improvement research using the same measures, on a 'returns on investment' criterion investment in NRM research should be reduced in comparison with crop genetic improvement research in the CGIAR (Renkow and Byerlee, 2010).

Box 5.1. Impact targets and measures: quotes on impact of NRM research from the 2011 CGIAR Strategy and Results Framework

115. e. Impact Targets and Measures: Impact assessment within the CGIAR for NRM research is still evolving (CGIAR Science Council, 2006; Waibel and Zilberman, 2007) and has primarily focused on impacts at the production system level, where impact is measured primarily through the productivity effect and where there are various attempts to value positive or negative externalities. Impacts at higher levels, for example in terms of reducing rates of deforestation, are rarely evaluated beyond adoption, e.g. adoption of CIFOR's timber certification scheme. Impacts at this level are specific to each sector and would generally be based on an evaluation of changes in the provision of ecosystem services. Specifying targets and impacts in terms of ecosystem services, however, requires a methodology for measuring baselines and changes due to the respective intervention, which is one of the critical implementation issues in development of carbon markets. To do this will generally require a monitoring system usually linked to a modeling capability, e.g. hydrological models, and a valuation system for the ecosystem service. This is methodologically demanding and a potential area of work for the CGIAR. What will probably emerge is a dual approach, i.e. at the production system level and at the landscape scale or other higher scales of evaluating changes in ecosystem services.

Success in NRM research is generally brought about when a solution addresses a local context. This led to the perception that any impacts are limited to a particular environment or population. As a result of this perception, there was discussion within the CGIAR about whether NRM research can meet the criterion of producing international public goods (see Barrett, 2003) or whether the tools and methods – the intermediate products of the research process – are themselves public goods. In the reform of the CGIAR and the casting of the goals in terms of the four system-level outcomes (SLOs), this debate has been tempered. However, it is still appropriate to ask how broadly we will be able to spread the outcomes of CGIAR research and how this consideration should influence research design, the choice of sites and approaches and, ultimately, what to fund.

The SRF describes three broad approaches for NRM research in the CGIAR:

- increasing resource use efficiency, or eco-efficient agriculture at the intensive margin (fundamental to the work on the food security SLO)
- reversing the cycle of land degradation in areas of high rural poverty
- determining climate change effects on agriculture and the adaptive response required, and identifying the contributions that agriculture could make in mitigating climate change at the landscape and regional levels.

The SRF further notes that these approaches to NRM are often framed in terms of operation at different scales: from production systems, to communities, to landscapes/watersheds, to national policy frameworks, to global conventions.

There is thus a methodology challenge for impact assessment. The challenge is complicated by issues of attribution, where the relationships between 'technological change' (more often new knowledge or changes in community practice) and the outcomes and impacts are less clear-cut than with, for instance, the adoption of new seed by farmers. Additionally, there are long time lags between NRM research discoveries and the full manifestation of impacts – potentially decades. Similarly, there are tradeoffs over spatial scales (local, regional and global). There are also aspects of NRM research which are conducted in a sector-specific manner (forestry, fisheries, etc.). More often, because of the connectivity of landscapes and water bodies, competition in the use or development of ecosystem services at the agriculture–environment nexus, and the actions of human communities under the influence of national and global policies, there is an inherent complexity in tracing the impacts of NRM research.

However, in order to both judge the effectiveness of its own research and to determine the impacts of CGIAR research on environmental sustainability and human welfare, the NRM community cannot opt out of the need for monitoring, evaluation and impact assessment simply on the grounds of complexity. Lifting the game will involve the development of more effective frameworks and methods for capturing the range of variables and prospective indicators of impact at the program design stage.

Planning for impact

There are several opportunities provided by the adoption of the CRP approach. First is to plan a research program that will have impact in (at least) one of the four SLOs. This requirement to deliver impacts for human welfare and the environment leads to more holistic thinking about program design; major stumbling blocks or levers must be addressed with the most appropriate science, rather than focusing solely on disciplinary outputs. This will allow for integrated programs in which crop genetic improvement, NRM, social science and policy research are intertwined. Frameworks that encompass the monitoring of progress and of outcomes from all avenues should be considered. There will thus be a need for effective scenarios of initial and desired states, based on an understanding of the context and baseline conditions of the research areas. This includes identifying the interactive factors governing the present system and its constraints, as well as a theory or plausible pathway for change that can move the system toward the desired impacts. This is akin to concepts of resilience (Walker et al., 2004) in which potential change and resistance to change in a system are considered for all key drivers. *Ex-ante* assessments of potential return to investment are essentially the creation of probabilistic scenarios and economic assessments may or may not be possible.

However, the conceptual framework and pathway for change should have clarity and

Box 5.2. Examples of factors determining impact at scale from NRM research

It is widely appreciated that the determination of impact of NRM research is challenging. Much of the NRM research framework is not amenable to easy impact assessment, as impacts can be diffuse, abstract and long term. Research that applies problem solving approaches to address specific goals are needed, but these are likely to be successful for only relatively narrowly defined problems (often as components of a broader set of objectives), rather than broader management challenges that include multiple stakeholders often characterized by conflicting opinions and inequitable power distributions.

Further, the CGIAR's mandate is to deliver impact *through research*, which is one (or more) step(s) removed from actual development outcomes. Thus, as well as direct measurement of resource changes over time, CGIAR research can have impact through:

(i) **New ways of thinking** about land management and production systems that change the paradigm of production. Examples include the recognition (captured by innovation systems and related conceptual frameworks) that agricultural production is not the only value emerging from agricultural landscapes. Recognition of ecosystem services, and the cultural and biodiversity values imbued in landscapes has substantially changed perceptions of land use priorities. It is now necessary to equip such conceptual developments with roadmaps and methodologies for implementing truly integrated research in socio-ecological systems (e.g. Collins et al., 2011).

(ii) **Decision-making and visualization platforms** in the form of computer-based simulations to help visualize the implications of management approaches across scales. NRM research needs to aggregate small-scale and individual studies to larger-scales that address rural development in the context of multiple demands and rapidly changing technologies. Such aggregation should inform, and indeed shape, new research agendas that both respond to and influence policy. There is much potential for capitalizing on the advances in remote sensing, computing and ICTs, and the progress in social and biophysical systems modeling for these purposes.

(iii) **Partnerships with innovators and entrepreneurs** who are best placed to take up research outputs and turn them into the above-mentioned practical appliances (e.g. software) and technologies. Although no longer within the frame of international public goods, the commercial development of such technologies could contribute to more effective management of natural resources for the benefit of the rural poor.

(iv) **Coordinated and widely accessible meta-data** that could provide an immense source of valuable information, particularly in the understanding of factors (e.g. land use, policy and investment decisions, or technology adoption) underlying changing patterns of wealth and natural resource security. Good use of ICT could be made to manage such meta-data and make it widely available.

the indicators chosen should be fit for purpose – i.e. they should be fit for monitoring and evaluation of the key variables (production, environment, social, economic), sufficient to judge progress and to provide for learning and adaptation by program management, program researchers and stakeholders. Without undermining research on the valuation of ecosystem services (which is an important contributory research stream) it is unlikely that all indicators need to monetized. Therefore, one of the challenges to the construction of an NRM framework will be to combine and properly attribute weights to different types of qualitative and quantitative indicators of change (and the drivers of change). Indicators need to be chosen which express impacts, not only scientifically but also in ways that other stakeholders (including funders) value – e.g. percentage of resources saved, disability-adjusted life years, negotiated changes in management of water and land resources, evidence of learning by resource managers, or contributions to global policy documents. The concept of deriving program outputs that have different internal and external functions are described in Clark et al. (2011), based on previous CGIAR experience. Indicators of the prospective impacts should be assiduously collected throughout the life of the project; when adaptive management is called for, only those changes that will not undermine the ultimate utility of the experiment should be made. This process will be aided by a full understanding of counterfactual or 'non-treatment' comparative sites. Although this enlarges the demands on the program design phase, it is critical to the final delivery of clear accounts of the program's impact.

It is understood that an *ex-ante* assessment of a 5-year or longer program should be treated as the best possible hypothesis at the time. Such hypotheses should be made as rigorously as possible and be subject to testing. There may be a progressive change in focus as elements of the overall approach require greater efforts – or become recognized as key constraints. Documentation of such changes of focus, efforts and results must be collected in sufficient detail to allow for later analysis.

One of the key elements of the new long-term CRPs will be the learning provided to program managers and scientists. Program monitoring and evaluation strategies will rely on key indicators; potentially less-structured observations and review processes need to be built into program plans to make the most of such evidence as it arises and to compare progress across the CGIAR portfolio. While there may be some context-specific variables (e.g. sector- or site-specific variables), cross-site comparisons will require that CGIAR programs agree to adopt fundamental indicators expressed in common metrics. The sharing of new knowledge and approaches remains at the heart of the public goods nature of NRM research.

Finally, the likelihood of tradeoffs between different values, and the issue of scale, need to be accommodated in planning, particularly as they are revealed during program implementation; one obvious example would be between increased productivity and incentives to conserve natural resources. The developers of indicator systems should remain alert to different dynamics in interacting systems.

It is necessary and legitimate to pursue research (both within the CGIAR System and working with international expertise) to develop new methods for NRM research impact assessment. Areas such as contingent valuation have been explored with mixed results, but the analysis of behavioral change and educational measures are less frequently encountered. There may be a need for additional emphasis on the development of proxies for the influence and awareness-raising that arise from the CGIAR's NRM research. The advent of the new CRPs and the application of adequate program monitoring frameworks will result in new data (of all types), which will require long-term storage, analysis and benchmarking across sites. Programs will have to ensure that data are developed as part of more comprehensive meta-data sets, to allow for comparison across programs. Thus, the data can enable collaborative research and learning, as well as opportunities to enhance the development of international public goods. Certainly methodologies need to keep pace with the reform goals of the CGIAR and will have to evolve in line with emerging concepts for more effective NRM research.[18]

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CHAPTER 6.
Opportunities

There are emerging research approaches which are likely to lead to greater impact from NRM research in the future. This chapter discusses some of these concepts, tools and frameworks important for the developmet of NRM research. The chapter encourages the CGIAR to test requirements for new skills and partnerships to ensure that these new approaches can be developed and accessed when required.

Science concepts: The multifaceted nature of NRM, which encompasses interactions across scales and land uses, and which involves dynamic non-linear processes and feedbacks spanning economic, social and environmental sectors, practically forces a systems approach to management and development.

The innovation systems approach

The more recent evolution of 'innovation systems' approaches is well suited to NRM research. These approaches seek to address technical, social and institutional constraints in collaboration with many actors to achieve innovation in agricultural-environment systems. Hall (2005) summarized a key debate over the role of NRM: whether it should "involve the development of human capital and research infrastructure, or whether it should encompass a wider range of activities which also include developing the capacity to use knowledge productively". Although there is still a perception that agricultural system innovation involves the development of new technologies to increase yields, this is now often set in the wider context of NRM; indeed it is also often presented specifically as an NRM issue, for instance in the case of raising yields to achieve NRM benefits through land sparing.

Innovation is rarely defined and the word is used in different ways. Here, we interpret it as: "the economically viable and socially acceptable implementation of new scientific outputs, management systems or technologies that improve natural resource (or agricultural) outcomes in a manner that has a significant impact in the area of application". The innovation systems approach recognizes that innovation requires partnerships across research, extension, and private and public institutions. There is a particular focus on how relationships between these different institutions and stakeholders facilitate innovation and learning. Much emphasis is placed on participation and entrepreneurial activity by farmers and local enterprises. Innovation, impact and scaling require the adaptation of new knowledge and technology to local conditions – often by local entrepreneurs and risk-takers. The success of this depends on incentive mechanisms (i.e. enabling market and value chain structures), and supportive policies and institutional environments. Consequently, these are also researchable issues within innovation systems approaches.

There is wide recognition across the CGIAR System of innovation systems approaches, the concepts having, in part, been developed by successive CGIAR initiatives. CRPs also demonstrate the adoption and uptake of innovation systems frameworks, with much reference to interdisciplinarity, diverse actors, dynamic learning, interactions across scales, participatory action, and institutional learning processes. More challenging is the implementation of these concepts, and this not just for the CGIAR. Such challenges do, however, have particular relevance for the CGIAR, as its mandate is: "to contribute, through its research, to promoting sustainable agriculture for food security in the developing countries". The CGIAR also has a comparative advantage over other research institutions in addressing these challenges, in view of its interdisciplinary structure and access to partnerships in the environmental and agricultural sectors. Given the adoption of, and dependence on, innovation systems concepts in the current CRPs, the CGIAR should invest in targeted research for the empirical development of methodologies to operationalize these approaches.

Development of NRM will likely be devolved to local institutions over time, particularly as land managers gain better access to technologies, financing, knowledge and markets. This creates fertile ground for market-oriented and farmer-led innovation across and within institutions. While research on the facilitation of such innovation processes is within the remit of CGIAR research, the actual brokering of innovation to deliver impact, as a CGIAR activity, is more problematic. Through its networks and partnerships it is clear that the CGIAR has potential to catalyze innovation (as defined above), but it is less clear how – or even whether – the CGIAR should do this. This would require increasing the breadth and depth of partnerships with private sector enterprises, NGOs and extension agencies, and exploring the means by which entrepreneurship can be promoted among farmers and natural resource managers. Brokering and facilitation skills are central to the implementation of innovation systems approaches but, in general, are relatively weak at local levels. The CGIAR should explore its capacity to develop entrepreneurial skills in the context of emerging opportunities, either directly or by working through appropriate partners.

Research organizations including the CGIAR have demonstrated considerable competence in developing appropriate technologies for agricultural production. However, they have less capacity for market development and analysis, developing effective institutional change, and supporting innovation more generally. Paradoxically, researchers have been at the forefront of advancing our understanding and development of agricultural innovation processes and systems, even while their empirical implementation of innovation systems approaches (and other system approaches such as IAR4D) is not yet fully operationalized. Meeting the conceptual and technical challenges to implementing innovation systems approaches requires capacity building and training within the CGIAR itself, particularly on issues of interdisciplinary research, scaling, alternative modeling approaches, as well as integration of data across modeling systems, data management, and archiving and analysis, as addressed elsewhere in this review.

Motivation also needs to be enhanced through more appropriate incentive and performance evaluation systems. This report has raised the issue of publications for science assessment. In areas where the operation/implementation of new paradigms is the major hurdle, new incentives will be required.

The inter-disciplinary, cross-scale analyses required by the innovation and IAR4D systems approaches require competencies at individual and organizational levels. Capabilities in systems thinking, strategic planning, data management and use of ICTs are required at individual level, and these likely require investments in training, skills development and mentoring across the CGIAR System. At an organizational level, incentive systems that encourage inter-disciplinary interaction, partnerships with other stakeholders, and effective knowledge management are required. While the CRPs capture many of these elements, the ability of scientists to fully implement such approaches – and the required incentives needed to motivate them to do so – remain uncertain. Nonetheless, CGIAR scientists are probably best placed to meet these challenges.

Integrative tools and frameworks

Integrative frameworks for NRM might be achieved by the recognition and inclusion of several elements and approaches, as indicated in the following paragraphs:

- **Land use management should be analyzed in terms of the interaction of social and natural processes.** These interactions determine the state of social, economic and ecological resource bases upon which the sustainability of agricultural and rural development depends. Explicit recognition of these interactions helps to identify externalities and ensures their inclusion in management systems and policies. Perhaps more significantly, quantifying interactions improves our understanding of synergies between scales (see below) or across sectors. Thus the introduction of IR8 rice in Vietnam in the late 1960s proved most successful at the farm scale when it coincided with road development at the regional scale:

roads allowed information and materials to flow into farmland, and for harvested crops to reach markets (Quinn, 2011).

- **The contextual dynamics of landscapes** can be encompassed both within the system of interest (where they are relatively easy to envisage and capture) or extraneous to it (where they are more difficult to incorporate or even recognize). Examples of the latter include: changes in consumer behavior and market demands (e.g. the rise of biofuels as agricultural commodities); shifting political-institutional frameworks (e.g. decentralization and democratization); or perturbations in global economic conditions. These contextual differences should be accounted for by research and modeling approaches, otherwise it will be more difficult to generate knowledge that can be widely applied. Even issues that form part of the landscape context can be missed – notably the importance of multiplier effects.
- **Interactions between scales** (e.g. plant, field, farm, landscape, national and global scales) are central to the innovation systems approach. Vertical up-scaling or down-scaling is particularly challenging, as it requires learning and participation across a range of stakeholders and institutions (Gündel et al., 2001). Often, there is limited recognition and inclusion of processes that operate or interact across scales. Land-use modeling approaches usually fail to capture the level of detail at the farm scale, while stakeholder-based approaches are limited in their capacity to derive regional-scale projections based on the aggregated interventions and interactions within and among land use units. Many economic and social processes that affect resource use, values and vulnerabilities are the result of aggregated effects that are only expressed at higher scales (e.g. substitution effects in economics, network externalities in social behavior, connectivity in ecology). Clear methodological procedures for up-scaling are limited, and mismatches in analysis of ecological and agricultural processes might be partly derived from different conceptual frameworks (Volk and Ewert, 2011). Relating farm-level production objectives to larger-scale landscape amenity or biodiversity values is challenging, as the landscape values can only be determined at higher levels of aggregation, often through non-linear pathways.
- **The role of consumers and society as a whole is crucial in interpreting what is meant by sustainability, and yet societal values are often assumed, rather than known.** ‘Boundary work’ research seeks to overcome the barriers to creative dialogue across interest groups and sectors, and should be included in NRM research, particularly where issues transcend disciplines and societal hierarchies (Clark et al., 2011). Boundary work emphasizes meaningful participation in agenda setting and information exchange across societal or stakeholder groups, a process that is facilitated by effective accountability and support tools.

What should result from research in NRM?

The role of research is, first, to generate new knowledge, and, second, to deliver new knowledge to stakeholders in appropriate formats that will contribute to shaping the development of informed responses to poverty and food security challenges. In the context of land use and associated public goods, NRM research that ultimately seeks to address poverty and food security should, among other things, achieve the following:

- Deliver new knowledge on, for example, the changing dynamics of biodiversity abundance and ecosystem functions in response to land use and climate change.
- Improve understanding of human–environmental feedbacks and dependencies in the context of changing land use at the landscape scale.
- Improve understanding of linkages between scales from local to regional and global, to allow up-scaling and the contextualization of knowledge within broader environmental, economic and political frameworks.
- Integrate knowledge across inter-disciplinary and transdisciplinary research frameworks. Past experience shows that this is not easy, and requires considerable individual and institutional investment for mutual understanding across disciplinary boundaries.

- Develop or apply new approaches, products and tools for analysis, monitoring, assessment and evaluation. These include refined methodologies, databases and maps, technologies, quantitative tools for interpretive analyses, spatially explicit models, and decision-support systems. Long-term and widely accessible meta-data from many geographically disparate locations can be a foundation for future research for development.
- Recognize, and capitalize on, opportunities afforded by the emergence of new technologies, developing infrastructures and new institutional structures from beyond the normal sphere of NRM.
- Understand and improve processes of engagement across stakeholder groups within and across social and political hierarchies.

Within this body of research there are considerable uncertainties. These fall within the remits of social science (e.g. livelihood and health dependencies on ecosystem services [ES]), natural science (e.g. rates of ES degradation and biodiversity loss in the context of land use and climate change, as well as the identification of tipping points that may lead to irreversible changes), economics (e.g. valuation of ES, opportunity costs and tradeoffs of ES preservation) and policy (e.g. aligning management options to minimize conflicts across ES, creating structures that internalize ES values).

Thus, NRM research has much to contribute from various disciplinary perspectives. The long-standing challenge is to integrate good science across disciplines (interdisciplinarity) and stakeholders (transdisciplinarity). While science can contribute to, and guide, more effective NRM through the provision of new knowledge, technologies, management options, and conceptual and operational frameworks, it is as yet unable to provide complete coherent and broadly acceptable solutions. The impact of research is contingent on the wider economic, institutional and political environments, and these are rarely included within existing models of socio-ecological systems. How processes operate across a range of spatial and temporal scales, and the links between scales, provide additional axes that NRM research needs to encompass. While many conceptual frameworks exist (see Haberl et al., 2006; Young et al., 2006; Fisher et al., 2008; Ohl et al., 2010) they provide little guidance as to how they should be methodologically implemented or analytically interpreted. They also tend to focus on a limited number of system components such as biodiversity, ecosystem services or livelihoods (see Collins et al., 2011).

What will be required to allow us to approach NRM research through a systems perspective?

A number of conceptual and methodological approaches continue to be developed in pursuit of an improved understanding of the dynamics and management of natural resources. These approaches are largely derived from particular disciplinary focuses, and are correspondingly limited in the degree to which they can contribute to a systems-level understanding of NRM. The following section explores some of these limitations.

Addressing NRM research from a systems perspective requires the recognition that systems are (i) understood in terms of the delivery of social, cultural and natural objectives; (ii) shaped by interactions between spatial (farm to landscape and region) and temporal scales; and (iii) heterogeneous across biophysical, ecological and socio-institutional entities. The various research and modeling approaches, each of which provide important information and tools for policy and decision support, need to be adjusted in line with this shift in land use and NRM research emphasis. In particular, here we propose that interdisciplinary research needs to be strengthened by improving the links between economic farm-based models coupled with economic–ecological models at landscape and regional scales.

A practical use of these approaches is to explore the various products and services provided by agricultural systems, as well as opportunities for minimizing negative externalities. Key areas for current and future research include potential opportunities for payment for environmental services to mitigate global warming through carbon sequestration or avoided emissions, as well as proposed payments for preserving biodiversity. At a larger scale, the competing claims on natural resources (Giller et al., 2008) and the conflicting demands on land for agriculture and nature are another key area. As research navigates multiple issues across levels and scales, methods are need to analyze the tradeoffs among stakeholders (e.g. Stoorvogel et al., 2004; Tittonell et al., 2007). This is a fruitful area for future NRM research.

New research and delivery tools, sensing, observing, modeling, communicating

The coupled challenges of agricultural development and NRM have spurred advances in biological, engineering and technical sciences. Advances born out of other developments and enterprises can also be adapted and applied to NRM and agricultural challenges. Some of these new technologies and approaches are already being applied, but have yet to be developed into cost-effective, pro-poor solutions that are part of systemwide frameworks. Others have yet to be fully operationalized, but represent areas of emerging research with the potential to deliver practical benefits within the next decade.

Recent developments relevant to agriculture include coupled advances in biotechnology and informatics, proteomics and plant biochemistry. These fields have led to considerable improvements in our understanding of plant metabolism and development, with valuable benefits to crop improvement. Most of these benefits lie outside the scope of NRM research (notwithstanding debates concerning land sparing and plant environmental tolerances). Beyond the broad field of biotechnology, advances in chemistry, engineering, materials science, remote sensing and ICTs have value for NRM. Emerging technologies and knowledge from these disciplines hold promise for understanding and managing soil, water, biodiversity and other resources within the agricultural landscape. Of course, while technological developments provide solutions to specific problems, they are not comprehensive solutions in themselves. Management of agricultural environments requires the integration of knowledge and technologies into localized contexts. Thus, the value of science-based advances is only realized within a receptive environment (e.g. an improved crop variety is less likely to deliver benefits when it is planted in an unsuitable environment or under inappropriate management regimes). Therefore, developing solutions to low agricultural productivity and sustainable land management requires a multifaceted approach.

Should the CGIAR seek to capitalize on these new advances and emerging technologies by being directly involved in their development, or by adapting and incorporating them for the benefit of tropical farming systems and NRM? It seems that the CGIAR is not well equipped to become directly involved in emerging research (with some exceptions) either because it lies outside the CGIAR remit, or because it lacks comparative advantage. Yet the CGIAR *is* well placed to explore how such technologies might be adapted and applied to pro-poor sustainable agriculture and NRM settings.

Examples of emerging scientific developments and technologies

Despite emerging from sectors that are far removed from agriculture and the environment, many new scientific developments are relevant to agriculture and NRM. Exploring the potential contribution of these technologies to agriculture and NRM also challenges the CGIAR to think beyond its traditional boundaries. The implication is that the CGIAR should consider broadening the scope of its research collaborations with new partners to take advantage of the opportunities that new technologies offer. These new scientific and technological advances include developments in plant physiology, materials science, remote sensing and ICTs. Some of these new technologies are well developed, but have yet to be adapted and applied to pro-poor contexts (see examples below). Others still require considerable research investment. Ignoring such technologies might limit what is achieved by the CGIAR in the longer term. Exploring the potential application of these emerging applications within the context of NRM and poverty requires a willingness to develop new partnerships with academics and the private sector, as well as a more liberal interpretation of the boundaries of CGIAR-based NRM research.

Climate and weather prediction: Improved weather prediction would provide farmers with valuable information for management decisions. Agriculture and NRM in the tropics would benefit from climate and weather forecasting through the provision of early warnings of severe weather, the likelihood and intensity of drought, and improved prediction of the onset of the monsoon. Climatic models, weather forecasting tools and monitoring devices still need to be elaborated and implemented for much of the tropics.

Information and communication technologies: The rapid spread of ICTs can greatly improve the dissemination of information (on weather, market prices, crop information, etc.) in accessible formats to poor farmers. Using ICT systems to help poor farmers access knowledge has already been trialed by the Government of India. Much research remains to be done on how to improve the delivery of information through different forms of ICT (radio, television, cell phones, the Internet, etc.), as well as on farmer access to (and interpretation of) information sourced through ICT, and on how such technology shapes decision making and, ultimately, farm production and NRM. The catalytic potential of ICTs for innovation is considerable.

Remote sensing technologies to improve farm management: Research that makes use of advances in plant, microbial and computational biology, materials science and optical sensing has led to new tools to improve soil structure, maximize the efficient use of water, and provide essential nitrogen and phosphorus to crops. Remote sensing of plant physiology is a promising development that can potentially enable farmers to better manage inputs, with the aim of increasing crop yields, decreasing input costs, and reducing adverse environmental effects. Farmers could potentially use remote sensing information to improve soil management. Such technology could also allow more targeted and efficient applications of fertilizer. Spectral data on plants and soils could be measured remotely and the information sent to farmers on cell phones or other communication devices; however, much work needs to be done to determine how this can be implemented.

Reliable energy systems: Small-scale farmers operate with minimal energy input, and increasing their access to reliable energy supplies could have transformative effects on their livelihoods. Energy is required to power pumps for irrigation and other tools that improve production and processing efficiency. Provision of alternative (non-biomass) energy supplies would reduce local environmental degradation. It would also provide access to radio, television and computers. Agricultural technology development has always been an important aspect of CGIAR research. Research and development of locally adaptable and affordable energy supplies, while not traditionally within the remit of the CGIAR, can be considered an element of the innovations systems approach to NRM. These research options should not be ignored. While recognizing that the development and success of technological innovations requires local expertise and participation, such innovations do not necessarily need to be based on 'low' technology.

Scaling of impact and research

Scaling-up of impact: There are no simple rules to scaling-up of research to achieve impact, although it is now broadly recognized that research must be integrated within the wider development process that transcends any single scale of analysis. This requires engagement with a variety of actors and institutions (Figure 6.1). In the past, scaling-up was usually viewed as an activity undertaken after completion of the research project; now, early planning in the pre-project phase for scaling-up is considered a necessary requisite for success. Box 6.1 describes 'theory of change' approaches to research planning that can clarify pathways to scaling-up.

There are two forms of scaling-up impact: (i) scaling-out (or horizontal scaling-up) involving the dissemination of new knowledge and technologies to people within the same target group but across geographical scales; (ii) vertical scaling-up, referring to the extension of ideas, knowledge and management processes across stakeholder groups and institutions, and to policy makers, private sector interests, development organizations and donors (Figure 6.1).

Important elements for successful scaling-up include engaging in policy dialogues, building networks to support pathways to scaling-up, building institutional capacities for dissemination and promotion, securing financial support for expansion, and developing methods for evaluating scaling-up impact (Gündel et al., 2001). The CGIAR has plenty of experience in several of these elements, even though 'capacity building' at this level, as opposed to that at the

Box 6.1. Theory of change

Theory of change (TOC) is a tool for developing solutions to complex social problems. A basic TOC explains how a group of early and intermediate accomplishments sets the stage for long-range results. A more complete TOC articulates assumptions about the process through which change will occur, and specifies the ways in which all of the required early and intermediate outcomes related to achieving the desired long-term change will be brought about and documented as they occur.

Source: Anderson, 2005.

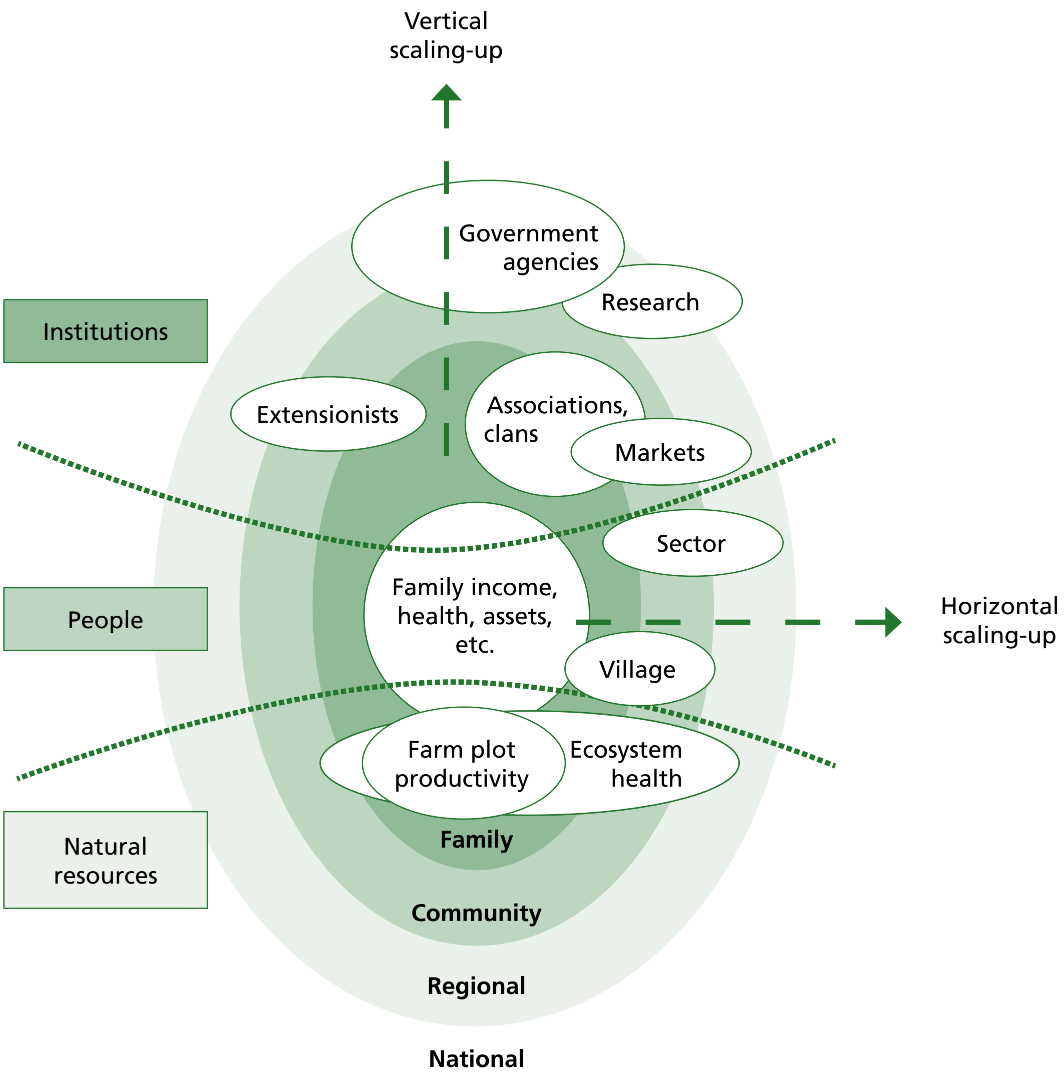

Figure 6.1. Scales of impact and processes of scaling-up. (Gündel et al., 2001; adapted from IIRR, 2000.)

disciplinary or technical level, has been considered to lie outside the CGIAR research remit. Boundaries between research for development, extension and capacity building are, however, blurred, and while the CGIAR might not be well placed to intervene directly in such activities, it needs to engage with and support such activities for its research to achieve impact at scale. The process for accomplishing this has yet to be developed. Theory of change might assist in developing scaling-up strategies, but methodologies for applying the theory of change approach to real-world situations are not well elaborated.

Scaling methods in research: *Biophysical and socioeconomic scales* need to be matched for effective decision making, yet even selecting the appropriate scales for conducting research on NRM can be problematic, in view of the multiple scales over which economic and biophysical processes operate. A systems approach to research embodies the integration of information across spatial and temporal scales; it also requires the accommodation of non-linear changes in outcomes and feedbacks among response variables across these scales. Methodologies that link observations, processes and models across scales have yet to be fully developed. Outstanding challenges include aggregation of data and indicators, establishment of linkages across scales, and integration of economic, social and biophysical models (Volk and Ewert, 2011). There are large gaps between models that explore hypothetical scenarios of future land use or climate change, and studies that evaluate the impacts of current decision-making processes at local scales. Failure to bridge these gaps is likely to result in a failure to recognize interactions across scales that give rise to positive or negative synergies, which could have substantial implications for outcomes.

Landscape-scale models and analyses tend to be based on the aggregation and averaging of data from smaller-scale land-use units (farms, forests etc). Synergies and step-changes resulting from interactions among multiple farm or other land use units are generally not accommodated by such models. Indeed, social processes underlying land management, if included at all, are usually aggregated with a concurrent loss of system heterogeneity. Thus the presentation of spatially explicit landscape outcomes can be highly effective for stakeholder and policy engagement, but downscaling is still necessary to capture the many heterogeneities across societies and landscapes.

Integrating models across *disciplines* also faces several unresolved challenges, including how to facilitate interaction among different stakeholders to enhance the impact of scientific knowledge, how to overcome conceptual differences between models, and how to link the different time scales over which biophysical, social and economic processes operate. There are no clear answers to these problems, but they are issues that lie at the heart of CGIAR objectives in NRM research.

Methodologies, such as 'hierarchy theory' as adopted by some of the CRPs, are being developed to address each of these issues. According to Allen and Starr (1982), hierarchy theory, which comprises scale-nested systems of analysis, "should be useful to understand integrative processes in a system when patterns and functioning of the system are determined by a set of interacting processes operating at a large variety of spatial and temporal scales" (Allen and Starr, 1982). However, this still requires the development of data extrapolation and aggregation techniques, model coupling and the scaling of model parameters. Integrated, multi-scale models are complex; they have high data demands and their understanding and application requires considerable technical expertise. Scaling has central importance to NRM research, to understand both system dynamics and impact. Consequently, the advancement of methodologies to integrate data across scales is a researchable issue to which CRPs could make a substantial contribution – and which the CGIAR is well placed to address (see section on Comparative Advantage, below). This, however, requires targeted research attention.

A major scientific challenge for INRM research is to address the integrated nature of biological and landscape systems themselves: the many concepts of multifunctionality, and many 'systems'-based research frameworks, recognize that NRM research encompasses diverse stakeholders and institutions, and multiple scales across which biophysical and human processes interact. The development of crosscutting methodologies that address systems and scale interrelationships concepts is in itself is a researchable constraint that should be afforded more targeted attention across the CGIAR. Advances in up-scaling and down-scaling methodologies, and integration of modeling platforms would have crosscutting benefits across a wide range of NRM research objectives, and would contribute to the effective implementation of NRM research and evaluation of its impact.

In summary, there is wide recognition of the need to integrate information across disciplines, scale-up and scale-out, harmonize information derived from different modeling approaches, and define impact pathways. This recognition is evidenced by the evolution of NRM research concepts, as expressed through previous CGIAR publications and, most recently, in the CRPs. Still, it is equally clear that considerable challenges in their implementation remain. The CRPs, for example, generally do not articulate in detail what methodologies or models will be used to scale-up, how data from different CRP components and disciplines will be integrated, and how these are expected to deliver impacts in the short and long term. The use of ICT to archive, manage and access data, within as well as across CRPs, requires elaboration. Assessing and quantifying impacts is also challenging, both in theory and in practice. Thus, processes for impact assessment should be initiated early in the research planning cycle.

These issues are not specific to the CRPs or to the CGIAR, but affect NRM research generally. Nevertheless, the CGIAR's research and development objectives make these priority issues for its research. The range of disciplinary expertise and the long evolution of these concepts (from innovation systems to IAR4D to innovation platforms) within the CGIAR research frameworks provide the CGIAR with the capacity to address these issues as researchable challenges in their own right. Thus while 'research systems' have been elaborated, revised and reframed, defining the operational and methodological processes is the next major challenge.

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CHAPTER 7.
Key messages and a potential way forward

The main messages of this report, discussed in Chapters 1–6, are summarized in this chapter. The Panel also focuses on the realization of the CGIAR's comparative advantages in organizing and supporting its portfolio of NRM research with partners as being critical to the CGIAR's future success.

Key messages

NRM plays a fundamental role in CGIAR research. The sustained productivity of the world's agricultural systems is critically dependent on the state of natural resources, most notably land, water, the biota and the atmosphere. Agricultural systems can also directly influence natural resources positively through the provision of environmental resources and services or negatively through loss of biodiversity, contamination of water systems, depletion of soil fertility and the release of GHGs into the atmosphere. NRM has always been important – for example, the Green Revolution came through the combination of new genotypes with improved management of water, nutrients and pests. Now, all indicators point to a growing importance of NRM issues over the coming decades, given the likely challenge of producing more food from increasingly constrained land and water resources. This must be achieved with more efficient use of inputs, enhanced soil health, reduced GHG emissions, and lower nutrient and soil losses to rivers and oceans.

The sharp division between NRM and crop genetic improvement is blurring. The renewed CGIAR has adopted a mission that places NRM firmly in the center of its agenda. Environmental sustainability is explicitly included among the four system-level outcomes (SLOs) as an essential element of future agricultural production and sustainability. Most research on agricultural issues today operates along a continuum that spans from genetics to farmers' fields and to the broader environmental and socio-political landscape. There is growing acceptance of the fact that NRM enables the impact of crop genetic improvement to be expressed and sustained over the long term.

NRM research in the CGIAR is ready for a comprehensive reframing. In the past, NRM research in the CGIAR evolved as a set of accumulating activities and Centers, without an overarching strategy of its place alongside genetic improvement and social/institutional research. Looking forward, a more integrated approached is needed to address the SRF – that is, an approach in which crop genetic improvement, NRM and socio-economic/institutional approaches are seen as interactive and intersecting and often co-dependent pathways for progress toward the SLOs. The concept of 'three pillars' of classification needs to evolve towards a solution framework embodied by (GxExM)^I (see Chapter 2), where interactions between the elements play out differently across spatial and temporal scales. This in turn requires a new organization of science based on the interactions of genetics (G), environment (E, including a changing environment) and management (M, done by and for people) in the most relevant institutional (I) context.[19]

The development of crosscutting methodologies that address systems and scale interrelationships is in itself is a researchable constraint that should be afforded more targeted attention across the CGIAR. A major scientific challenge for NRM research is to address the integrated nature of biological and landscape systems themselves. There are many concepts of multi-functionality (Caron et al., 2008a, b), and

19 The term 'Institutions' is used in the broadest sense of the word – often described in terms of efforts to "reduce uncertainty in human interactions". The term covers both the formal and informal 'rules of the game'. Policy and organizational structures are part of this broader notion of institutions. Institutions are the constraints that human beings impose on human interaction. They consist of formal rules (constitutions, statute law, common law, regulations) and informal constraints (conventions, cultural norms and self-enforced codes of conduct) and their enforcement characteristics. Those constraints define (together with the standard constraints of economics) the opportunity set in the economy. http://129.3.20.41/eps/eh/papers/9309/9309001.pdf

many systems-based research frameworks, that recognize that NRM research encompasses diverse stakeholders and institutions, as well as multiple scales across which biophysical and human processes interact. These concepts also recognize that up-scaling and down-scaling are non-linear, that there are complex interdependencies, tradeoffs and feedbacks between and within scales. Factors that lie outside the normal realm of NRM research can have large impacts on system outcomes. People's livelihoods are themselves diverse and dynamic, and short-term goals might be very different to long-term aspirations. CGIAR NRM research recognizes these issues, as evidenced by the existence, structure and function of the CRPs. The elaboration of impact pathways helps to conceptualize these challenges and focus research on the key issues. Yet the methodologies to address such issues (notably scaling, but also the coupling of economic, social and biophysical models) are not yet well established. Advances in up-scaling and down-scaling methodologies, and in the integration of modeling platforms, would have crosscutting benefits across a wide range of NRM research objectives, thus contributing to the effective implementation of NRM research and the evaluation of its impact.

Monitoring, evaluation and impact assessment for NRM research need to be improved. There is a paradox that must be addressed at the heart of the debate over NRM research. Effective NRM is increasingly important to the attainment of the global goals for agriculture and sustainable development, yet the evidence that the contributions of NRM research have had impacts at scale is patchy at best. The NRM community cannot opt out of the need for monitoring, evaluation and impact assessment on the grounds of complexity. There must be continuing efforts to demonstrate and document the outcomes of NRM research. It is therefore necessary and legitimate to pursue research (in the CGIAR and working with international experts) to develop new methods for impact assessment that recognize the contributions of NRM research.

Donor commitment and discipline is needed to reap the rewards of changes to the CGIAR System. Considerable investment of time and effort has gone into the restructuring of the CGIAR and the establishment of the CRPs. Donors have been both an important trigger for, and a part of, this ongoing reform. Now that the process of preparation is giving its first fruits, it is important that donors maintain their commitment of investment to achieve the development aims that have been agreed in the SRF. It is important that the donors accept and support the CRPs that have emerged through a rigorous and far-reaching consultation and review process. Success of this new CGIAR model can only be achieved if continuity and stability are guaranteed for the coming decade, at least. This is not to say that further refinement of the CRPs should not occur, but if reflexive monitoring and evaluation systems are in place the CRPs will continually learn and adapt to new challenges. **There is a mutual responsibility: researchers must deliver NRM outcomes and donors must remain committed to sustaining the inclusion of NRM work in the CRPs in the years to come.** The responsibility for the conduct of this newly restructured program is thus shared by both researchers and donors. If too large a proportion of funds continues to be funneled through short-term projects, this will undermine and possibly derail some of the CRPs; in particular it may jeopardize their capacity to achieve the environmental sustainability of food production systems.

There is a need to invest in strategic leadership. 'Thought leadership' in both science and the pathways needs to be invested in the CRP management and the advisory scientific panels. Also, we must create a culture of openness to allow partner input and innovation. The CRP leaders must be vested with the authority to drive forward teams comprising staff from different CGIAR Centers, as well as other partners.

Is comparative advantage being realized?

Where interdisciplinarity is recognized as being relevant, a skills base for the integration of data and research approaches across disciplinary boundaries should be developed through training, mentoring and targeted research. Although the broad interdisciplinary aims of CGIAR research are well articulated in the CRPs, individual work packages do not clearly detail how interdisciplinary goals will be pursued – and neither is it obvious that CGIAR scientists have particular capabilities in this respect. The fast pace of disciplinary advancement contributes to the fragmentation of systems analysis and constrains the emergence of a shared research language. Current shortcomings in interdisciplinary NRM research at CGIAR Centers are probably not due to a lack of operational practices, financial resources or viable solutions. Rather, they are the result of a failure of CGIAR scientists to make best use of the opportunities that the CGIAR structure affords for emerging from disciplinary outlooks. This is exacerbated by the limited training available to staff on how to draw on and integrate knowledge and methods across disciplines to find solutions to real world problems.

Emphasis should be given to the complementarity of the roles of the CGIAR and its partners according to the comparative advantage of each. The CGIAR might not be able to compete with universities or the private sector in some areas of emerging science, but it does have comparative advantage in exploring how new science and emerging technologies might be adapted to pro-poor NRM challenges. The CGIAR could be an effective bridge through which new scientific developments arising in developed countries could meet the needs of developing countries. The bridging function of the CGIAR might be enhanced through new private enterprise initiatives catalyzed by CGIAR research, as has occurred previously. However, it is not clear whether these are actively planned or whether they arise serendipitously and opportunistically.

The role of the CGIAR as a broker of innovation should be explored further. By bridging different knowledge sets and different institutions, CGIAR researchers could improve engagement with innovators of scientific theory, methods and technologies. Collaborations with private corporations do exist (e.g. Syngenta, Nestlé), but these could be expanded and developed further, particularly to include and stimulate local private enterprises. Past research activities (e.g. CIMMYT's no-till agriculture) have demonstrated that there is potential to catalyze new private enterprises that facilitate the uptake of improved methods, while delivering multiplier effects through job creation. However, as with collaborations it is not clear whether such instances are actively driven by planned CGIAR research and implementation pathways, or whether they arise spontaneously.

Research partnerships with university scientists are common, but the depth of collaborative commitment is unclear, as is the commitment to shared research and impact objectives. Lack of engagement in teaching and project supervision may disadvantage CGIAR scientists by limiting access to young scientific 'innovators' (e.g. Masters and PhD students and postdocs). This might slow the rate at which new techniques and research methodologies are encountered, developed and adopted within the CGIAR, and might also constrain the exposure to new ideas that transcend the more usual agriculture and NRM research boundaries.

Performance evaluation criteria and different career structures at universities might create a mismatch between research priorities, outlooks and time frames of university partners of CGIAR programs. An analysis of how such collaborations develop and unfold could provide valuable insights for strengthening engagement with universities. The bibliometric analysis of NRM research across the CGIAR (see Chapter 3 and Annex 6) illustrates that collaboration with university and other non-CGIAR scientists has a substantial positive impact on the number and quality[20] of resulting publications. Many of these publications are, however, led by non-CGIAR researchers, suggesting an asymmetrical distribution of contributions within such collaborations. Options such as shared CGIAR–university positions, or placement of CGIAR staff in universities, has been previously discussed and should perhaps be revisited for the purpose of strengthening such research partnerships.

Additional and complementary investment

- **Skills:** A key question arising from the above focus on 'future-oriented research' is whether the CGIAR has the necessary

20 As judged by impact factors and citations.

skill sets for tackling such research? Several of the new proposed CRPs place systems approaches at the center of their programs, but with one or two exceptions there are few CGIAR Centers with strong skills in *integrative* systems research. Many are looking for collaborations and appointing new staff to fill this gap. This emphasizes the need for strong partnerships with advanced research institutes (ARIs) as well as with national agricultural research and extension systems (NARES).

- **Modeling:** Although one emphasis has been on modeling, and the need for 'modelers', capacity in *systems analysis* is the essence of the requirement. Simulation is one tool to explore the dynamic interactions and feedbacks in the model. There are other types of model that are key tools for NRM research, such as optimization models, which are an important tool for examining the influence of feedbacks.
- **Invest in soft and hard infrastructure:** The associated skill sets and facilities required to make NRM research function according to the recommendations set out in this paper will require bringing in social scientists to help establish long-term monitoring and evaluation systems that can measure and benchmark changes. Such an approach can help researchers learn from successes and obstacles as they are encountered. The CGIAR can achieve its goals only if it invests in the professional staff best suited to meeting emerging research challenges.
- **Need for effective data storage:** In the past the CGIAR has paid insufficient attention to maintaining a central facility for collection, quality control and archiving of data. While experimental data from research conducted on the main research stations may be archived, the stored files often lack sufficient meta-data and annotation to allow their ready use. The situation concerning data from experiments conducted on smaller research stations or in farmers' fields is parlous. Data have often disappeared with departing scientists or have been lost due to problems with disk storage. The conduct of syntheses or follow-up studies is thus compromised. A promising initiative established through the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is the Global Agricultural Trial Repository.[21] At the time of writing (mid-2012) some 2,500 trials had been uploaded. The Panel therefore recommends that all programs be charged with contributing their data to this, or similar repositories agreed at the Consortium level. Programs will have to ensure that data are developed and stored as more comprehensive meta-data sets for comparability across programs. Thus, they can serve collaborative research and learning, as well as opportunities to enhance the development of international public goods.
- **Measurement:** The CGIAR is uniquely placed to collect detailed information on farming systems and broader land-use systems, on livelihoods, and on the embedding of technology performance within different institutional settings. Unfortunately, these opportunities are often not realized due to lack of coordinated methods and data collection.

Many of the key questions concerning global food security cannot be answered without a full understanding of local realities in developing countries. Few studies have monitored and measured change in farming systems. Detailed information collected at village and household levels allows a retrospective analysis of changes in livelihoods and living standards. In order to be able to understand actual and possible adaptive responses to changes in the agro-ecological and socioeconomic environment, we need an understanding of past trends. There appear to be few longitudinal studies that can be drawn from to elaborate clear trends in the productivity of crops over time. Without measurements of yield and production, analyses cannot be properly grounded. For instance, at present, the best yield gap analysis for the major crops in developing countries is an analysis based on 'expert judgment' (Waddington et al., 2010).

- The CGIAR is well-placed to lead a grounded yield gap analysis to better understand the primary constraints to agricultural production, and to use this as a basis for an analysis of regional and global food security, and for priority setting in research.

21 See www.agtrials.org

Box 7.1. Climate change – an example of the need for systems analysis and modeling approaches

The greater involvement of CGIAR institutes in climate change research through the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is likely to stimulate deeper thinking and analysis of future scenarios. Climate change research in agriculture with farmers in both developing and developed countries indicates that other threats and pressures, notably market volatility and the cost of inputs, are much more acute than impacts of climate change *per se*.

- CCAFS brings the CGIAR into the research community on climate change.
- CCAFS needs to carve out a special niche for the CGIAR, not duplicating continuing initiatives elsewhere, but exploiting the comparative advantages of the CGIAR.

The comparative advantage of the CGIAR in climate change research, as well as scenario-based research on other issues, lies in its geographical location and links with NARES and farmers. Other research groups around the world are better placed to run detailed modeling studies on the future impacts of climate change. The CGIAR should focus on developing (local) adaptation approaches and other issues that need studies grounded in local realities. Analyses of the local potentials for REDD and REDD+ is another fruitful area where the CGIAR could play a central role through its partnerships.

- The CGIAR can contribute enormously by revealing the problems of achieving change and impacts in terms of uptake of different approaches to agricultural practice or land management in developing countries.

Considerations for partnerships

Working with NARES and the additionality of CGIAR research. In some regions and countries, the NARES are increasingly strong and effective (e.g. China, Brazil, India), whereas in other regions – notably many countries of Asia and sub-Saharan Africa – the NARES remain underfunded and have few skilled staff. The challenge is to develop a strategic approach that allows locally appropriate results to be scaled to a regional understanding of opportunities. This appears to be an area where much reflection is needed to develop a strategic approach that can demonstrate the additionality of CGIAR research.

For example, basic agronomic principles are well established for: nutrient management using inorganic fertilizers and organic nutrient sources; planting dates and plant population densities; crop residue management; land preparation and erosion control (e.g. in conservation agriculture, water-saving production system for rice); and livestock feeding. What is the benefit of more plot-based studies?

The CGIAR should adopt a focus of working more on the farm household or livelihood level in its technology for development work. In essence this can be summarized as 'It's all about context'. A shift is needed from the idea of 'best bet' technologies to 'best fits', recognizing the diverse socio-ecological niches within rural communities (Giller et al., 2006, 2011). At the same time, CRP leaders and CGIAR Centers should cross-reference results and methodologies among different sites to ensure the creation of international public goods. A powerful approach for sharing knowledge and program experiences, and for capacity building, is to develop learning materials based on the insights and outcomes of research programs.[22]

22 These learning materials, in the form of sets of conceptual diagrams, methods and approaches, photographs and other illustrations, together with explanatory texts, can then be adapted to the specific needs of users. In particular, ideas and case studies for practical exercises are difficult to develop and are highly valued by lecturers. The lecture notes and training materials produced by ICRAF Southeast Asia are good examples of highly appropriate and useful materials (search for lecture notes on the publications page of http://www.asb.cgiar.org/).

The balance of these requirements is a key issue in answering critiques regarding the local nature of NRM research impacts. Reflection is needed on how to obtain and embed different types of research as well as wider knowledge on the institutional conditions necessary for development, and so provide 'recommendation domains' for technologies and enabling policies.

Precisely because of the *international* nature of CGIAR research, and the needs to produce international public goods, both in terms of outcomes (learning and knowledge) and eventually impacts, the time frame within which measurable impacts can be seen may be long (15 years or more) and difficult to measure and attribute. The CGIAR's NRM research should add value beyond that produced by national partners, through comparison, coordination, or crossover between countries.

As the national research programs of many developing countries are still organized around commodities or disciplinary teams, there is a clear opportunity for the CGIAR to encourage interdisciplinary approaches. Instead of working on individual components (crops or animals), research needs to focus to a greater extent on integrating new components (varieties, breeds or management packages) within the farming system. To support such approaches, the Panel strongly recommends that the role of CGIAR in building capacity in NARES – at both the scientist and technician levels – should be reinstated and reinvigorated.

The new look CGIAR and the effectiveness of large collaborative projects. The scale and size of the coordination and collaboration expected within the CGIAR System appears to rise inexorably. We have moved from Systemwide Programs to Challenge Programs to Mega-programs, now called CRPs, which have projected budgets of US$150–250 million. There is a danger that the transaction costs incurred in such large projects will lead to a gridlock of intersecting coordination. Above a certain size, coordinated projects seem to lose effectiveness and productivity rather than increase it.[23] More partners leads to more planning of meetings and workshops, more email, more transaction costs and eventually less impact.

What is the optimal size of a project or research team? How can large projects be organized to reap the benefits of collaborative and comparative research, while allowing individual creativity and responsiveness? One approach is to establish and work within networks. Such networks can be an effective way of leveraging research and development funds for partners, and executing both research and development projects in an effective and coordinated manner. It is clear that the success of such initiatives relies on strong strategic leadership and sound management. Having small teams work on similar issues could create the kind of healthy competition on which many researchers thrive. This needs to be encouraged while still maintaining coordination.[24] Although the optimal size for a collaborative project will differ depending on the specific question at hand, there is an emerging consensus that groups of around 10 scientists from various disciplines working closely on a common topic approximates the optimal situation.

A portfolio approach for NRM research: The wide diversity of problems and issues addressed by the CGIAR System makes

23 The EU started Framework Program 6 (FP6) by funding 'integrated programs (IPs)' to the tune of €1,015 million with 30–50 partner institutions and more than 150 collaborating scientists. The size of later projects in FP6 and FP7 has been reduced in response to the difficulties encountered in delivering effective research with so many individuals involved.
The experience gained from some of the larger Challenge Programs is informative, for example the Sub-Saharan Africa Challenge Program was subject to multiple inputs from funders and a wide variety of organizations that insisted on involvement of numerous partners with an IAR4D framework. There appeared to be a belief among some that including more partners leads to more success, and is more efficient in terms of delivering value for money and stretching funds further in terms of the impact generated – in short 'more partners, more impact'. The opposite can be argued.

24 Examples that have been successful in bringing together CGIAR institutes, NARES, NGOs and other partners are: the Consortium for Improving Agriculture-based Livelihoods in Central Africa (see www.cialca.org) in which CIAT, IITA and Bioversity play leading roles, together with ARCs such as the Katholiek Universiteit, Leuven, Belgium; and the Pan-Africa Bean Research Alliance (http://www.ciat.cgiar.org/work/Africa/Pages/PABRA.aspx)

it clear that a one-size-fits-all approach is inappropriate. Readers may be disappointed to discover that the Panel believes it is impossible to provide a blueprint for how to 'do' NRM research. A portfolio approach is recommended, using Ockham's Razor as a guide.[25] In some cases, for example the ecological intensification of the production of a given commodity, a linear value-chain approach may be appropriate. When dealing with more complex issues such as common property resource management, an innovation systems approach may be needed.

The portfolio of CRPs offers new opportunities for learning and sharing best practices across the CGIAR Research Centers and their partners, and provides the best means to embed sustainability science in the collaborative achievement of the CGIAR's long-term goals.

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25 Ockham's razor is a principle that generally recommends that selecting the hypothesis that makes the fewest new assumptions usually provides the correct one, and that the simplest explanation will be the most plausible until evidence is presented to prove it false (based on Wikipedia).

ANNEX 1.
Steps of the *Stripe Review of NRM Research in the CGIAR*

The ISPC, cognizant of concerns by the CGIAR and SPIA that the impacts at scale from CGIAR research were poorly reported or difficult to find, described the need for a study on NRM research in its Work Plan prepared for 2011/2012. The *Stripe Review of NRM Research in the CGIAR* was therefore designed to provide CGIAR Centers and other stakeholders with perspectives that influence the achievement of impact at scale from NRM research, with a view to enhancing the quality of NRM research programs in the CGIAR.

The design of the *Stripe Review of NRM Research in the CGIAR* started in December 2010. The Review was undertaken under the guidance of ISPC Member, Prof. Jeffrey Sayer (School of Earth and Environmental Sciences, James Cook University, Cairns, Australia) through the contributions of an *ad-hoc* panel (the NRM Stripe Review Panel[26]) set up in March 2011. The Panel consisted of four eminent scientists: Dr P. Caron (Director General, Research and Strategy, CIRAD), Dr J. Ghazoul (Professor of Ecosystem Management, ETH), Dr K. Giller (Professor of Plant Production Systems, University of Wageningen), Dr B. Keating (Director, CSIRO Sustainable Agriculture Flagship), supported by the ISPC Secretariat.

Official invitations to participate in the *Stripe Review of NRM Research in the CGIAR* were shared with the Centers' Directors General in March 2011. Although welcoming the initiative and showing interest in participating, the Centers suggested postponing the interactive component of the study until the end of the year, once the work load for the preparation of the CRPs would have decreased. Centers' focal points were nominated in late April 2011. It was therefore agreed to hold the first consultations of the initiative at the Science Forum 'The Agriculture–Environment Nexus' in Beijing in October 2011.

26 Role of the Panel Members reported in NRMR Stripe Review concept note

Background material for the consultations with the Centers and to facilitate the work of the NRMR Stripe Review Panel was provided beginning in January 2011. In this framework the ISPC Secretariat undertook a review of literature in the Science Council/ ISPC archives to examine and learn from the NRM research in the CGIAR System. The reviewed archives included: (i) summaries and/or assessments of CGIAR NRM research; (ii) External Program and Management Reviews (EPMRs); (iii) relevant material Centers shared with the ISPC; and (iv) assessments of outcomes and impacts submitted by the Centers in the framework of the performance measurement system (PMS). The database and detailed classification of NRM research examples and outcomes originated from this review are available from the ISPC Secretariat upon request. A bibliometric study was commissioned to an external expert (Dr Petrokofsky, Templeton College) for the period 2000–2010 (inclusive). Issue papers and thought pieces on NRM research, the CGIAR's role and the factors leading to impact at scale were drafted by the Panel Members.

Discussions of preliminary considerations from the background material (including the thought pieces) with the Centers' focal points and other relevant stakeholders took place at the NRM research Stripe Review workshop (Beijing, 16 October 2011) and expanded into the Sustainability Science sessions at the Science Forum 2011 (Beijing, 17–18 October 2011).

The feedback received during the consultation step was elaborated and, between November 2011 and February 2012, the thought pieces and the bibliometrics were revised accordingly. An additional literature review was undertaken at this stage to finalize the selection of the examples of NRM research from the CGIAR, from which important lessons could be learned on past CGIAR NRM research and impact at scale.

Further **consultations** with the Centers took place in February 2012, when the list of potential examples of NRM research in the CGIAR was shared with Centers and there were iterative exchanges of materials and the checking of the bibliometrics study. The Stripe Review was in fact attempting to develop **a short set of accounts of NRM research** conducted in the past decade and which demonstrated: (i) impact at large scales of NRM research conducted by the CGIAR; (ii) innovative methodologies/ approaches; (iii) international public goods derived from NRM research; and (iv) limitations, obstacles or other lessons that the broader CGIAR needs to be aware of in considering future NRM research initiatives. The examples would serve as inputs for the understanding of the type of NRM research conducted by the CGIAR, and also as a tool for the NRM research Stripe Review panel to identify potential 'clever hooks' or factors leading to impact at scale. A preliminary list of stories was prepared by grouping together: (i) the list of NRM outcomes that received high scores from the PMS 2005–2009; (ii) 'best' impacts and 'best' outcomes (self-selected by the Centers from those submitted to the PMS database); and (iii) other relevant research cited in past EPMRs or NRM research assessments. Attempts were also made to capture stories which provided lessons on 'what not to do' (e.g. submitted program reports with a low score in the impact or outcome PMS database). The list was shared with CGIAR Centers as one of the preparatory documents of the NRM research Stripe Review workshop, and it has been subsequently revised taking into consideration the feedback received at the event. Specific selection criteria are available upon request to the ISPC Secretariat.

The drafting of the present report (a strategic paper on a potential way forward for NRM research in the CGIAR) started in February 2012 during the NRM research Stripe Review writing workshop (Penang, Malaysia, 15–17 February). Here the NRM research Stripe Review team prepared an initial draft of the strategic report, putting together the lessons learned, the information captured through the review of past NRM research in the CGIAR, the consultations with Centers, and the knowledge of the Panel members. The workshop also had the aim of exchanging information with the NRM Impact Assessment group currently being established among the CRPs.

ANNEX 2. Typology of NRM research according to the examples selected during the NRM research Stripe Review

The summary below is based on the material shared by the Centers on each example reported in Box 3.2. It is not meant to judge the research, but it was used as a tool to help the NRM research Stripe Review panel in discussing a potential typology of NRM research in the System.

Type	Example number	Main disciplines	Main scales	Lead Center	Local specificity / generalization (up-scaling)	Model / cross-scale model	Participatory approaches and boundary objects	Dissemination and transfer approach (out-scaling)	Impact assess-ment (including side effects)
I.1 – Status and dynamics of one particular resource	7	Soil sciences (pedology), Agronomy	Farm, farming-system, watershed	ICRISAT	Local specificity	No	Participatory sampling methods + farmers' participatory action research	Technical support, capacity-building measures, enabling policies and appropriate institutional mechanisms	Yes (cost–benefit analysis per crop type)
I.2 – Management of one particular resource	12	Economy, Hydrology	Farm, farming-system, sub-national	IWMI	Generalization	No	No	State institutionalization	Yes (including externalities)
	6	Technological research, Agronomy	Local (farm), farming-system, sub-national, cross-scale	ICARDA	Local specificity	Yes/No	Community-based participatory methods + participatory methods, involving researchers, 'extensionists' and policy makers	Field visits, farmer field schools, workshops, meetings with development technicians and policy makers, dissemination through adoption by following projects	Yes
I.3 – Ecosystem management	13	Ecology, Social sciences	Regional, cross-scale	World Agro-forestry Centre (ex. ICRAF) and CIFOR	Local specificity (benchmark sites)	No (but it is one of the prospects for future work)	Network approaches rather than full participatory approach	A learning organization thanks to various partnerships including research institutes, NGOs, universities, community organizations, farmers' groups, and other local, national, and international partners	Yes

Typology of NRM research according to the examples selected during the NRMR Stripe review (continued)

Type	Example number	Main disciplines	Main scales	Lead Center	Local specificity / generalization (up-scaling)	Model / cross-scale model	Participatory approaches and boundary objects	Dissemination and transfer approach (out-scaling)	Impact assess-ment (including side effects)
I.4 – NRM institutional arrangements	8	Social sciences: socio-economy, institutional and law	Local, community, landscape level, cross-scale	IFPRI	Generalization	Yes/No	Participatory action research: multi-stakeholder's	Workshops and information dissemination via web site. Collaboration with local organizations and researchers in policy workshops	Yes
I.5 – Policy for NRM	5	Policy research, Economy, Agronomy	Farming system, national, multi-country	ICARDA	Local specificity	Yes	No (It analyzed participatory approaches but didn't use one)	No training or transfer	Yes
II.1 – Adaptation of agriculture because of an environmental question	3	Technological research, Agronomy	Local, farming-system, sub-national	CIMMYT	Local specificity	No	Learning platforms to engage, catalyze and support NARS technology developers and associated stakeholders	Training platform, innovation network	
	10	Epidemiology, Agronomy, Entomology	Farming-system, protected area, landscape, sub-national, national, multi-country	IITA/CIAT	Local specificity	Done by partners/ No	No	Training, capacity building through training and facilities	Yes
	4	Agronomy, Agricultural engineering	All (from local to multi-country) and cross-scale	CIMMYT	Local specificity	No	Participatory approach to promulgate the new practices	Through networking	Yes with farmers + cost–benefit
	11	Agronomy, Hydrology, Agricultural engineering	Sub-national, national, multi-country	IRRI	Local specificity	No	Participatory research to validate technologies	Training and extension material	Yes

Typology of NRM research according to the examples selected during the NRMR Stripe review (continued)

Type	Example number	Main disciplines	Main scales	Lead Center	Local specificity / generalization (up-scaling)	Model / cross-scale model	Participatory approaches and boundary objects	Dissemination and transfer approach (out-scaling)	Impact assess-ment (including side effects)
III.1 – Production of natural resources by agriculture	4	Agronomy, Agricultural engineering	All (from local to multi-country) and cross-scale	CIMMYT	Local specificity	No	Participatory approach to promulgate the new practices	Through networking	Yes with farmers + cost–benefit
	11	Agronomy, Hydrology, Agricultural engineering	Sub-national, national, multi-country	IRRI	Local specificity	No	Participatory research to validate technologies	Training and extension material	Yes
	1	Sociology	National, multi-country	CIATA	Generalization	No	No	No training or transfer	No
	9	Agroforestry, Economy, Ecology	All (from local to multi-country)	IITA	Generalization	Yes/No	A cross-country platform for the multiple stakeholders of the program	No training or transfer	Yes
	14	Economy, Agronomy	All (from local to multi-country)	WorldFish	Generalization	Yes/No	No	No training or transfer	No
III.3 – Land use at the global level	2	Economy, Geography	National	CIFOR	Local specificity	Yes/No	Not clear…	No training or transfer	Yes

ANNEX 3.
Defining the NRM research domain: an alternative approach

Given that NRM research means different things to different people, a working definition is essential. A typology has been adopted for this paper which allowed review and classification of the case studies provided by CGIAR Centers. An alternative is to adopt a conceptual approach, which is provided in the following example.

The term itself can self-evidently be unpacked into two concepts, namely 'natural resources' and 'management'. The overarching purpose within which we are considering NRM is essentially the purpose of the CGIAR – to reduce hunger and poverty in the developing world, most recently and most comprehensively expressed in the System-level outcomes (SLOs) of the CGIAR Strategy and Results Framework (SRF), namely; "reduction of rural poverty, increase in food security, improving nutrition and health, and more sustainable management of natural resources" (SRF, 2011). In terms of Millennium Development Goals, that is an aspiration (increasing distant) to halve world hunger and poverty by 2015 relative to 1990 (UN, 2000). Hence, 'natural resources' relevant to this overarching purpose would at the highest level include land, water, oceans, atmosphere and the biota that occupy these domains. More specifically, it is the critical biological and physical cycles for water, soils, nutrients and energy that underpin ecosystem function as well as the maintenance of biological diversity that is in itself inextricably linked to ecosystem function – including the sustained functioning of the agro-ecosystems that produce our food. The 'management' component of NRM, denotes specific human intervention to achieve some purpose.

Recombining these ideas, we have a working definition of NRM in the CGIAR context as being defined in terms of: "*human interventions in the natural world of land, water, oceans, atmosphere and biota that can influence (positively or negatively) food security and rural poverty in the developing world*".

This is still an enormously broad scope. In Table A3.1 an attempt is made to create some structure to this definition. This table shows we can think of types of NRM research that differ in scale and degree of direct linkage to food production activity. The NRM research Stripe Review directed its focus to types 3, 4 and 5 (see below) on the grounds that they are inextricably linked, in an agroecological sense. However, the report also highlights the critical interfaces with types 2 and 6. Type 1, while important, is largely outside the mandate of the CGIAR and best pursued by other agencies.

Table A3.1. A typology of research fields relevant to NRM within the CGIAR context

Title	Description	Example
1. Conservation Research	Research on the natural world driven by intrinsic conservation goals	Investigation of the population ecology of threatened species to inform conservation planning
2. Institutional Research	Research into social, economic, political or cultural institutions that shape resource use, food security and poverty reduction	Investigation of land tenure and property rights issues as a driver of sustainable land management
3. Agri-environmental Research	Research into reducing any adverse effects agriculture has on the natural environment but where there is no close coupling to production outcomes	Investigation of off-site impact of nutrient losses from agriculture on waterway and coastal ecosystems
4. Agri-sustainability Research	Research into sustaining the natural assets upon which agricultural productivity is critically dependent	Investigation of longer-term soil physical, chemical or biological implications of farming systems design
5. Agronomic Research	Research that identifies how best to optimize agricultural production activity in the context of climate, soil, water, nutrient, biotic and abiotic constrains and other input considerations (including germplasm options)	Investigating productivity outcomes by combining genetics and management options that target climate and soil conditions (GxExM)
6. Technological Research	Development of new technologies for deployment in agricultural systems – typically new plant and animal germplasm, but can also be other technologies coming out of information and communication technology (ICT), advanced materials, agro-chemical development, etc.	Development of new plant varieties or animal selections. Development of ICT-based technologies such as those deployed in precision agriculture of controlled traffic

ANNEX 4.
Insights from the 'top 100 questions' exercise

Pretty et al. (2010) report the results of a recent exercise to identify the 'top 100 questions' facing global agriculture – from the perspective of science, policy and practice. The exercise deployed a 'horizon scanning' technique (Sutherland et al., 2010b) in an effort to provide a transparent and rigorous means of sorting all the ideas into the 100 top issues. While the group conducting this exercise was far from fully representative of the global agricultural research and policy community, being heavily biased toward western Europe (55%) and north America (20%), it is still instructive to reflect on their findings as part of the framing for this NRM review in the CGIAR.

The process involved the identification of 618 critical questions facing global agriculture. Some involve needs or prospects for new technologies or management systems, and some were about issues better defining the global challenges to inform further policy development and investment action. A meta-analysis of the 100 questions that survived the assessment process reveals some insights of relevance to the CGIAR generally and the NRM research review specifically. Pretty and his 53 co-authors classified the 100 questions into four classes, namely natural resource inputs, agronomic practice, agricultural development, markets and consumption. Questions don't always fit neatly into these categories and questions are not all independent of one another – in fact there are a number of questions that overlap considerably. Noting these limitations, a first pass classification of questions is presented in Table A4.1.

The dominance of both NRM research related questions and policy/institutional research related questions is the outstanding finding from this meta-analysis. One could argue that the NRM net has been cast too wide here and it is picking up research on agronomic practice that not everyone would see through an NRM lens. With this in mind, a second classification was undertaken, this time pulling out questions clearly focused on field/farm-scale agronomic practices (Table A4.2).

The conclusions are similar, the vast majority of the critical questions that this group of researchers and policy makers are asking relate to: (a) the availability and sustainable use of natural resources for food production and related implications for environmental health; and (b) the institutional settings (including markets, trade, development policies, consumption issues) that can lead to better outcomes in resource use sustainability, food security, rural livelihoods and poverty alleviation. Only seven of the 100 questions directly related to genetic improvement – something that seems at odds with the focus given to genetic improvement in the CGIAR. One could dismiss this as an aberration – something coming out of a bias in who was involved in the process. The western European dominance in the Pretty

Table A4.1. A meta-analysis of the top 100 questions developed by Pretty et al. (2010) classified into broad research categories in CGIAR terms

Section identified in 'top 100 questions'	Number of questions identified			
	Total	NRM	Genetic improvement	Policy and institutional
Natural resource inputs	33	27	1	5
Agronomic proctice	25	17	6	2
Agricultural development	20	2	0	18
Markets and consumption	22	2	0	20
Total	**100**	**48**	**7**	**45**

Table A4.2. A meta-analysis of the top 100 questions developed by Pretty et al. (2010), in this case with an additional systems agronomy category

Section identified in 'top 100 questions'	Number of questions identified				
	Total	NRM	Systems agronomy	Genetic improvement	Policy and institutional
Natural resource inputs	33	20	7	1	5
Agronomic proctice	25	11	6	6	2
Agricultural development	20	2	0	0	18
Markets and consumption	22	1	1	0	20
Total	**100**	**34**	**14**	**7**	**45**

et al. team may be part of the explanation, but this could be a matter of degree, not broad direction. The big challenges global agriculture faces are challenges of resource use efficiency and sustainability for an increasingly contested set of resources facing the uncertainties of climate change. Genetic solutions are still part of the mix – but are just that: only part of the solution and dependent upon NRM, and the global, regional and local institutions loom large in people's minds as the sources for solutions. Interestingly, genetics was the only 'technological solution' that really received any attention in the Pretty et al. study. Advances in information and communications technologies and advances in sensing (both remote and proximal), and advanced materials were overlooked. All of these complement genetics in the technological toolkit. Many are gaining traction in developed country agriculture and we can expect some form of spillover into the developing world in time.

The 'top 100 questions' process also allowed us to check the pulse on climate change drivers of research questions. Fourteen of the 100 questions specifically related to climate change (Table A4.3) spread over impacts, adaptation and mitigation issues.

Recently, political interest in climate change has dominated the fields of sustainable agriculture, rural development and food security. However, as important as it is, the climate change challenge is just one of a host of challenges facing global agriculture and it is important to keep some balance between the full set of drivers and solutions. It is perhaps impossible and certainly unproductive to disconnect the climate change issues from the evolving set of issues around agricultural productivity, sustainable resource use, rural development and poverty alleviation. The connections in the real world are deep and systemic, and our structural arrangements for R&D are frequently challenged by this.

Table A4.3. A meta-analysis of the top 100 questions developed by Pretty et al. (2010), from a climate change perspective

Section identified in 'top 100 questions'	Number of questions identified			
	Total questions	Climate change related	Climate impacts and adaptation	Climate mitigation
Natural resource inputs	33	12	4	8
Agronomic proctice	25	1	1	0
Agricultural development	20	1	1	0
Markets and consumption	22	0	0	0
Total	**100**	**14**	**6**	**8**

ANNEX 5.
What the Strategy and Results Framework says about INRM and framing of NRM issues for the CGIAR

The text below was extracted from the CGIAR SRF 2011, from pages 53 to 65 and reported herewith for potential reference during the reading of this strategic report.

Paragraphs 107–115, pages: 53–56

107. a. Problem Structure: Sustainable management of natural resources has been a central objective of the CGIAR since the expansion in the number of Centers in the late 1980s. Research within the CGIAR has essentially been organized by Centers working on particular natural resources, namely water, forestry, fish, agroforestry and biodiversity, and with two Centers working on soils and savannas as part of their mandate. The objectives of NRM research within the CGIAR have evolved and broadened over time. The initial rationale for the expansion was built around the development of sustainable production systems, where research on productivity was integrated with research on NRM. This nexus between research on productivity and enhancing the provision of ecosystem services was considered to be a particular comparative advantage of the CGIAR. However, the development of an organizational framework to integrate this research proved difficult. The ecoregional programs in the late 1990s were one such initiative, especially the rice–wheat consortium in the Indo-Gangetic Plain and the Alternatives to Slash and Burn, which were the most successful platforms, but in general, the INRM framework developed in the early part of the last decade did not gain traction elsewhere in the CGIAR System.

108. Moreover, the problem structure of NRM is usually framed in terms of operation at different scales from production systems to communities to landscapes/watersheds to national policy frameworks and to global conventions. Sustainable management of natural resources such as water, forestry, grasslands, capture fisheries, and biodiversity has been framed within this hierarchy of interacting scales. This has facilitated the transition of NRM research into the areas of mitigation of climate change and the provision of ecosystem services. These are quite different objectives, and this difference hinders the specification of a clear development outcome around which to align NRM research within the CGIAR System, which would possibly be most clearly defined in terms of the intersection between productivity and ecosystem services. However, different objectives require quite different alignment of research activities and imply different accountability frameworks, as, for example, with the interacting roles of tropical forests, livestock, and land degradation in climate change mitigation.

109. Defining boundaries and points of integration across the breadth of NRM research gives rise to a range of arguments. On the one hand, there are particular disciplines which define research in the areas of water, forestry, fisheries, rangelands, and soils. Each has a particular knowledge base, quantitative methods, and a research agenda. Also, at least for water, forestry and fisheries, there are often separate ministries in charge of management of these resources and river basin institutions that arbitrate on cross boundary issues in managing water resources in the basin. Moreover, international conventions also tend to focus on particular sectors, as, for example, the focus on forestry in the REDD convention. All of this tends to reinforce sectoral boundaries in how NRM research is carried out, as is reflected in the mandates of the NRM Centers. There were a range of initiatives in the early part of this decade towards defining a framework for integrated natural resource management (INRM) (Science Council, 2004). However, the principal focus was on sustainable production systems. INRM was quickly displaced by a focus on landscapes as the appropriate research and management unit, partly driven by the increasing interest in provision of and payment for ecosystem services, especially the development of carbon markets. However, it remains to be seen whether managing carbon, hydrology, nutrient flows, and biodiversity within critical landscapes is possible and generates potential benefits. As with INRM, there

have not been mechanisms within the CGIAR to systematically test the approach.

110. b. Target Areas: Natural resources virtually by definition are universally distributed, whether water, soils, or trees. Nevertheless, effective management of these resources is conditioned by local context. This has made it difficult to target NRM research as well as to demonstrate impact at the local level. Rather, each of the NRM Centers has tended to define for a particular natural resource target areas where the resource quality is degrading, utilization rates are outstripping sustainable supply, or conversion rates of the natural ecosystem represent significant loss of ecosystem services. The comparison of the map for tropical rainforests and agroforestry demonstrates how little potential overlap there is for different domains in managing these two resources. On the other hand, there are apparent criteria that would define priority locations for more integrated approaches to improvement of ecosystem services and other higher objectives might be applied. For example, the upland areas that provide the water sheds for the Asian river deltas or the East African highlands that provide water, agricultural production, and pockets of critical biodiversity are possible examples of target areas where the interaction between ecosystem services affect the future livelihoods of the region.

111. c. Strategic Approach: The strategic outcome encapsulated in sustainable management of natural resources encompasses significant diversity in objectives, in problem structure, and in targeting. Is there an approach to integrated natural resource management within the CGIAR at scales higher than production systems and does this involve integrated management of ecosystem services. Currently, the dominant axis of integration is vertically across scales by natural resource. This particularly reinforces the links between policy formulation at national and global level and adaptive resource management at local levels, which in turn recognizes the sectoral focus of the policy formulation process, whether water, forests, or fisheries. This says little about relative priorities across natural resource domains, which will have a regional focus, e.g. the primacy of water in WANA and southern Africa, and could be framed in terms of the relative valuation of ecosystem services deriving from management of that particular resource.

112. A second potential axis is at the production system level. The intent of the INRM agenda of 2004 was to integrate productivity and NRM research at that level but this did not gather any momentum over the rest of the decade. To address system-level outcomes this work needs to proceed along two different tracks. The first is the search for increased resource use efficiency, or eco-efficient agriculture, at the intensive margin primarily in breadbasket areas, as fundamental to the work on the food security SLO. The other would focus on reversing the cycle of land degradation in areas of high rural poverty, especially in sub-Saharan Africa, i.e., work at the more extensive margin, under conditions where input and output markets are not well developed. The trajectories for sustainable intensification and the research strategies designed around those trajectories would be quite different.

113. Finally, the growing significance of climate change reveals a need to ensure that new natural resource management strategies anticipate changes in the quality and variability of natural resources at the landscape and regional level. This, in turn, could imply a third axis of research at this higher level into climate change effects on agriculture and the adaptive response required, and conversely on the contributions that agriculture could make in mitigating climate change. Although carbon is the focus of much of this work at the moment, integration of water, soil, and biodiversity is critical for adaptation at the level of the agricultural sector.

114. d. Institutional Arrangements: Institutional arrangements in the area of NRM are as diverse as the subject matter, operate at different scales with a particular differentiation between policy and implementation, and are often such that the CGIAR is not a central actor. At the same time realization of development outcomes in sustainable management of natural resources occurs primarily at the local level. The CGIAR is one of the few institutions that can provide a bridge

between the local and the global levels. Most of the NRM Centers exploit this bridging function between global, regional and sub-regional policy fora and systematically test new approaches across different local contexts, as for example ICRAF's RUPES project on payment for ecosystem services or the Alternatives to Slash and Burn program. However, this bridging function between levels tends to be specific to the particular NRM sector. An area that is more cross-sectoral is that of climate change, particularly when considering both mitigation and adaptation. CGIAR work on climate change needs to integrate the CGIAR's NRM work and link it to the evolving policy framework for both mitigation and adaptation. Here, collaboration with environmental institutions working on climate change prediction, adaptation and mitigation will be essential.

115. e. Impact Targets and Measures: Impact assessment within the CGIAR for NRM research is still evolving (Science Council, 2006; Waibel and Zilberman, 2007) and has primarily focused on impacts at the production system level, where the impact is measured primarily through the productivity effect and there are various attempts to value positive or negative externalities. Impacts at higher levels, for example in terms of reducing rates of deforestation, are rarely evaluated beyond adoption, e.g. adoption of CIFOR's timber certification scheme. Impacts at this level are specific to each sector and would generally be based on an evaluation of changes in the provision of ecosystem services. Specifying targets and impacts in terms of ecosystem services, however, requires a methodology for measuring baselines and changes due to the respective intervention, which is one of the critical implementation issues in development of carbon markets. To do this will generally require a monitoring system usually linked to a modeling capability, e.g. hydrological models, and a valuation system for the ecosystem service. This is methodologically demanding and a potential area of work for the CGIAR. What will probably emerge is a dual approach, i.e. at the production system level and at the landscape scale or other higher scales of evaluating changes in ecosystem services.

Paragraphs 124–127, pages: 60–62

124. b. *Natural Resource Management:* Agriculture occupies almost a quarter of the terrestrial land area of the globe and consumes about 70% of water withdrawals for irrigation. Agriculture has the largest impact on the global provision of ecosystem services, either directly through its use of land and water resources or indirectly through its impacts on land use change, biodiversity, savannas and grasslands, and water quality. The CGIAR is unrivaled in having research capacity across a range of natural resource sectors, including land, water, forestry, rangelands, aquatic systems, and biodiversity, and in being able to connect research on natural resource management at the production system level with research at the landscape and national and global policy level. The world faces major tradeoffs concerning how to feed itself to the middle of this century while maintaining and enhancing the provision of ecosystem services. Meanwhile the CGIAR can offer its unrivaled research capacity in the tropics and subtropics, which can be directed at the challenge of achieving sustainable intensification of agriculture, jointly with the effective management of the natural resource base in that portion of the globe where agricultural and land use change is most dynamic.

125. NRM Centers tend to be smaller in size and budget than commodity or ecoregional Centers. Institutional linkages to the larger community working on a resource are critical, defining the Center's niche in that community. Translating research and methodology development into action is the hallmark of Center strategies. Each one of them is primarily organized around and draws on the disciplinary depth of particular resource sectors. In this regard, NRM research is already quite efficiently organized within the CGIAR System. Since the inclusion of the NRM centers into the CGIAR, there have been three major initiatives attempting to achieve greater integration of agricultural and NRM research. The first was the series of workshops at the beginning of the last decade defining Integrated Natural Resource Management with its focus on integrating productivity and NRM research at the production system level (more on this below). The second initiative was the Alternatives to Slash and

Burn program which focused on land use change at the forest margin, and particularly on stabilizing the rates of conversion and ensuring sustainability of agricultural systems in these areas. The third initiative is the Challenge Program on Water and Food which focuses on land and water management at basin scale in six target river basins. The latter two reflect the benefits to undertaking research at multiple scales within a research framework of comparative sites. There was more project-based work on managing the interface between agriculture and rangelands, e.g. in South American savannas, and in sustainable land and water use management in lake basins, such as Lake Victoria. All of this work reflected movement towards integrated land and water management at different scales within the context of either dynamic land use change or natural resource degradation. Such evolution would provide one possible pathway for further integration of sustainable production systems with natural resource management at higher scales.

126. The four areas where there may be further gains from joint management across Centers are in those of climate change, payment for ecosystem services, eco-efficient production systems, and a continued consolidation of a network of comparative or sentinel research sites. Climate change and production systems are considered elsewhere in this report. Payment for ecosystem services has primarily been motivated by the development of carbon markets and the potential of different land uses for carbon sequestration. However, they can equally be applied to water and to reducing nutrient fluxes into aquatic ecosystems, which in turn motivate farmer investment in land management practices where there is a lag between investment and farmer return. PES would cut across most of the NRM Centers and would require methods for measuring ecosystem services as the basis for constructing contracts for ecosystem services. In conclusion, there are multiple pathways to achieving the SLO of sustainable natural resource management, but at the moment there is little framework for effectively choosing between these pathways.

127. This last point raises the succeeding question of whether there would be gains through more effective priority setting in the NRM area. Priority setting is essentially an aggregated model of *ex-ante* impact assessment and has rarely, if ever, been applied in the NRM area across sectors. Methodology development in the area of *ex-post* impact assessment in the NRM area is noted for both its complexity and the need to adapt the methods to the particular problem or resource. A comparative methodology across different resource sectors does not exist, much less to disaggregate and prioritize investments by different research components or problem areas. Development of such a priority setting capacity would require significant investment and would only be justified if budgets for the NRM research portfolio were especially constrained and some type of priority setting framework were deemed to aid in defining a fair allocation of resources.

Paragraphs 133 and 135, Page 65

133. Resource use efficiency (and its trade-offs with productivity), especially in terms of water and nutrients, optimizing biomass flows within the system, exploiting synergies in crop, livestock and resource components within the system, and reducing negative externalities are all sub-objectives within this research agenda. Moreover, system constraints and dynamics are very different between, for example, the intensive production systems in the Asian rice bowl and the degrading farming systems in much of sub-Saharan Africa. The SRF offers the potential to develop this agenda as an explicit inter-Center activity which exploits the crop, livestock and resource component research capacity across the System, on the one hand, and the regional deployment of Centers, on the other hand. The efficiency gains in an integrative approach are obvious, as no Center has the scope of research capacity to undertake it alone, which is partly why the CGIAR has had such difficulty over the decades in developing research capacity in the area of production systems.

135. b. *Climate Change:* Climate change will have the greatest impact on agrarian economies with high rates of rural poverty, namely target areas of high priority for the CGIAR, and will introduce higher variability in world food supplies, during a period

when balancing world food supply and demand is becoming more precarious. Not only is climate change important to the CGIAR's realization of its four SLOs but the CGIAR is well placed to contribute to research on climate change and to the development of strategies to lessen the impacts of climate change on some of the most vulnerable areas in the world. The CGIAR's comparative advantage in adaptation is relatively clear. However, given the broad array of research areas on the mitigation side of the climate change equation, the strategy will be determined by where the CGIAR can contribute most to carbon sequestration or reduced greenhouse gas emissions and by the potential for agriculture to participate in carbon market development.

ANNEX 6. Bibliometric component: methodology and process

Methodology[27]

Preliminary study

A scoping exercise was undertaken in May 2011 to develop a transparent, repeatable method to assess impact using citation rates of research published by the Centers. The objectives and results of the scoping exercise are available from the ISPC Secretariat upon request. Briefly, the exercise aimed to identify publications that were specifically focused on NRM and determine how best to objectively assess impact. The analysis was conducted after a series of discussions and trials between the consultant and NRMR panel members, with the aim of developing a robust method. It used a list of keywords that could be expected to appear in the titles, abstracts or keywords of bibliographic database records of NRM studies, journals considered of high status for natural resources by Elsevier's SciVerse Scopus (http://www.info.sciverse.com/scopus/), and journals in which studies considered by CAB International's CAB Abstracts[28] to be of interest in terms of natural resources were published. Many of the Centers have had name changes since their creation, and these names were incorporated into the search strategy. Additionally, several misspellings were found during the preliminary phase of the project, and these were added to the search strategy. Finally, variants of American and English spelling were both searched, where appropriate. Spanish and French names for the Centers were included; the preliminary work had indicated no additional records found for German or Portuguese names, which occasionally occur in the literature, though never without the English, French or Spanish versions. A list of all names and variants of names (in English, French and Spanish) was produced for each Center to limit studies to those coming from the target Institutions.

Choice of bibliographic database

The database options for a bibliometric study of research papers from CGIAR Centers are specialist bibliographic databases of academic publications and Google Scholar. The relative merits of working with any or all of these were considered during the scoping phase of the project. The main characteristics are summarized below:

a) Thomson Reuters' ISI **Web of Knowledge** (WoK) (http://www.isiwebofknowledge.com) indexes a collection of significant bibliographic databases which are relevant for this work, which are collated into its Web of Science (WoS).
b) Elsevier's SciVerse **Scopus** (http://www.info.sciverse.com/scopus/) is equally comprehensive for this area of work and has some significant advantages for bibliometric work (Ball and Tunger, 2006),[29] notably that it is possible to search 'stop words' in phrases, which is useful in the present investigation. Stop words are frequently-used words that rarely have significance in a search strategy. Examples include: some articles (such as '*the*', '*an*'); some conjunctions (such as '*as*', '*because*', '*if*', '*when*'); most personal pronouns (such as '*he*', '*she*', '*we*'); some prepositions (such as '*at*', '*for*', '*on*').
c) **CAB Abstracts** is a bibliographic database published by CAB International (CABI), a not-for-profit international organization. CABI's records are coded and indexed using a widely-used specialist Thesaurus of controlled keyword terms and coding schedules that have been retrospectively applied to older records in the database, and which are assigned to individual papers by subject specialist information professionals. This does confer benefit in terms of the quality of descriptions of the individual records in the database (the meta-data).

27 Modified from Dr Petrokofsky's final consultancy report to the NRM research Stripe Review.

28 See www.cabi.org

29 Ball R. and Tunger D., 2006. Science indicators revisited – Science citation index versus SCOPUS: a bibliometric comparison of both citation databases. *Information Services and Use* 26(4):293–301.

CABI also includes in their database a larger proportion of non-English literature from more obscure journals than are found in Scopus or Web of Science. However, they do not include information on citation rates. The database was used only to create sets of NRMR keywords and journals, which were then used to search Scopus.

d) **Google Scholar.** Although it is a useful tool because it is free and has a wide scope, it was not selected for the work because its search functions are more limited than any of the specialist bibliographic databases. It was particularly difficult to create focused sets of records for a topic as complex as NRMR. The search architecture does not allow long strings of search terms, which would have meant creating a lot of small sets and assembling them in other software (Excel, EndNote, RefWorks, etc.) to do the analysis. The main drawback, however, is that it is not clear which sources are searched by Google Scholar, and how complete their searches are of archives of journals.

Final choice of database: Scopus

Though there is very little difference in functionality of subject coverage between Web of Science and Scopus, the final choice of database was Scopus, because it has benefits that are useful for searching, some very useful benefits for saving searches and sets (making it ideal for shared work or for work spread over time), and it does not have significant disadvantages over WoS.

Revised method assessing all CGIAR Center publications

Although objective and easy to replicate, the preliminary method was considered to have too little precision in terms of identifying studies of broad NRM focus. So the method was amended to one in which selected studies were assessed for NRM relevance by a panel of experts from a short-list of studies retrieved using a simple method of citation counting. The aim was to capture all (NRM and non-NRM) studies indexed by Scopus that included an author address of at least one of CGIAR Centers in the time frame 2000–2010, and produce a short list of most highly cited studies and to produce graphical illustrations of relative performance of the Centers, based on the agreed method. Scopus was searched on 2/9/2011 and 3/9/2011.

> Impact factor of a journal is calculated as:
>
> X = the number of times articles published in Year n and Year $n+1$ were cited by indexed journals during Year $n+2$.
>
> Y = the total number of 'citable items' published by that journal in Years n and $n+1$.
>
> Impact factor for Year $n+2 = X/Y$.

A simple citation index was devised as a measure of research impact, based on that of Garfield (1955),[30] which is widely used to determine the citation index of journals.

The whole corpus of publications indexed by Scopus is considered the total number of 'citable items', and the total number of citations received for all publications from a given Center is used without reference to the year of publication. To capture a more complete picture of impact of each Center, the numbers (and percentages) of papers with no citations are recorded. Data were tabulated on number of publications, number of citations for these papers, number of papers receiving no citations, and citation indexes for each Center (based on consideration of the total number of publications).

Second revision of the method

Following discussion among Panel members and on the advice of an external academic librarian, the bibliometric method was revised to introduce some weighting of publications to take account of the year of publication. The logic here was that a cruder analysis that grouped all research from 2000 to 2010 greatly disadvantaged more recent publications that were beginning to attract citations, but which had not had enough time to reach the citation

30 Garfield E.1955. Citation indexes for science. *Science* (AAAS) 122 (3159): 108–111. http://scimaps.org/static/docs/Garfield1955cit.pdf.

count of earlier studies. The decision was also taken to limit the studies to those considered to be research articles; specifically, correspondence and editorials, and other minor categories were considered outside the remit of the project and were excluded. Minor changes to the list of names and variants of the Centers were also made following feedback from Centers. Tabulated data showing number of publications receiving no citations were considered by the external reviewer to be irrelevant to the study and were therefore excluded from the final method.

Final method for the bibliometric component

The bibliographic database Scopus, originally searched on 2/9/2011 and 3/9/2011, was re-searched between 30/1/2012 – 2/2/2012 for three document types:[31] (i) journal article; (ii) review; or (iii) conference paper that included an author address from at least one of the CGIAR Centers [see Table A2.1] for papers published between 2000 and 2010. Additional variants of the names of Centers (many incorrectly cited in the journals) were added to the search strategy, and Scopus was searched again during Jan 27 to Feb 6 and March 6–8, 2012 to take account of those changes. Centers that were re-searched following feedback on name variants, are indicated by an asterisk.

The citation analysis was performed for four time periods:

- 2000–2002
- 2003–2005
- 2006–2008
- 2009–2010

The citation index was calculated as number of citations received in each time period for any of the papers up to and including the end of the time period. This metric gives a measure of the impact of a paper over time, and goes some way to reducing the bias towards Centers with high numbers of older papers, whose initially high citation indexes would continue to dominate the cumulative results, even where citation rates for these older papers started to decline in later time periods. This was a limitation noted from earlier stages of the method development, where the citation index was calculated as a proportion of total number of papers. The method could be refined still further to produce rolling figures for citation, on a yearly basis, should even greater detail ever be required. ... Results of the citation index analysis are presented in four 'radar' charts [Figures A6.1 to A6.4], which show Centers in order of decreasing citation index in a clockwise format, from the highest at '12:00 o'clock' on the chart, to the lowest, immediately to the left.

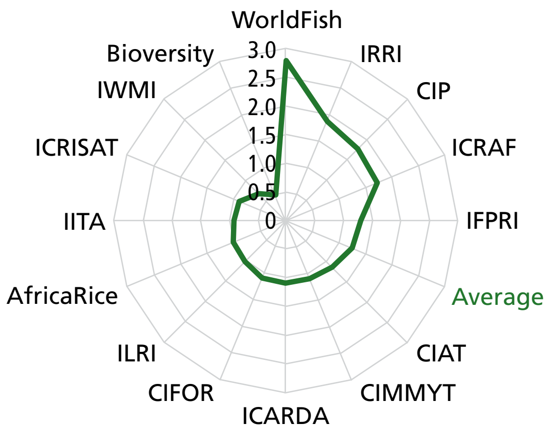

Figure A6.1. Citation index 2000–2002

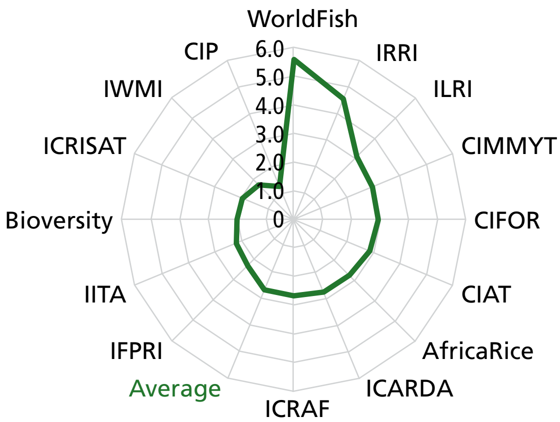

Figure A6.2. Citation index 2003–2005

31 Citation counts are based on the September, 2011 searches, except for Centers who supplied additional variants to their name in Jan and in March, 2012. It is noted that this introduces a small amount of variance to the method, but the number of papers retrieved using the new names was in two cases (IWMI and ICRAF) relatively small (as a proportion of the total number of papers) and in other cases, actually small (fewer than 35): the variation did not alter the citation indexes.

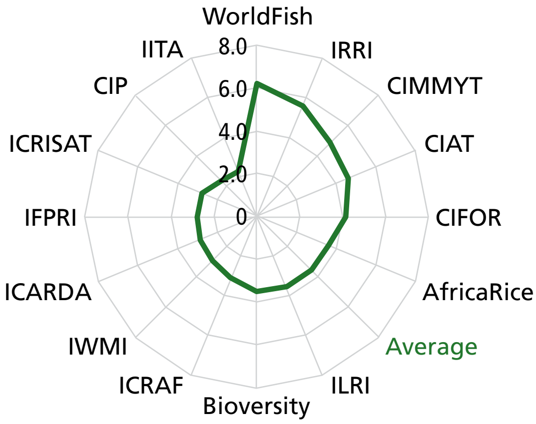

Figure A6.3. Citation index 2006–2008

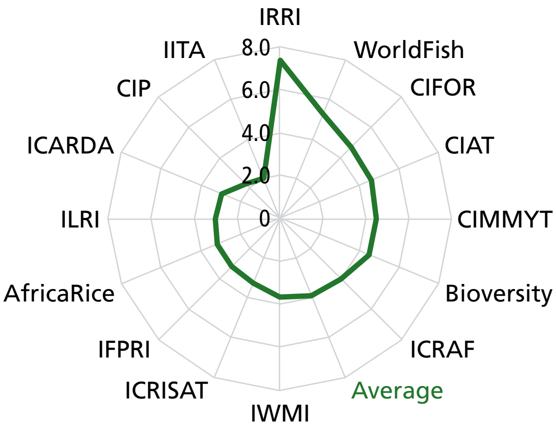

Figure A6.4. Citation index 2009–2010

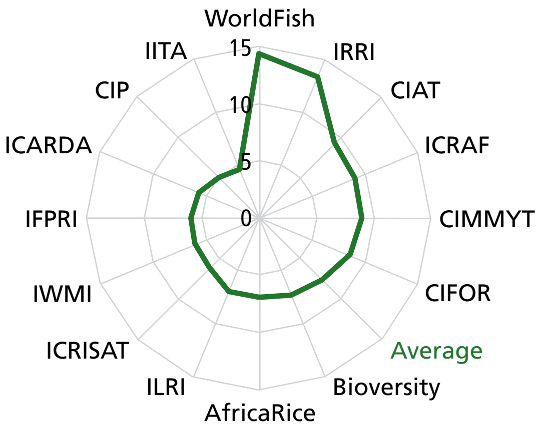

Figure A6.5. Citation index for all publications 2000–2010

Limitations of the method chosen

Choice of bibliographic database: Three major bibliographic databases which index natural resource management research were explored in the scoping phase of the project: Scopus, Web of Science (WoS) and CAB Abstracts. Scopus was selected because it offers certain advantages for citation counting over WoS. CAB Abstracts does not provide data on citations, though it is a more comprehensive database for the type of research conducted by CGIAR Centers. However, when concentrating only on journal articles, much of this advantage is removed.

Using address to select Centers' research: A large number of variants of names were found during the different phases of method development, some of them emerging late in the project. A number of mis-spellings of names have also been found. These have not been picked up by the searches, and although they are few in number, they do represent some potentially influential research. Errors introduced by primary journals and/or Scopus indexing also account for some minor omissions. However, it is likely that alternative methods obtaining sets of publications from the Centers themselves would be inconsistent and would certainly require careful collating and formatting to ensure consistency. Feedback provided during the project demonstrated this inconsistency and inaccuracy clearly. The table of names of Centers should be considered a work in progress. Clearly, other minor variants (mainly mis-spellings) will emerge over time, and these should be noted and added to the table for further work. However, care should be taken by authors in citing their Centers clearly and consistently.

Limiting document type: Although small in number, there were examples of what Scopus classifies as letters, editorials and short surveys, which were highly cited. These could have been included in the analysis without loss of credibility, given that Scopus indexes only formally published journals. Other research outputs, such as videos, training manuals, web pages, etc. can be highly influential, but they are not indexed in any of the major databases, which makes robust analysis and comparison very difficult.

Analysis of the search results from the NRMR Stripe Review Panel Members

There are a host of challenges in the conduct of valid bibliometrics. The Panel ran into many challenges in this exercise but has sought expert advice to avoid the worst pitfalls. Challenges include the difficulty of comparing like with like across research fields, the challenge of choosing the appropriate database for searches, the challenge of capturing all relevant publications, and so on.

Citation indices are increasingly used as a performance measure of science output and impact around the globe. An analysis of CGIAR publications was conducted for this study by Dr Petrokofsky (Department of Plant Science, Green Templeton College), and revised with advice from the Wageningen University library. While such analyses can be useful inputs to assessments of the performance of individual scientists and of research groups or institutes, they have a number of weaknesses and pitfalls. For this reason they are usually used as an input to a review based on expert opinion, but should not be used in isolation.

One of the major issues is whether Google Scholar or Scopus/Web of Science should be used for such analyses. The main arguments to use Scopus revolve around reproducibility and transparency, but there are some valid counter arguments. For instance, many of the target beneficiaries of CGIAR research in developing countries do not have direct access to scientific journals. For such readership, many outputs are also translated into a form of policy briefs and reports for a broader readership beyond the scientific community. Information provided by CIFOR, for instance, indicated more than 4.5 million downloads of publications from their website between 2007 and February 2012, which is indeed suggestive of a wide readership of their work. Further, the panel acknowledges that the bibliometric analysis, for the way it was agreed and structured, does not give full credit to some books and other publications that may be very influential in their field. Nevertheless, given the research mandate of the CGIAR, the panel considers that the citation analysis is worthwhile.

As part of the bibliometric analysis, an Excel speadsheet was created with all papers cited more than 20 times, a somewhat arbitrary cut-off point. Such analyses always include some subjective judgment, in the case of this analysis not least based on the decision as to which articles should be included as falling within the domain of NRM research. Further pitfalls relate to the comparison of publications across fields of research. Journals and articles in the fields of genetics and biotechnology tend to have higher impact factors, but yet shorter half-lives of citation than journals and articles in the fields of agronomy, soil science or ecology. While such a list is difficult to interpret, a number of observations can be made. For example, papers concerned with climate change, conservation ecology tend to be cited often. Papers that report new developments in methods and critical review articles published in journals are also highly cited.

A further problem with citation analyses is the use of the same metrics to cover different fields of research. If researchers work in a field of science where there is a small number of other researchers publishing in the same field, then inevitably the number of citations is limited. This is particularly true if the researchers in that field do not publish frequently. So the most-cited researchers in a highly-specific field may still score poorly if evaluated using citation analyses.

Accepting these caveats, a bibliometric analysis could be a useful tool for benchmarking performance both within and across institutes. The Panel suggests further normalization of the data between CGIAR Centers based on numbers of full-time researchers working on NRM research, or based on the amount of funding available for NRM research. Both are good suggestions, but insufficient accurate information was available and such normalization could not be performed.

ANNEX 7.
List of relevant literature reviewed during the NRM research Stripe Review

A selection of the literature reviewed during the NRM research Stripe Review is reported below because of the important role it plays in the describing the history of the NRM research in the System, in understanding potential impacts up to the present, or for relevant insights and thoughts it has generated from outside CGIAR.

CGIAR Technical Advisory Committee. 2001. Environmental impacts of the CGIAR: an initial assessment (SDR/TAC:IAR/01/11). Rome, Italy: Technical Advisory Committee (TAC) Secretariat.

Barrett C.B. 2003. Natural resources management research in the CGIAR: a meta-evaluation. Thematic working paper for the operations evaluation department (OED) report 'The CGIAR at 31: an independent meta-evaluation of the CGIAR'. Washington DC: World Bank, 41 pp.

Campbell B., Sayer J.A., Frost P., Vermeulen S., Ruiz Pérez M., Cunningham A. and Prabhu R. 2001. Assessing the performance of natural resource systems. *Conservation Ecology* 5(2):22.

Caron P., Reig E., Roep D., Hediger W., Le Cotty T., Barthélémy D., Hadynska A., Hadynski J., Oostindie H. and Sabourin E. 2008a. Multifunctionality: epistemic diversity and concept oriented research clusters. *International Journal of Agricultural Resources, Governance and Ecology* 7(4–5):319–338. http://dx.doi.org/10.1504/IJARGE.2008.020080

Caron P., Reig E., Roep D., Hediger W., Le Cotty T., Barthélémy D., Hadynska A., Hadynski J., Oostindie H. and Sabourin E. 2008b. Multifunctionality: refocusing a spreading, loose and fashionable concept for looking at sustainability? *International Journal of Agricultural Resources, Governance and Ecology* 7(4–5):301–318. http://dx.doi.org/10.1504/IJARGE.2008.020078

Cassman K.G. 1999. Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proceedings of the National Academy of Sciences (USA)* 96:5952–5959

Cassman K.G. 2001. Crop science research to assure food security. Pp. 33–51 In: Noesberger J., Geiger H.H. and Struik P.C. (eds). *Crop Science: Progress and Prospects*. Wallingford, UK: CAB International.

Cassman K.G., Dobermann A., Walters D.T. and Yang H. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. *Annual Review of Environment and Resources* 28:315–358.

de Wit C.T. 1992. Resource use efficiency in agriculture. *Agricultural Systems* 40:125–151.

de Wit C.T. 1994. Resource use analysis in agriculture: a struggle for interdisciplinarity. Pp. 42–55 In: Fresco L.O., Stroosnijder L., Bouma J. and van Keulen H. (eds). *The Future of the Land: Mobilising and Integrating Knowledge for Land Use Options*. Chichester, UK: John Wiley.

CGIAR ISPC. 2011. Measuring the environmental impacts of agricultural research: theory and applications to CGIAR research. Rome, Italy: Independent Science and Partnership Council Secretariat (ISPC).

CGIAR INRM-Task Force. 1999. Integrated natural resources management research in the CGIAR. Report on the 1st Integrated Natural Resources Management Workshop held in Bilderberg, Netherlands, 27–29 September 2000.

CGIAR INRM-Task Force. 2000. Integrated natural resources management research in the CGIAR: approaches and lessons. Report on the 2nd Integrated Natural Resources Management Workshop held in Penang, Malaysia, 21–25 August 2000.

CGIAR INRM-Task Force. 2000. Integrated natural resources management research in the CGIAR: a brief report on the INRM Workshop held in Penang, Malaysia.

CGIAR INRM-Task Force. 2001. Integrated management for sustainable agriculture, forestry and fisheries. Report of the 3rd Integrated Natural Resources Management Workshop held at CIAT in Cali, Colombia, 28–31 August 2001.

CGIAR INRM-Task Force. 2002. Putting INRM into action. Report of the 4th INRM Workshop held at ICARDA, Aleppo, Syria, 16–19 September 2002.

CGIAR Interim Science Council (ISC) and Center Directors Committee on Integrated Natural Resources Management. 2003. *Research Towards Integrated Natural Resources Management: Examples of Research Problems, Approaches and Partnerships in Action in the CGIAR*. Harwood R.R. and Kassam, A.H. (eds). Rome, Italy: CGIAR. 168 pp.

CGIAR ISPC. 2010. Report of the Second external review of the Sub-Saharan Africa Challenge Programme (SSA-CP). Rome, Italy: ISPC Secretariat.

CGIAR Science Council 2003. Towards INRM: evolution of NRM research within the CGIAR. Rome, Italy: Science Council Secretariat.

CGIAR Science Council. 2003. NRM research in the CGIAR: background papers considered by TAC/ISC. Rome, Italy: CGIAR Science Council Secretariat. 47 pp.

CGIAR Science Council. 2006. Report of the External Review of the Systemwide Program on Alternatives to Slash and Burn (ASB). Rome, Italy: CGIAR Science Council. 127 pp.

CGIAR Science Council. 2006. Report of the external review of the Systemwide Program on Alternatives to Slash and Burn (ASB). Rome, Italy: Science Council Secretariat.

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CGIAR Science Council. 2008. The role of systemwide initiatives in implementing the CGIAR's research agenda. An assessment of current systemwide and ecoregional programs (SWEPs). Rome, Italy: Science Council Secretariat.

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CGIAR Technical Advisory Committee. 1996. A strategic review of natural resources management research on soil and water (compiled by P.B. Tinker and J.R. Anderson). Report SDR/TAC:IAR/96/9. Rome, Italy: TAC Secretariat.

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CGIAR Technical Advisory Committee. 2001. NRM in the CGIAR: a framework for program design and evaluation. Rome, Italy: TAC Secretariat.

CGIAR Technical Advisory Committee. 2001. Evolution of NRM concepts and activities in the CGIAR (SDR/TAC:IAR/01/18). Rome, Italy: TAC Secretariat.

CIFOR. 2005. Achievements of the Center for International Forestry Research 1998–2005. Bogor, Indonesia: Center for International Forestry Research (CIFOR).

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Crosson P. and Anderson J.R. 1993. Concerns for sustainability: integration of natural resource and environmental issues for the research agendas of NARSs. ISNAR Research Report #4. Washington, DC: IFPRI.

Evans A. 2010. Globablization and scarcity – multilateralism for a world with limits. New York, NY: Center on International Cooperation, New York University.

Fujisaka S. and White D. 2004. *Ex-post* methods to measure natural resource management research impacts. Aleppo, Syria:

ICARDA. 26 pp. www.icarda.cgiar.org/INRMsite/documents/others/expost.pdf

Giller K.E., Leeuwis C., Andersson J.A., Andriesse W., Brouwer A., Frost P., Hebinck P., Heitkönig I., van Ittersum M.K., Koning N., Ruben R., Slingerland M., Udo H., Veldkamp T., van de Vijver C., van Wijk M.T. and Windmeijer P. 2008. Competing claims on natural resources: What role for science? *Ecology and Society* 13(2):34.

Godfray H.C.J., Pretty J., Thomas S.M., Warham E.J. and Beddington J.R. 2011. Linking policy on climate and food. *Science* 331:1013–1014.

Harwood R.R., Kassam A.H., Gregersen H.M. and Fereres, E. 2005. Natural resources management research in the CGIAR: the role of the Technical Advisory Committee. *Experimental Agriculture* 41:1–19.

ICARDA. 1999. ICARDA's achievements in natural resources research: a basis for integrated management. Aleppo, Syria: ICARDA.

ICRAF. 2001. Towards a natural resource management paradigm for international agriculture: the example of agroforestry research. Izac A.-M.N. and Sanchez P.A. Nairobi, Kenya: ICRAF.

ICRISAT. 2005. *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts.* Shiferaw B., Freeman H.A. and Swinton S.M. (eds). Wallingford, UK: CAB International. 382 pp.

IFPRI. 2008. International model for policy analysis of agricultural commodities and trade (IMPACT): model description. Washington, DC: IFPRI.

Izac A-M.N. 1998. Assessing the impact of research in natural resources management: synthesis of an international workshop held at ICRAF in Nairobi, Kenya, 27–29 April 1998.

Keating B.A., Carberry P.S., Bindraban P.S., Asseng S., Meinke H. and Dixon J. 2010. Eco-efficient agriculture: concepts, challenges, and opportunities. *Crop Science* 50:S-109–S-119.

Kelley G. 2005. NRM impact assessment in the CGIAR: meeting the challenges and implications for the CGIAR. In: Shiferaw B., Freeman H.A. and Swinton S.A. (eds). *Natural Resources Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*. Wallingford, UK: CAB International.

Kok K., Biggs R. and Zurek M. 2007. Methods for developing multiscale participatory scenarios: insights from southern Africa and Europe. *Ecology and Society* 13(1):8.

Lele U.J. 2003. The CGIAR at 31: an independent meta-evaluation of the Consultative Group on International Agricultural Research. Washington, DC: World Bank.

Pachico D. 2000. Approaches and challenges in impact assessment of agricultural and natural resources management research. Paper prepared for the Impact Assessment Workshop organized by the Standing Panel on Impact Assessment (SPIA) of the Technical Advisory Committee (TAC) of the CGIAR, FAO, Rome, Italy.

Pretty J. et al. 2010. The top 100 questions of importance to the future of global agriculture. *International Journal of Agricultural Sustainability* 8:219–236. (Also available from Earthscan at: http://ucanr.org/blogs/food/blogfiles/5698.pdf.)

Renkow M. and Byerlee D. 2010. The impacts of CGIAR research: a review of recent evidence. *Food Policy* 35:391–402.

Sayer J. and Campbell B. 2001. Research to integrate productivity enhancement, environmental protection, and human development. *Conservation Ecology* 5(2):32.

Scherr S.J., 2000. Downward spiral? Research evidence on the relationship between poverty and natural resource degradation. *Food Policy* 25:479–498.

Turkelboom F., La Rovere R., Hagmann J., El-Khatib R. and Jazeh K. 2003. Putting INRM into action: workshop documentation. Presented at the 4th INRM workshop in Aleppo, Syria, 16–19 September 2002.

Waibel H. and Zilberman D. (eds). 2007. *International Research on Natural Resource Management: Advances in Impact Assessment*. Wallingford, UK: CAB International.

Waibel H., Zilberman D. and Kelley T. 2006. Assessment of the impacts of natural resource management research in the CGIAR. Paper presented at Tropentag, Bonn, Germany, October 11–13.

ANNEX 8.
List of available background documents generated during the NRM research Stripe Review

During the implementation of the NRM research Stripe Review, a series of documents was prepared as background material and thought pieces to facilitate the preparation of this final report. The documents listed below are available on request to the ISPC Secretariat.

- Natural resources management: challenges and way forward for the new CGIAR – a stripe review. Concept note
- Natural resources management: challenges and way forward for the new CGIAR – a stripe review bibliometric study component: final report and full list of CGIAR publications (2000–2010)
- Natural resources management: challenges and way forward for the new CGIAR – a stripe review selection of examples of CGIAR NRM research and their use as learning tool to extract factors leading to impact at scale (includes criteria for selection of the examples)
- Summary of the NRMR Stripe Review workshop (16 October 2011, Beijing, China)
- Compilation of selected NRM research outcomes and projects of CGIAR 2000–2010 (Box A8.1)
- Caron P. and Botta A. 2011. From use toward production of 'natural' resources: shifting of agricultural paradigms requires more than technological based innovation. Thought piece Prepared for the NRMR Stripe review workshop, 16 October 2011, Beijing, China. (unpublished)
- Ghazoul J. 2011. Natural resources management in multifunctional landscapes: research challenges and the way forward. Thought piece prepared for the NRM research Stripe Review workshop, 16 October 2011, Beijing, China. (unpublished)
- Giller K. 2011. Farming systems. Thought piece prepared for the NRM research Stripe Review workshop, 16 October 2011, Beijing, China. (unpublished)
- Keating B. 2011. NRM research in the CGIAR – some reflections from the outside looking in. Thought piece prepared for the NRM research Stripe Review workshop, 16 October 2011, Beijing, China. (unpublished).

Box A8.1. A database of NRM research in CGIAR

Literature and data sources reviewed during the NRM research Stripe Review are organized in a database that also includes a further detailed classification of case studies and NRM outcomes that were submitted by the Centers in the framework of the PMS 2005–2009. The database is available from the ISPC Secretariat for consultation.

ANNEX 9.
Summaries of NRM research examples (presented in Box 3.1)

The selection of NRM research examples from the CGIAR System was first discussed at the NRM research Stripe Review workshop (Beijing, 16 October 2012). In February 2012 Centers were contacted again to share their feedback on a preliminary list of examples and to ask their collaboration to collect updated material related to the final selected examples. To facilitate the work of the Panel Members the ISPC Secretariat also requested Centers to share a brief description for each of the examples. The summaries and statements – as shared by the Centers – are reported in the next pages. Where the Centers shared publications related to the example, but not a brief summary, other sources were used to extract a short summary (i.e. the outcome statement previously submitted for the PMS database, websites or text from past EPMRs).

Example 1. Better beans in Africa: towards valuing indirect and overlooked environmental impacts – CIAT

New crop varieties and farm practices can improve the environment. Yet, potentially substantial impacts, which are not directly attributable to changes in crop technologies, are often ignored. Inability to measure, attribute and ultimately estimate the values of these diverse impacts can misguide development and conservation policies.

The objectives of this paper are to understand how beans impact soil and forest resources, and estimate what the changes are worth. Genetic improvements of beans, along with how they are cultivated and cooked, affect the performance of these resources by changing their capacity to supply provisioning, supporting, regulating and cultural services. In attempt to comprehensively and objectively estimate the value of environmental impacts, the ecosystem services framework (Millennium Ecosystem Assessment, 2005) is used while assessing three elements that establish plausibility of estimates: (i) capacity of selected proxy variables to represent changes in ecosystem service; (ii) impacts being attributable to causes; and (iii) legitimacy of methods to value the change in services.

Characteristics of new bean varieties, such as higher yields, resistance/tolerance to pests and diseases, and fixing nitrogen, help to increase the performance of farm soils. A combination of improved bean traits and management practices also generates positive (and negative) environmental impacts off-farm. For instance, farm productivity gains help alleviate pressures to expand agricultural production into forests. New varieties cook quickly, and if soaked overnight, cook even faster, thereby reducing fuelwood use. Cultivating, and not collecting, staking material decreases the need to cut tree saplings and branches. With less deforestation and forest degradation, forests provide a wide range of ecosystems services. They help mitigate climate change and regulate water flows. Forests are also a supporting habitat to many rare animal species. The analysis is based on a case study of the Kisoro district, near the Bwindi Impenetrable and Mgahinga National Parks in the highlands of southwest Uganda.

Example 2. Financial due diligence for natural forest protection – CIFOR

The study estimates that the overall result of these changes has been the averted loss of between 76,000 and 212,000 hectares of natural forest, depending on assumptions applied, with 135,000 hectares of natural tropical rainforest saved under the main set of assumptions. Much of the savings is in areas of deep moist peat, with more than 1,000 t of carbon stored per hectare, and in areas of high biodiversity.

An economic surplus framework is developed to value averted natural forest clearance based on the external environmental benefits of forest conservation and the avoided consumption of implicit subsidies from underpriced wood royalties. This framework is used in conjunction with the counterfactuals to identify economic benefits attributable to CIFOR. These benefits, which principally result from reduced carbon emissions, are determined to range from US$19 million to US$583 million, depending on assumptions used, with a main estimate of US$133 million (discounted US dollars). In the context of less than half a million dollars of direct research costs, this represents an exceptional return on investment, and illustrates the potential effectiveness of advocacy bodies as an intermediary audience for policy oriented research findings.

Example 3. The conservation agriculture hub in the cradle of the Green Revolution – CIMMYT

Summary and main results: Coordinated innovation and learning platforms established in key farming systems to engage, catalyze and support NARS technology developers and associated stakeholders (notably researchers, farmers, policy makers) to develop widely applicable technologies and identify policies to increase system productivity and sustainability including improved input use efficiency (including water, nutrients and labor) and soil quality management. The scientific lessons learned were included in several publications, the conceptual lessons learned related to innovation networks were included in the 'Take it to the farmer' project, an important pillar of the current multi-million MasAgro project with the Mexican government.

Research governance, management and learning process: CIMMYT began the implementation of its conservation agriculture hub, integrating existing research efforts into the overall hub innovation concept in order to stimulate and catalyze the interest of all actors of the production chain. A local farmer organization, Patronato para la investigacion y experimentacion agricola del estado de Sonora A.C. (PIEAES), was immediately interested and actively supported the development of a farmer training module. This module, jointly managed by the CIMMYT crop management team and PIEAES, serves as a training platform, and based on this several on-farm modules have been implemented. Both actors were the main drivers of what is now a multi-institutional multi-disciplinary innovation network. Current governance is done through different thematic inter-institutional working groups and through yearly hub meetings. Day-to-day coordination is done by a project hub manager. The local office as well as some of the strategic research platforms are installed on fields and ground provided by the farmer group. Primary users of the output include: farmer unions and associations, farmer union technicians, machinery manufacturers, NARS scientists, private sector representatives (seed, fertilizer and herbicide retailers), public sector representatives. Partners organizations that took up the technology are the State research organization (INIFAP), the Association of Farmer Organizations (AOASS) whose member organizations each bought and were trained in the use of the equipment. PIEAES, which has now funded demonstration and research work on permanent beds, the Commission of the National Wheat Chain (CONATRIGO) which set up the subsidy scheme supported by the federal department of agriculture to buy the machines, and the 'Produce Sonora' Foundation funded the extension projects. Secondary users of the output through the proof of concept, CIMMYT scientists together with the NARS colleagues will be users of the output through replication of the implemented processes.

The principle focus of CIMMYT's efforts in research on conservation agriculture and related Resource Conserving Technologies (RCTs) is to identify functional, resource efficient alternatives to conventional agriculture that offer farmers major sustainable benefits under different conditions, agro-ecological zones and farmer circumstances. This is approached through innovation and learning hubs in key agroecosystems where maize- and wheat-based systems are prominent. These hubs provide benchmark sites for research on the impacts of conservation agriculture on crops and the environment in the prevalent cropping systems of these regions, and importantly provided the focal point for regional (agroecological) capacity-building on conservation agriculture and research on innovation systems. Through the research and training, regional conservation agriculture networks are established which facilitate and foment research and extension of conservation agriculture innovation systems and technologies. Importantly research at the hubs also provides an example of the functionality of conservation agriculture systems. The key output: "Coordinated innovation and learning platforms established in key farming systems to engage, catalyze and support NARS technology developers and associated stakeholders (notably researchers, farmers, policy makers) to develop widely applicable technologies and identify policies to increase system productivity and sustainability including improved input use efficiency (including water, nutrients and labor) and soil quality management." As a proof of concept of its strategy related to conservation agriculture innovation systems, in mid-2007 CIMMYT initiated a conservation agriculture hub on irrigated wheat-based systems in Mexico. The hub capitalized on the considerable effort of CIMMYT over many years related to conservation agriculture in these systems. A long-term experiment was initiated in 1992 to compare common farmer practice (based on extensive tillage to destroy the existing raised beds with the formation of new beds for each succeeding crop) with the permanent raised bed system combined with different crop residue management options. Several component technology trials to fine-tune different aspects of the permanent bed planting system were implemented to support and provide inputs to the long-term system trial. The main factor that has limited extension and adoption of permanent raised beds has been the lack of appropriate implements, especially seeding equipment. During several years CIMMYT worked on the development of multi-crop/multi-use prototype implements that could be simply reconfigured to reshape beds, seed both small and large seeded crops easily and rapidly, and manage band application of both basal and post-emerge fertilizer.

Example 4. On-farm impacts of zero tillage wheat in South Asia's rice–wheat systems – CIMMYT

Explanation and information on potential interaction among scales and up/out scaling: Despite the demonstration of compelling economic and yield advantages, zero-tillage (ZT) in the Indo-Gangetic Plains was almost entirely the purview of researchers rather than farmers until the early 1990s when the Rice–Wheat Consortium (RWC) for the Indo-Gangetic Plains was formed. The reasons for this were multi-faceted but included a lack of appropriate and commercially available machinery, insufficient attention to the refinement of companion technologies such as essential adjustments to weed control strategies that could be reliably adopted by farmers under ZT, and lack of a regional knowledge sharing network that could spur innovation and consolidate lessons learned at broader spatial scales. Through the strong public–private partnerships formed through the RWC and continued through regional projects like the Cereal Systems Initiative for South Asia (CSISA), significant progress has been made in refining ZT technologies at the field and sub-national scales and subsequently using the partnership network for out-scaling across the region.

Summary of main results: Refining technologies: Since 1998, over 75 improvements have been made to the first Pant Nagar zero-till drill developed in the early 1990s. Some of these innovation have been revolutionary: the new versions of the 'turbo seeder' developed in through public–private partnerships in the Punjab are able to plant wheat into full residue cover, thereby avoiding rice residue burning which is responsible for wide-spread air pollution in northwest India along with substantial GHG emissions.

Achieved impact with farmers: Impact studies of ZT in India (Erenstein et al., 2007a; Farooq et al., 2007) revealed net revenue increases of US$36 and US$108 per hectare in Haryana and Punjab, respectively. These increases are attributed both to higher crops yields and lower production costs. ZT plots thereby achieved a significantly higher return on production costs (17%) and significantly higher estimates for net-revenue-based water productivities. The combination of a significant 'yield effect' and 'cost-saving effect' makes ZT adoption worthwhile and is the main driver behind the rapid spread and widespread acceptance of ZT among farmers.

Demonstrating performance in new ecologies: In the warmer eastern Gangetic Plains (EGP), terminal heat significantly diminishes wheat yield potential for late-sown crops. This scenario is worsening with climate change (Ortiz et al., 2008). ZT can significantly reduce the turn-around time between the rice and wheat crops by eliminating the process of land preparation. On-farm technology demonstrations of ZT by CSISA indicate that wheat yield performance can be improved by about 2 t/ha by facilitating timely planting in the EGP.

Generating environmental public goods: At the same time as ZT is benefiting farmers with lower production costs and higher yields, significant environmental benefits accrue: adoption of zero tillage technology can result in the saving of 98 liters of diesel fuel per hectare, thereby eliminating 0.25 t of CO_2 emissions per hectare (Reeves et al., 2001).

Research governance, management and learning process: The RWC and projects like CSISA that were built off of the operational model and partnerships network developed by the RWC employ a participatory approach to technology development that is now termed the 'hub-based' approach. The hub concept implicitly recognizes that innovation is not a single act but an amalgamation of linked activities that require coordination to ultimately achieve durable impact with farmers. To identify and make progress towards location-specific priorities like accelerating adoption of ZT, each hub brings together a wide range of project partners that can include private-sector companies involved in agricultural inputs and supply and marketing services, equipment manufacturers, public-sector research and extension agencies, universities, cooperatives, water management associations, non-governmental organizations, and farmer groups. As described above, research progress on ZT in the Indo-Gangetic Plains has been made through the formation of close partnerships and networking of international agriculture research centers (IARCs), national agriculture research system (NARS), and the private sector. Co-learning with farmers is embedded in the hub-based approach to technology development.

Example 5. Returns to policy-oriented agricultural research: the case of barley fertilization in Syria – ICARDA

Research governance, management and learning process: ICARDA and its Syrian partners initiated farming systems research that led to a change in national fertilizer allocation policy. Evidence is assessed on the policy influence of the fertilizer-response research and on the impact of switching to a more inclusive policy that relaxed the government's probation of fertilizer allocation to barley. Interviews with key informants make a persuasive case for attribution; estimates from economic surplus models are consistent with a high rate of return on investment in the policy-oriented research. This case study provides a contribution to the limited empirical literature on returns to research under policy distortions. Details can be found in Ahmed M.A.M., Shideed K., Mazid A. 2010. *World Development* 38: 1462–1472.

This research was interdisciplinary and included agronomic trials determining the technical feasibility of fertilizer use on barley in drier environments, farm surveys, and economic and risk analyses of fertilizer use on barley in drier areas. Trials on farmers' fields were conducted to investigate whether the large yield response to fertilizers obtained on research stations held up under the highly variable soils and rainfall conditions that farmers face in marginal dry areas. Researcher-managed agronomic trials were carried out in 75 sites over 4 years. Data on productivity, soil analysis, and rainfall were collected and analyzed. The economic assessments addressed the assumptions underpinning the prevailing perception that applying inorganic fertilizer on barley did not pay. Several workshops on fertilizer use on barley were organized. Every year, research results were discussed in an annual national coordination meeting with the presence of a large number of people influential in Syrian agriculture, including the Minister of Agriculture and the Director General of ICARDA. This research examined the role of well-defined research in changing fertilizer policy that led to the inclusion of rainfed barley in the government's 1989 decisions on crop-wise fertilizer distribution. The research project produced clear evidence of economic response to moderate levels of fertilization of barley in arid agriculture. After the policy change, fertilizer access increased markedly for barley production in two of the three major regions where it is produced in Syria. Simultaneously, government credit became available for the purchase of fertilizer by barley farmers in the higher rainfall region.

Example 6. Water/land productivity in irrigated systems – ICARDA

Explanation and information on potential interaction among scales and up/out-scaling: The on-farm work is affected by the water delivery amounts, scheduling and quality at the scheme level and at the same time affect downstream by producing drainage water that is reused/recycled by farmer downstream several times.

Summary of main results: After 3 years of testing, water use on farmers' fields fell by about 30%, with corresponding pumping costs. Labor costs for land preparation, irrigation and weed control fell by 35%. Yields were the same or higher than the conventional system, and farmers' net income increased by 15%. Crop water productivity increased by over 30% and the net return per unit of water was 20% higher. As the package was developed in participatory mode with farmers, communities and NARS researchers, rapid dissemination took place. It was also transferred to other farmers by NARS extension through field visits, farmers' field schools, workshops, meetings with development technicians, policy makers, and publications. Most farmers within the project and neighboring communities have already adopted the new package. Other development projects in Egypt have adopted the package including: the East Delta Rural Development Project financed by IFAD and the World Bank, the Crop Intensification Project of Middle Egypt financed by IFAD and the Water Management Improvement Projects in Behaira and Sharkieh governorates. The national extension system is transferring the package to six additional governorates in Egypt. Thus, project interventions, originally tested at a few pilot sites, are being rapidly scaled out over a large area by a range of partners, leading to impacts on water productivity and farm incomes. The raised bed (wide-spaced furrows) irrigation package, adapted and tested in the ICARDA-led Water Benchmark Project, is being endorsed by the authorities in Egypt, widely disseminated and adopted by three development projects and over 1,000 farmers in the middle delta. It is recommended by the Ministry of Agriculture of Egypt for implementation by a mega-development project planned to cover 40,000 hectares. Later the soil preparation and planting was mechanized which reduced the cost and improved the system performance

Research governance, management and learning process: The research was led by ICARDA's Integrated Water and land Management Program and financed by the Arab Fund for Economic and Social Development, IFAD and OFID. An integrated team of scientists from ICARDA and from Egypt national institutions (Agricultural Research Centre [ARC] of the Ministry of Agriculture and Water Management Institute of the Ministry of Water and Irrigation) was formed to conduct the research. A project manager, a coordinator and field team leaders managed the project. The teams included representatives of the local communities, farmers' associations/water user associations. Frequent participatory sessions with farmers and other stakeholders took place during the planning, design and implementation of the research. Other partners such as development projects were later involved in the dissemination of the project results.

Farmers in the Egyptian delta mainly use surface irrigation (flood and furrows), where the whole cultivated area is flooded, either with closely spaced furrows or small basins. The system allows applying excessive amounts of irrigation resulting in low water-use efficiency, nutrient leaching, more plant diseases and soil and water pollution, and related high pumping and labor costs. Although land productivity is high, the resulting water productivity is low.

The project introduced, adapted and tested a better alternative. The package is based on introducing widely spaced furrows with broader 'crop strips'. An improved crop variety is planted on slightly raised beds 1.0–1.5 meters wide, with the number of furrows cut by more than half the conventional practice. Over-irrigation is automatically reduced. The modified furrows are part of a package including lower seed and fertilizer rates, and fewer chemicals for pest and disease control. The package was tested in farmers' fields on wheat, berseem, faba bean, maize and cotton. The research was conducted on farmers' fields in fully participatory mode and community based.

As farmers were part of the process, many parameters of the system were adopted from their experience with other systems and proved to be useful. Although the scientists were convinced of the benefits of the package, farmers waited until they harvested their fields to be convinced. Adoption afterwards increased very quickly across the Delta.

Example 7. A new protocol adopted by NARS for assessing soil health at watershed scale and recognition of widespread micronutrient deficiencies in India soil – ICRISAT

Explanation and information on potential interaction among scales and up/out-–scaling: All districts (30) in the State of Karnataka, expanding to Andhra Pradesh. Soil nutrient deficiency maps for whole State have been produced.

Summary of main results: To address the issue of stagnant agricultural growth in Karnataka, a mission project '*Bhoochetana*' is successfully intensifying rainfed systems and bridging existing yield gaps between the farmers' present yields and achievable potential yields by taking science to the doorsteps of the farmers. Karnataka is the second largest state (4.2 million ha rainfed areas out of 7.2 million ha) with dryland agriculture in the country; is a representative of rainfed agriculture in the semi-arid tropics, with millions of smallholders deprived of scientific information, a lack of institutions, inappropriate policies and a lack of credit and extension mechanisms in the region. Millions of smallholders with an average productivity of less than one t/ha subsistence agriculture productivity over hundreds of years have not only mined their soils for nutrients but also severely degraded them, with increased erosion. Further, depleted animal population, skewed agricultural policies favoring irrigated areas, lack of soil health knowledge, and inappropriate soil, water, nutrient and crop management practices adopted by the farmers have resulted in severe degradation of soils continuing the downward vicious spiral of low crop yields and increasing degradation. ICRISAT scaled up the pilot initiative of productivity enhancement in rainfed agriculture by adopting the science-led development approach by technically supporting the Department of Agriculture (DoA). The journey in Karnataka started in 2005 through the Sujala–World Bank aided watershed program for productivity enhancement in 50 micro-watersheds, where on 3,700 ha crop yields increased by 58% with a number of dryland crops in six districts of Karnataka. In 2009, ICRISAT initiated a mission approach for increasing productivity of all rainfed areas in 30 districts covering 4.2 million ha by 20% in four years with DoA as nodal agency. *Bhoochetana* adopted the consortium approach for technical backstopping and capacity building in partnership with state agricultural universities and government line departments such as Watershed Development Department and Department of Economics and Statistics. The principle of convergence was operationalized by converging all agricultural schemes in Karnataka. A novel extension mechanism to reach millions of smallholders through Farm Facilitators (FFs, one per 500 ha) with capacity building by ICRISAT-led consortium was adopted. A massive soil sampling covering 92,000 farmers' fields from 25% of villages by adopting stratified farmer participatory sampling method (Rajasekharao et al., 2010; Sahrawat et al., 2008), was adopted, samples were collected and analyzed. The results revealed that soils in Karnataka have multiple nutrient deficiencies and farmers were unaware about the balanced nutrient management approach. The ICRISAT-led consortium mapped soil health in 30 districts, developed Taluk-wise soil test-based recommendations for all the crops, and disseminated the information to farmers through wall writings, village meetings and by distributing soil health cards. They also made appropriate arrangements for the timely supply of nutrients in the villages through Raitha Samparka Kendras (a cooperative farmers society), and proper incentives along with capacity building and hand-holding support were operationalized. In 2009, some 1.6 million ha were covered in six districts and the results showed increased crop yields (32–66%) of maize, sorghum, soybean, pigeon pea, greengram, chickpea, rabi sorghum, finger millet, groundnut, among others. During the subsequent years in 30 districts, 3 million ha of area covering one million families of smallholders were reached by the mission project. With technical support and capacity building measures, enabling policies and appropriate institutional mechanisms, millions of farmers have harvested increased crop yields irrespective of rainfall (i.e. favorable or unfavorable) situations in the state. The cost–benefit ratios clearly demonstrated the economic viability of improved management practices (balanced nutrient management, sites of improving varieties, biofertilzers and bio-control agents and equipment). The cost benefit ratio for ragi varied from 1:3.5 to 7.8, for maize 1:7.9 to 12.6, pearl millet 1:1.7 to 4.7, green gram 1:2.4 to 6.6, pigeonpea 1:4.6 to 11.4, groundnut 1:2.5 to 14.6, soybean 1:4.0 to 7.4 and sunflower 1:1.2 to 2.8 in different *taluks* of different districts. These results have clearly shown the potential to benefit millions of smallholders in the semi-arid tropics. During 2009/10 agricultural income in the state was increased by 412,990 million rupees (US$ 8260 million) and recorded 5.8% agricultural growth rate. However, it was only by adopting a new paradigm of scaling up the research for development and for impact by adopting holistic approach addressing the issues of technologies, knowledge sharing mechanisms, input availability, enabling policies and mobilizing political will and demonstration support for achieving the impact. The Department of Agriculture of the Government of Karnataka has become a model department for science-led development, not only in the state but also in the country. Looking at its success, the governments of Andhra Pradesh and Tamil Nadu have adopted a similar approach of providing technical support through ICRISAT-led consortium to benefit millions of smallholder farmers.

Example 8. Collective Actions and Property Right (CAPRi) – IFPRI

Several different useful documents were shared, but no specific summary was prepared. The quick description reported herewith has been extracted from the CAPRi website (www.capri.cgiar.org) and from the CAPRi EPMR.

CAPRi is a systemwide network project launched in 1998 with an overarching goal of contributing to policies and practices that alleviate rural poverty by analyzing and disseminating knowledge on the ways collective action and property rights institutions influence the efficiency, equity, and sustainability of natural resource use. CAPRi has run three competitive grant programs in the period reviewed by the Panel. Funding decisions are made by the CAPRi Executive Committee, an independent group of experts that advises the program, after recommendations from an independent Proposal Review Panel.

The CAPRi program, convened by IFPRI, has demonstrated the central importance of property rights and collective action for effective natural resource management: property rights provide the necessary authorization and incentive for long-term investments in the resource, and collective action provides coordination for resource management practices that occur above the level of the individual farm (see http://www.ifpri.org/2020/focus/focus11.htm). In the past 5 years, areas of particular focus for the CAPRi program have included examining the role of collective action and property rights in the management of genetic resources, poverty reduction, decentralized management of resources, payment for environmental services, and managing conflicts over natural resources. The program collaborates closely with the International Association for the Study of the Commons, and has been influential in helping strengthen management of common pool resources such as forests, water, and rangelands.

According to the CAPRi review (2003), '[t]he Review Panel concluded that CAPRi's thematic foci are highly relevant to CGIAR goals. The Review Panel is very positive about CAPRi's outputs and their impacts, and particularly CAPRi's role in creating increased awareness by centers and NARS of the role of CA [collective action] and PR [property rights] research in natural resource management and technology adoption is it worth/useful to use (drawn from WB Meta-evaluation)" (cited in Science Council, 2008). The Panel (of the CAPRi review) considers CAPRi to be an example of an effective and innovative structure for promoting crosscutting research.

Example 9. Sustainable Tree Crop Program – IITA

Explanation and information on potential interaction among scales and up/out-scaling: The underlying premise of the productivity interventions developed by the Sustainable Tree Crop Program (STCP) is that low yielding extensive agriculture in West Africa has been the main driver of deforestation. In coastal West Africa the three fastest growing commodity sectors are smallholder cocoa, smallholder oil palm and smallholder cassava. To address deforestation and conserve the remaining protected areas in West Africa land-sparing interventions are urgently needed for these commodity subsectors. The STCP provided a cross-country platform for the multiple stakeholders of the program to share and discuss the progress and impact of interventions ranging from the public sector provision of farmer field school training on integrated pest management for cocoa to the quasi-private sector provision of fertilizers. The program also had a heavy focus on policy interventions to support sustainable intensification. Price endogenous multimarket models of regional cocoa production were used to examine the impacts of significant shifts in regional demand and supply on prices and regional and country welfare levels. Fertilizer subsidies, extension programs, and seed distribution mechanisms were the principal policy levers with significant impact on land sparing technology adoption.

Summary of main results: Research has focused on the impact of extensive versus intensive farming practices in the Guinea forest agroecology of West Africa vis-à-vis poverty alleviation, deforestation, climate change and greenhouse gas emissions, biodiversity conservation and foreign exchange earnings outcomes. Results have shown that extensive farming practices are much more widespread than are intensive farming practices in the cocoa subsector, and if the intensive farming technologies had been adopted 25 years ago when these technologies were first validated, over 21,000 km^2 of deforestation and forest degradation would have been avoided, along with 1.4 billion t of CO_2 emissions and uncounted species extinctions. With the exception of the western region of Ghana, which is been targeted by the High Tech Program of the Ghana Cocoa Marketing Board, most of the cocoa sector in West Africa remains under these extensive no-input production systems. Detailed field research of cocoa intensification over the last 10 years in the western region attributes the recent near-tripling of cocoa yields due mainly to the increased adoption of fertilizer and insecticides. Yields were also significantly impacted by improved planting material although less than 10% of farmers had adopted the best available cocoa hybrids. Farmers who participated in field school training developed by the Sustainable Tree Crop Program had much higher productivity, but they only accounted for an estimated 6% of the surveyed population of producers. Cocoa incomes on average had doubled over the last 10 years and a significant number of households had escaped from chronic poverty. This research found that the addition of 1 t of fertilizer increased output by the equivalent of 2.4 ha of extensive cocoa. The combination of random field surveys and the monitoring of land use change using remote sensing in proscribed areas has been proposed as a mechanism for the distribution of REDD+ resources to support decentralized research on sustainable intensification and to support knowledge transfer of those research results.

Research governance, management and learning process: The Sustainable Tree Crop Program is a public–private partnership between the global chocolate industry as represented by the World Cocoa Foundation and the US Agency for International Development. The program was administered by the International Institute of Tropical Agriculture and was governed by a steering committee composed of national and multinational stakeholders from both the public and private sectors. Steering committees took place on a biannual basis with *ex officio* participation of the five country managers and the regional program leader and regional manager from IITA. The original research agenda was designed on the basis of a consensus among stakeholders over a range of researchable issues that emanated from the stakeholders' expert knowledge and a baseline diagnostic survey conducted at the beginning of phase 1. As the program evolved, a multi-market equilibrium model of cocoa and related markets was used to predict and prioritize impacts of various potential interventions.

Example 10. IPM Systemwide program – IITA

Explanation and information on potential interaction among scales and up/out-scaling: Local experiments, national scaling up, multi-country sharing of information/ *experience/knowledge.*

Summary of main results: New knowledge on whiteflies and whitefly-transmitted viruses; farmer experimentation with novel control approaches including both cultural practices and new varieties (with virus resistance); wide-scale promotion and dissemination of virus-resistant varieties in target countries.

Research governance, management and learning process: The Project was part of the CGIAR's Systemwide Program on IPM. Overall co-ordination was from CIAT. IITA ran a DFID-funded component on whitefly research in Africa. IITA worked with NARS partners in target countries. NARS partners ran their own sub-grants and results were shared among all partners. Within their sub-grants, NARS worked with local partners, primarily extension services. The research was designed in a consultative manner involving IITA, CIAT and NARS partners in target countries in Africa. This was achieved through both stake-holders meetings and regular electronic communications. Needs were identified nationally, and needs for specific field research elements were designed through consultation between NARS researchers, extension staff and local communities.

Example 11. Alternate wetting and drying is adopted by hundreds of thousands of farmers in South and Southeast Asia – IRRI

(Outcome statement submitted during the PMS by the Center)

IRRI research that resulted in the output: Although the concept of using intermittent irrigation for saving water has been studied for more than a decade, most of the initial studies were site-specific and scientists did not generate recommendations accepted by farmers. In 2002, IRRI, together with IWMI, CSIRO, Chinese and Philippine NARES, started a systematic investigation on a form of intermittent irrigation called Alternate Wetting and Drying (AWD) – a technology that can save 30% of water input without compromising rice yield (MTP 2003–2005 Project 5, Output 1, 2004 milestone 'Potential for water savings of three technologies [raised beds, alternate wetting and drying, and aerobic rice] assessed' and 2006–2008 MTP Project 5, Output 1 2006 output target 'Synthesis of advancements in development of water saving irrigation technologies'). Key products included enhanced understanding of agro-hydrology, soil and plant responses to different water stress levels, nutrient and weed management in AWD.[32]

From 2004, IRRI organized training courses to enhance NARES' capacity to carry out participatory research in validating AWD technologies and in developing extension materials for farmers to implement AWD.

Use/adoption of outputs: Through large IRRI networks participatory research to

32 E.g. http://www.springerlink.com/content/mdvxvf5xd9db/?p=36ccae96a54442cfb83f36c246241318&pi=20

validate AWD and develop training and extension material in local languages was carried out by: Bangladesh Rice Research Institute, Rural Development Academy in Bangladesh; PhilRice, National Irrigation Administration, Central Luzon State University, Bulacan Agricultural State College and other state colleges and universities in the Philippines, Philippine Council for Agriculture, Forestry and Natural Resources Research and Development, Bureau of Soils and Water Management, Department of Agriculture-Regional Field Units; Department of Plant Protection (DPP), Department of Agriculture and Rural Development of An Giang Province (DARD-AG) in Vietnam.

The Bangladesh Agricultural Development Cooperation, Barenda Multipurpose Development Authority, and Department of Agriculture Extension (DAE) established demonstration plots on farmers' fields in different ecological zones in Bangladesh. DAE trained more than 400 of its staff members on AWD and established 460 demonstration farms in 25 districts. Practical Action, an NGO, conducted the demonstration with 400 farmers, Syngenta, a private company, has trained 1,200 employees and work with 50,000 farmers on AWD. The AWD work in Bangladesh culminated in a national Workshop on 'Adoption and success of AWD Technology for Rice Production' held in July 2009 in which the Secretary of the Ministry of Agriculture supported AWD and directed DAE to upscale the technology nationwide (http://www.scribd.com/doc/86314263/Ripple-Sep-Dec-2009). DAE, other agencies including NGOs and Syngenta, have plans to disseminate AWD to over 50 districts in 2010, covering more than 120,000 ha of Boro rice. In the Philippines, AWD has been included as one of the key technologies promoted through the National Rice Sufficiency Program. The Department of Agriculture Secretary has issued an Administrative Order directing all agencies concerned to adopt AWD and other water saving technologies in all water management nationwide. Under the name 'controlled irrigation', AWD has been included in the official Rice Check (in Filipino: Palay Check) (http://www.pinoyrkb.com/watermanagement). In Vietnam, DARD-AG organized four training courses for district extension workers, established 50 demonstration plots in 2009. DARD-AG and DPP have included AWD in their Provincial Program 'one must; five reductions' (http://www.irri.org/irrc/news/IRRC%20sponsors%20An%20Giang.asp). As a result, tens of thousands farmers in Bangladesh, more than 60,000 in the Philippines and thousands in An Giang, Vietnam have adopted AWD (http://beta.irri.org/images/stories/ar2008/Prog02/Prog_2_Responding_to_water.pdf).

Significance of use/adoption: Sattar (2009) reports a consequent reduction in water use of 15–30% in Bangladesh, which translates into a reduction in pumping cost and fuel consumption, and increased income of US$67–97 per hectare. In Vietnam, the technology is expected to result in a 15% yield increase, thanks to a reduction in lodging, which often occurs in direct-seeded rice. Although the technologies are already nationally promoted in Bangladesh and the Philippines, the potential adoption domain is far beyond these countries and includes most of the irrigated rice area in Asia, especially during the dry season where farmers have to pay for their pumping cost or where there is water scarcity. Already, IRRI's Irrigated Rice Research Consortium has received requests from Myanmar, Laos, Indonesia, and Thailand to help them disseminate AWD. AWD is likely to prove to be a key means to help alleviate the water scarcity that is likely to otherwise affect 15–20 million hectares of irrigated rice by 2025.

Example 12. Co-management of electricity and groundwater in Gujarat, India – IWMI

Explanation and information on potential interaction among scales and up/out-scaling: Local use impacts up to subnational scales.

Summary of main results: Complete change in groundwater and rural electricity use in one of India's largest states, now in two other states and probable expansion to others.

Research governance, management and learning process: Part of the IWMI-Tata Water Policy Program, which uses a distinct process for selecting issues to work on building cases for involvement by the research community beyond the program.

Example 13. Alternatives to slash and burn – ICRAF

(Outcome statement submitted by the Center in the framework of the PMS)

This study focused on the use of Alternatives to Slash and Burn (ASB) methodologies, empirical results and lessons, and communication products related to human–environment interactions by a range of research, development, and policy related organizations working in tropical forest margins. Outputs include characterization methods developed for forest margins; tradeoff analyses tools developed; methods for assessing environmental services in land uses developed; lessons for technology, institutional and policy options for forest margins developed; lecture notes and policy briefs developed.

ASB methods, empirical knowledge, and lecture notes have been used both by individuals and institutions. The number of organizations formally associated with ASB mushroomed to around 80 at the beginning of 2005, up from 18 at its inception. There are many national partners from Asia, Latin America and Africa. Recently, the World Bank and FAO have adopted the ASB tradeoff matrix method as a land management assessment tool. Empirical lessons from ASB have helped contribute to the World Bank's new forest development strategy. ASB contributed to the sub-global assessments of the Millennium Ecosystem Assessment, completed in 2005. ASB was formally recognized for these achievements by winning the CGIAR partnership award in 2005. Uptake of ASB outputs was through publications, website downloads, attendance at conferences and meetings, training in ASB methods, and expansion of the ASB network. The outputs were used to assist in policy formulation, course curricula, in advancing research, and in improving development decision making. All the evidence on outcomes reported is from the review of the ASB program (CGIAR Science Council, 2006).

Example 14. Impact of the Development and Dissemination of Integrated Aquaculture–Agriculture – WorldFish Center

From the Report of the Third External Program and Management Review of the WorldFish Center (CGIAR Science Council, 2007)

Adoption of the Integrated Agriculture–Aquaculture (IAA) technology by more than 200,000 families (Malawi). The adoption of IAA in Malawi has reduced childhood malnutrition by 15%, increased the number of fish farmers from 400 (1980) to 4000 and increased total annual fish production by more than 160%. In the areas of Malawi where IAA technology was adopted productivity of farm ponds improved substantially with the average yield more than doubling, from 1.34 to 2.73 t/ha. It has also been instrumental in increasing income (three to four times in some cases). Fish consumption in the project areas rose by about 160% and childhood malnutrition fell by 15%. The IAA technology has led to fish constituting an increased share of incomes in farming systems from some 5% before projects to more than 35% after. Geographical expansion of the IAA technology is creating conditions for spin-offs and contributes towards macroeconomic growth, job security, exports and food security for the country's increasingly urban population. The IAA technology has been adopted as the official production technique by the Government of Malawi. IAA and the rice–fish systems are more dynamic, durable and resilient sources of livelihoods than traditional farms. This is demonstrated by the fact that IAA farms are 18% more productive during drought than traditional forms of farming. This has great implications particularly in Southern Africa where, with almost four farmers per hectare, even mild droughts can lead to food shortages. The IAA and rice–fish systems however have potential for conflicts with regard to water use and management. In this context, the Panel commends the Center for the excellent collaborative work with IWMI in the Mekong Region and invites further strengthening of such interaction to address issues related to water management. Raising fish in rice fields in Bangladesh increased the productivity and efficiency of farms and profitability was increased up some 20–85%.

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