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INTERNATIONAL PUBLIC GOODS THROUGH INTEGRATED NATURAL RESOURCES MANAGEMENT RESEARCH IN CGIAR PARTNERSHIPS

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SUMMARY

The CGIAR System conducts research to produce international public goods (IPG) that are of wide applicability, creating a scientific base which speeds and broadens local adaptive development. Integrated natural resources management (INRM) research is sometimes seen to be very location specific and consequently does not lend itself readily to the production of IPGs. In this paper we analyse ways in which strategic approaches to INRM research can have broad international applicability and serve as useful foundations for the development of locally adapted technologies. The paper describes the evolution of the IPG concept within the CGIAR and elaborates on five major types of IPGs that have been generated from a varied set of recent INRM research efforts. CGIAR networks have both strengths and weaknesses in INRM research and application, with enormous differences in relative research and development capacities, responsibilities and data access of its partners, making programme process evolution critical to acceptance and participation. Many of the lessons learnt regarding challenges and corresponding IPG research approaches are relevant to designing and managing future multi-scale, multi-locational, co-ordinated INRM programmes involving broad-based partnerships to address complex environmental and livelihood problems for development.

PURPOSE OF THE PAPER

This analysis focuses on the generation of international public goods (IPG) through agricultural research in the International Centers of the Consultative Group on International Agricultural Research (CGIAR) and in their partnerships. It focuses on the international nature and applicability of research towards effective management of agricultural systems and of the natural, economic and human capital bases upon which they depend and influence. It has long been known that traditional, discipline-focused natural resources management research, as well as that on agricultural systems that have high interaction with local environments, is often very location-specific. Modern methods and tools, implemented through partnerships of institutions, can apply data bases and models for extrapolation across ecosystems and ecozones, which facilitate local adaptive development by groups with location and region-specific research and development responsibility. This is being shown to extend CGIAR research to have

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international applicability, to achieve cost-effectiveness and generate outputs which can lead to broad impact if other aspects of the development environment are in place. This analysis looks at ways that modern approaches to integrated natural resources management research (INRM) can have broad international applicability and serve as a highly useful foundation for development of locally adapted technologies.

A brief history of the evolution of IPG in the CGIAR is presented, followed by discussion of the relationship between CGIAR-related use of IPG terminology and the broad theoretical base of public goods. Several types of 'public' goods derived from INRM research will be presented, but only general relationships to theoretical classes are described, with no attempt being made to sort out the complex theoretical relationships among IPGs and to assign definitive classification. The 'utilitarian' definition of IPG, as commonly used within the CGIAR, is also used in this paper. We use examples of ongoing research in the CGIAR as a base, but look forward in dealing with current research planning and vision. No attempt is made to be comprehensive in reviewing IPG in the CGIAR, but examples are provided in key research categories from INRM research. The participation and investment of development-focused partners and their growing slate of scientific outputs are cited as outcomes. The paper does not speak to ultimate impact on the poor, nor is it implied that outputs are 'better' than those of location-specific research in site-specific impact. It is evident, however, that the scale of INRM research applicability can be markedly enhanced using a strategic IPG approach.

EVOLUTION OF THE IPG CONCEPT WITHIN THE CGIAR

The CGIAR and its partners now have more than 40 years of experience in the generation and application of science and technology for development. The record in NRM has been mixed, leading to considerable insight into both high and low-output approaches. A brief summary of that history and the lessons learned provides the basis for conclusions as to IPGs that are needed to provide the framework for an INRM approach.

From its very early days, with its focus on the genetic improvement of wheat, rice and maize (the main world staple cereals providing 60 % of global calories), the CGIAR aimed at developing improved, high-yielding cultivars with wide adaptability internationally across a range of growing environments. Breeding nurseries and international testing strategies were set up in pursuit of this aim, and improved 'green revolution' cultivars, particularly irrigated wheat and rice, were able to offer higher productivity and output in 'favourable' irrigated ecozones across international boundaries and continents. When, in the early 1970s the CGIAR added four ecologically oriented Centers with commodity mandates (CIAT[1], IITA, ICRISAT,

[1]The international (CGIAR) Centers mentioned here are: Centro International de Agricultural Tropical (CIAT), International Institute of Tropical Agriculture (IITA), International Crops Research Institute for he Semi-Arid Tropics (ICRISAT), International Center for Agricultural Research in Dry Areas (ICARDA), International Rice Research Institute (IRRI), Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), International Potato Center (CIP).

ICARDA) to the global commodity Centers IRRI, CIMMYT and CIP, it began to embrace elements of natural resources management and sustainability in its research agenda. However, the actual expression in scope, complexity and effectiveness of the themes in the CGIAR research agenda, and the research strategies on NRM have evolved in tandem with the evolution of the CGIAR goals and mission (Harwood and Kassam, 2003; Harwood *et al.*, 2005). In the 1970s and 1980s, the main research strategy continued to be the commodity approach, and the expression of the NRM concern was more in terms of understanding the nature of farming systems within which CGIAR commodities were expected to perform. NRM research mainly addressed production and associated socio-economic issues and their extension across production zones having similar environmental characteristics (Garrity *et al.*, 1978; 1981).

The second System review of the CGIAR in 1981 (CGIAR, 1981) and the priorities and strategies report of 1987 (TAC, 1987) emphasized that the CGIAR System was designed to pursue agricultural research that is international in scope and in potential impact, and where it had comparative advantage. The need for a supra-national effort was considered to be a decisive indicator of efficiency for the CGIAR System research effort, and referred to the number of countries potentially benefiting from the commodity improvement research. Transferability of potential technology across regions, national boundaries and cultural areas was considered to be an indicator that referred specifically to the ability to apply or adapt the potential results of the CGIAR System's commodity research on a broad level. This indicator emphasized that it was neither efficient nor cost-effective for the CGIAR System to undertake highly location-specific research. For maximum efficiency, it was emphasized that commodity research carried out by the CGIAR System should reflect its comparative advantage, and the CGIAR Technical Advisory Committee (TAC) selected four indicators to assist in this determination. These were: the need for a concentrated interdisciplinary research effort, the need for research at the strategic or applied level, the need for continuity and stability of effort, and the need for access to characterize germplasm.

The second System review (CGIAR, 1981) defined four types of research (basic, strategic, applied and adaptive) and emphasized that CGIAR's comparative advantage was in strategic and applied research while working in partnership with advanced institutions in basic research and with national programmes in adaptive research. The four types of research were defined as: basic research – designed to generate new understanding; strategic research – designed for the solution of specific research problems; applied research – designed to create new technology; and adaptive research – designed to adjust technology to the specific needs of a particular set of environmental conditions. As already indicated, the main focus of research at that time was on the development of improved cultivars with wide adaptability across international boundaries.

In the CGIAR priorities and strategies report in 1987, the growing complexity of technology development, the pressure on natural resources and the intensification of integrated land use were seen to pose significant challenges to international research to develop technologies, policies and institutions required to meet future needs.

Sustainable production systems based on NRM and conservation were identified as a major priority area. Advanced scientific institutions mainly in the North were considered to have comparative advantage in basic research, national institutions in the South in adaptive research, and the need for partnerships with advanced institutions and national systems was highlighted.

In 1990, in response to the growing international concern for sustainability and natural resources management, the CGIAR incorporated natural resource Centers in forestry (CIFOR[2]), agroforestry (ICRAF), fisheries (ICLARM) and water management (IWMI), and introduced an ecoregional organizational approach to strengthen natural resources management research and partnerships across the System. This move constituted a historical 'defining moment' for the CGIAR in the area of NRM research. For this expansion of the mandate and research to occur rationally, the CGIAR System in its strategic planning had to pay attention to elaborating: (i) the nature of the future challenges of sustainable food security with its use and management of natural resources; and (ii) the strategic and applied research effort needed in international public goods to address the challenge.

In the CGIAR expansion report in 1990 (TAC, 1990), and in the CGIAR priorities and strategies report of 1992 (TAC 1992), TAC emphasized the international nature of CGIAR's research, and defined this as 'activities which address significant global, continental or transnational problems, consistent with CGIAR mission and goal, and where it had comparative advantage'. TAC also introduced the notion that a substantial part of CGIAR research activities must be both strategic and applied in nature for research to be international in character and lead to discovery and/or development of new knowledge or technology that could produce benefits in terms of rapid international exchange of materials and information. Strategic research was seen as mission-oriented basic research aimed at discovering the generic principles explaining phenomena or a process, and applied research as applying the generic principles and knowledge in generating improved technology or innovation of international applicability and high pay-off.

In the 1987 and 1992 CGIAR priorities and strategies reports, the term international public goods was not explicitly used, but CGIAR's comparative advantage in addressing issues of global and international concern was repeatedly emphasized. We believe this was because the approach to priority setting was supply-driven and priority activities were regarded as being a research and research-related undertaking. In 1992, the CGIAR's research and research-related activities were classified into five major undertakings: conservation and management of natural resources; germplasm enhancement and breeding; development and management of production systems; socio-economics, public policy and public management research; and institution building. In 1995, in preparation for the Lucerne Consultation, these activities were regrouped and renamed as follows to reflect their aggregate outcome and the fact that the CGIAR had begun the process of transforming into a

[2]Center for International Forestry Research (CIFOR), World Agroforestry Centre (ICRAF), WorldFish Center (formerly ICLARM). International Water Management Institute (formerly IIMI).

demand- and impact-driven system: increasing productivity; protecting the environment; saving biodiversity; improving policies; and strengthening national research programmes.

The 'holistic', production systems research, and in the 1990s, the ecoregional programmes which have sustainable resource use as a focus have come under intense scrutiny to evaluate effectiveness in dealing with productivity across large areas, and for their success in targeting environmental issues (TAC, 1999; World Bank, 2003). Lessons learnt for natural resources-focused research have been reviewed by TAC (TAC, 1997a) and include the following:

1. An 'active' strategic and detailed knowledge base of the production regions must be available to the Centres and their partners to include data in each of the resource domains (bio-geo-physical, social, political, economic and infrastructure). The personalized knowledge of previous decades, residing with long-experienced researchers was no longer adequate because of staff turnover in the Centres and their partners, the information was not quantifiable and subject to analysis, and was not readily available nor transferable to new researchers. Research outputs were clearly not fully in the public domain.
2. A quantifiable and geo-referenced data set of the major production systems was needed.
3. Partnerships built on long-term relationships were essential, to include the research-policy-development spectrum.
4. Frameworks for conceptualization and improvement of the major production and natural resource-use systems must be evolved through participation of the key stakeholders to assure proper prioritization and relevance, and to achieve stakeholder ownership and clarity of roles.
5. Improved technologies must be available for improvement of the limiting production and NRM issues. These technologies, for ready application by development groups, should be 'embedded' within a matrix of process information to permit their extrapolation over time and gradients of change in their target ecoregions.
6. Meaningful and useful ecoregional research and impact areas must be identified.

Numerous examples of success and failures have been documented in review literature, nearly all of which could be traced to the presence or absence of combinations of the above requirements. The IPGs listed below are a clear reflection of those experiences.

In 1997, and with the years of experience clearly in mind, TAC, as part of the CGIAR priorities and strategies exercise, engaged in a major effort to classify activities to improve the CGIAR planning process and to put it in a larger logical framework. The CGIAR's concern for efficiency in priority setting led TAC (1997b) to state explicitly for the first time that:

> 'Centers' products should be international public goods. The reason being that, given the high opportunity cost of CGIAR resources, product limited to use in a single country that also meet the CGIAR's opportunity

cost criteria would be so valuable in terms of local opportunity cost that the country itself would finance the effort, and at lower costs, thereby becoming its own alternate supplier. The reason why the CGIAR will have higher opportunity costs than a nationally focused programme is that the latter will treat benefits to other countries as spillovers, not counting them in calculating opportunity costs, while the CGIAR, given its international role, will count all benefits in calculating its opportunity costs. As the quality of being an international public good is either present or absent, this characteristic is viewed by TAC as a necessary condition for consideration in priority setting.'

In the 2000 CGIAR vision and strategy (TAC, 2000), production of international public goods was stated as being a criterion for making strategic choices amongst research themes.

DEFINITION OF IPG IN THE CGIAR

The use of the term 'international public goods' within the CGIAR refers to research outputs falling into several 'types' of goods with relatively free (or low cost) access, having broad applicability across international boundaries. Its use by TAC was meant to direct the majority of research funded through the CGIAR to outputs having those characteristics. Quantification of eventual impact derived from those outputs will depend on the types of goods produced and on analytical methods appropriate to their theoretical foundation. While that foundation is essential for analysis, it also provides useful guidance in the applicability of IPG guidelines, particularly for integrated NRM (INRM) research.

There is a wide literature in the economic theory and differentiation of types of public goods, crossing fields of law, economics, environmental and social sciences (Coase, 1974; Samuelson, 1954)[3]. The intersect with property rights and the differences between private and public ownership as economic variables that could be manipulated were succinctly summarized in a seminal article by Alchian (1965). 'Pure' public goods have two distinct aspects; 'non-excludability' and 'non-rivalrous consumption' (Cowen, 1992; Golden, 1992). They are completely open and free to all (globally), and their supply is not diminished by use. These conditions occur, but are not fully met by most public goods. In general use, public goods theory defines four types of goods (Kolliker, 2004):

Non-rival		
	Non-excludable	public goods
	Excludable	club goods
Rival		
	Non-excludable	common pool resources
	Excludable	private goods.

Most research outputs, whether of knowledge or of information, can be non-rival, i.e. not diminished with use. Excludability is usually an imposed constraint, as through intellectual property rights or secrecy. In practical terms, exclusion can result from

[3]For authoritative overviews of public goods theory see Cowen (1992), and Cornes and Sandler (1996).

the inability to access and use for a variety of reasons. In the case of natural resources research application where the outputs may be scientifically complex, with high environmental interaction and the need for local calibration, reduction of exclusion (including both ready access and increase in applicability) is accomplished in part through partnerships designed both to enhance the knowledge itself as well as to enable partners to apply the results easily. In this instance the 'public goods' take on some of the characteristics of 'club goods', in that collaborative partners in the research projects have familiarity and capacity in use of the outputs which have been derived, in part, through their input. Strictly speaking, club goods theory assumes that rivalry in consumption begins as soon as the number of participants crosses a certain threshold (Cornes and Sandler, 1996), but for research outputs from collaborative partnerships within the CGIAR these limits probably do not apply within the defined geographical boundaries of most institutional research partnerships.

The collective action dimension with respect to natural resources use brings in the additional concepts of centripetal v. centrifugal effects (Kolliker, 2004). Centripetal refers to a force which pulls toward the centre of movement (here meaning to draw additional participants and to encourage their investment in property, research output and eventual application). The INRM research approach has, as its core, the structuring of process to enhance inclusion (Harwood and Kassam, 2003). Theory holds that the 'publicness' of a good is not an inherent characteristic of the good itself, but of the manner in which it is produced. Any good can be either a public or a private good, depending on the choice of production methods (Golden, 1992).

In the CGIAR, the meaning of the term 'international' has remained as defined earlier (TAC, 1987) – meaning applicable across international boundaries with high potential pay-off consistent with CGIAR goals. This definition is used for all aspects of CGIAR research outputs, including social, economic and bio-geo-physical applications (Dalrymple, 2006). At the international level, public goods are often viewed as being freely available, meeting some public need or concern, and requiring collective action to be provided. Thus, in the CGIAR:

> 'International public goods are taken to mean research outputs of knowledge and technology generated through strategic and applied research that are applicable internationally to address generic issues and challenges consistent with the CGIAR goal.'

CGIAR research that is aimed at producing IPGs must also meet the criteria of (a) having a high probability of success and significant impact, (b) being cost effective and (c) the CGIAR having a comparative advantage in doing it. A very few of the key IPGs of the CGIAR are global (the in-trust germplasm collections, for instance), but most outputs, certainly including those from INRM research (specific land management techniques, for instance), have more limited, multi-national, regional or ecozone applicability, although the underlying principles may have global relevance.

During the 1990s, which also included the explicit addition of poverty alleviation to its goal statement, the CGIAR advanced towards multi-scale INRM research to generate, with communities and stakeholders and governments, the scientific knowledge base and intellectual capital required for improved productivity leading to poverty alleviation and sustainable rural development. The ecoregional approach was formally instituted within the CGIAR in 1991 (TAC 1991). Production areas having reasonably similar biological, edaphic and economic characteristics are identified as target areas for problem-focused research and extension, to extend greatly the research impact. Lessons learnt from one area can also greatly speed the research process in similar ecoregions. The NRM case studies in Harwood and Kassam (2003) provide a glimpse of examples of INRM research problems, approaches and partnerships in action in the CGIAR. These reflect both the state-of-the-art in projects planned and organized during the 1990s, as well as their adjustments to incorporate the rapidly evolving fields of NRM as a science applicable to the CGIAR and its partners.

Finally, at the practical level of designing and implementing research, we believe that the above elaboration implies that true IPG research needs to actually plan for use across nations. Public goods research is by definition and conceptually freely available across national borders according to the definition of public goods. To make research truly focused on international public goods, it is a necessary condition that the research plan and activity include international elements. Cross-country comparative studies are a good example as is the development of methodology or technologies that are deliberately introduced and/or tested across countries. The point is that if the explicit internationalization of research is not included, then it is easy to slip back into the problem that almost anything and everything can be classified as (potentially) being an IPG. The integrated, 'I' nature of INRM, with inclusion of the multiple resource domains, implies that solutions tend to become increasingly localized in focus as integration becomes more holistic.

It is the working hypothesis of this paper that if INRM research is directed toward IPG from the outset, the outputs can have both international applicability as well as the potential to solve, with relatively modest investment in application, location-specific problems at the field and local community levels.

THE NATURE OF INRM REQUIRING A BROADER SET OF RESEARCH-RELATED IPGS

INRM has been articulated as:

> 'Integrated natural resources management offers a way of doing development oriented research that aims to simultaneously reduce poverty, increase food security and achieve environmental protection. These three key factors that influence human well-being are inextricably linked to the health of the ecosystems in which people live and work. INRM reflects these broad interactions. It focuses on ecosystems rather than commodities; on underlying processes (both biophysical and socioeconomic) rather than simple relationships; and on managing the effects of interactions between various elements of the ecosystem.' (Task Force on INRM, 2000).

The INRM approach thus includes several key factors that suggest the need for an array of scientific tools, approaches and partnerships beyond those of more traditional, component-focused research if it to be both efficient and effective:

1. Production ecosystems and the natural resource base they depend on and influence often cover broad geographical areas, including river basins, flood plains and other features that are often not related to political boundaries or to the research domains of single institutions. Broad partnerships are usually required.
2. The integrated nature of the research requires placing of research sites within matrices of resources (such as soils, water, climate, demographics, poverty distribution, market infrastructure) and extrapolating results across gradients of spatial and temporal change in those parameters. This requires, at a minimum, data sets configured for interaction analysis. It also suggests interdisciplinary teams working across institutions.
3. The research must be hypothesis-based and strategic, testing improvements in key processes or technologies across gradients of change in the interacting variables. This is best done with support from process-based models.
4. National programmes, particularly for the many small countries, will always be forced to prioritize their research carefully, with limited ability to develop all of the scientific tools necessary to address INRM issues. They must have access to networks for providing information and assistance.
5. At the end of the research process, improved technologies, institutions, and/or policies, set within their contextual matrix, and extrapolated across gradients of change must be in place for widespread impact. *The successful integration of change elements to enhance appropriate resource use within (and across) the production ecosystem is the ultimate test of the 'I' dimension of INRM, not the creation and use of 'tools', the use of multidisciplinary partnerships, nor the building of institutions.*

It is not suggested that these dimensions are new. What is important is that the tools, data sets and partnerships are far more critical to tomorrow's INRM research than they have been in the past, and that it is impossible, and certainly not cost-effective for any single institution or team to acquire, in-house, all of the necessary science to be effective. Those tools, data sets, and the co-ordination of INRM-dedicated partnerships have become important IPGs in themselves. Their development and calibration to major ecosystems and environments is a form of upstream research that generates true IPGs.

MAJOR TYPES OF IPGS IN INRM

INRM research can, when appropriately designed, generate at least five types of IPGs:

1. Tools and methods for research or development that have applicability beyond one nation's borders.
2. Global and regional approaches for INRM research co-ordination and facilitation services that involve more than one country.
3. Development at both field and landscape levels of management and institution-building principles and methods that have applicability in more than one country for suggesting the appropriateness of technologies and policies.

4. Contributions to technology development for INRM-based production systems that can be effectively used, with modest adjustments for site-specific conditions, in more than one country context.
5. Scientific understanding of the nature of ecosystem problems, their driving factors and their consequences/interactions with poverty and productivity are IPGs. Understanding the principles of managing ecosystems (across spatial and temporal scales) are also IPGs (that is, lessons for technology, institution, and policy interventions).

The five types are not listed in order of priority or necessarily of programme implementation. All are necessary, often to be carried out in a synchronous approach for optimum achievement of IPGs. While not expressly mentioned in each case, all are assumed to include capacity-building and training. Further, it is highly important to build the capacity for impact assessment (IA) into the project from the start, to generate appropriate baseline data, and to identify probable causal factors in addition to those being researched. It is beyond the scope of the present paper to deal at any length with the IA process, but rather to suggest that the methods and techniques for its successful application, subject to local adaptation, are very much IPGs. The reader is referred to the excellent assessment of the implications of INRM for developing evaluation methods by Douthwaite *et al.* (2004), and to the papers in the proceedings of the Combined Workshop of the Standing Panel on Impact Assessment (SPIA) of the CGIAR Science Council and the 6th Meeting of the CGIAR Task Force on Integrated Natural Resources Management (SPIA-INRM Task Force, 2005).

Type 1 – Provision of tools and methods for research or development that have applicability beyond one nation's borders

The ecosystems within which INRM research is conducted have dimensions which cross a range of scales, often extending beyond national borders to regional levels. Many of the techniques used in INRM research are common within broad geographical regions, with some having global applicability, with modest adjustment. Also, many of the major NRM problems faced at one site, such as the effects of land use on hydrological systems, are similar to those faced at another site. These factors all suggest that many of the data sets, methods and tools for INRM research have applicability beyond national boundaries, the various ecosystem scales and beyond. In some cases a river basin or a watershed may be used to delineate research programme boundaries.

Decision support tools. INRM researchers have been developing and testing procedures for many years for approaches, organizational and collaborative methods and research design aimed at producing 'knowledge chains' from fundamental concepts through basic ecosystems understanding down to specific problem-solving and community and farm-based interventions (Sayer and Campbell, 2003; Thomas, 2002). These are often most effective if they have cultural orientation and local specificity. It is being found, however, that many of the general procedures and concepts can be packaged as 'decision support tools' (DSTs) which serve as a basis for broad training and for local adaptation. Some tools have had a surprising level of international effectiveness and acceptability.

In South America, as series of DSTs were developed (Zapata and Ashby, 2003) to address training needs among INRM researchers. The guides were intended for the end user who will make decisions at the local level. Each guide contains the following:

- Flow diagrams – of the whole guide and the different sections for instructors to present the distinct themes.
- Guiding questions – to start dialogues and motivate the audience before approaching the theory.
- Technical content – to present the theory and steps to be taken in the process described.
- Exercises – adaptable to any audience or that can be replaced by problems relevant to the locality.
- Feedback sessions – these sessions complement the activities and help evaluate the achievement or objectives.
- Annexes – to add depth to aspects treated briefly in the text.

Topics have included:

Identifying and classifying local indicators of soil quality
Photographic analysis of land use trends in hillsides
Participatory mapping: analysis and monitoring in a watershed
Identifying levels of well-being
Identifying market opportunities
Developing organizational processes for natural resources management.

Application of the DSTs has had broad use in the initial target countries, but have proven useful in African settings as well.

The extensive CIFOR research effort to develop Criteria and Indicators for sustainable forest management is another example of a DST generated as an IPG (Spillsbury, 2005). That research has gone through multiple iterations and phases to provide policy and management capacity and insight. Several resource dimensions are now included in the Indicators. It is stressed, as with most tools, that the tool itself does not constitute INRM. It is merely one instrument to be used in final policy/technology integration.

GIS-based tools for organizing data sets. Data needs are determined by stakeholders and scientists as they seek to provide quantification of context for the issues they have identified. It is highly important to identify key system drivers to reduce data to an optimal level. The organization and presentation of data in a user-friendly form are equally critical. Demographics, physical infrastructure, rainfall, topography and soil factors can be overlaid with market channels, or eventually with the movement of races of plant pathogens or other variables that are of interest. Emphasis is placed on the factors that are thought to be most closely related to, and causes of, the priority problems. Technical assistance is often acquired from advanced laboratories or commercial vendors to make the data system more efficient and user-responsive. In some cases the data derived from models, such as evapotranspiration data for determining water management needs, are of far higher quality than can be measured in field projects. Secondary analysis of relationships among variables can be of major assistance in the planning of priorities and the selection of entry points. The data sets themselves are accessed and developed from public domain materials, and in most cases, public access can be negotiated for GIS software for specific, geographically targeted markets. Every attempt is made to have the materials available as IPGs.

In an Andean example (Quiroz *et al.*, 2003), the high spatial heterogeneity of the mountain environment limited the quality of geospatial data. A heavy reliance on remote sensing data (initially in a single watershed) permitted the delineation of agro-ecological zones to determine land use/cover, primary productivity, dynamics of changes and seasonality. Soils data, demographics, and infrastructure could then be overlaid. The GIS model was advanced with the help of a commercial vendor. This resulted in a capacity for graphic illustrations and virtual visual 'over flights' of the mountain valleys, superimposing soil and crop fertility data, to demonstrate technological options and their predicted economic and environmental impacts to villagers. Thus, the model served as both a research and a learning/extension tool. The building and application of such data sets requires an expertise not always available at the local level. They are often expensive for small user groups to acquire, and efficiencies are only found at larger scales of adaptation and use.

In a second example having an international scale from the beginning (Swallow *et al.*, 2003), a study of the Lake Victoria basin made use of selected GIS data from a long-standing data base for the region to identify the specific river basins contributing the largest amounts of sediment and other loadings into the lake. Using Kenya as a focal country, they developed numerous tools to identify past erosion hotspots and then to predict the most likely future hotspots. Potential impacts of alternative land use and management options on poverty alleviation, soil quality and productivity, water quality and hydrological function could then be projected, subject to validation and on-the- ground, multi-institutional, community-based participant research.

Type 2 – Global and regional approaches for INRM research co-ordination and facilitation services that involve more than one country

In order for the several factors above to be utilized on an effective and efficient scale, which is appropriate to the ecosystem boundary(ies) and problem sets being addressed, and to enable appropriate access to the technologies and resources needed for effective INRM research, it is often useful to address problems at a scale beyond the jurisdiction of individual research institutions. Secondly, INRM research usually requires science beyond the disciplinary limitations of given institutes. In each example cited above research co-ordination brought together a range of institutions and disciplines within a region or more broadly across regions. It should be stressed that all the documented projects are working towards problem solution at the research end of the development spectrum. (Rural development and the actual management of natural resources are nearly always the province of a different institutional set). Complex research co-ordination can be done in several ways, as follows.

By institutions that have at least some resources and the scientific capacity to make significant contribution on their own. They must be active partners participating fully and have the respect of those groups in the region that provide input, support and expertise. That capacity and respect comes only from long experience and contribution within the regions. The CGIAR-co-ordinated projects above are examples. The co-ordinating roles are nearly always governed by consortia partnership arrangements or steering committees. In the Mashreq and Maghreb regions, ICARDA and IFPRI have co-ordinating roles for portions of the research agenda (Thomas *et al.*, 2003), with the actual national and site administration done by national institutions. The CGIAR Centre-co-ordinated Challenge Programme, Water for Food, hosted by IWMI (IWMI, 2002) is yet another example, where IWMI is a full consortium partner, hosts the Programme and provides services, but management and financing are mostly independent of IWMI.

By established institutions that serve a primarily co-ordinating role. The Sub-Saharan African Challenge Programme, Building Sustainable Livelihoods Through Integrated Agricultural Research for Development (IAR4D), is co-ordinated by Forum for Agricultural Research in Africa (FARA), and having an organizational structure specific to the Programme. Its initial pilot research sites are co-ordinated by sub-regional organizations, which in turn will co-ordinate the several institutions, both national and international, that have specific research roles in the sites (FARA, 2004).

For these co-ordinating institutions to be effective in INRM co-ordination, they must have a strong and recognized presence in the INRM research-impact area, must have recognized expertise and must have both scientific and managerial capacity appropriate to their co-ordinating roles. They must co-ordinate with recognition of the highly collaborative and participatory processes required for effective INRM research and eventual vertical and horizontal scaling for impact. Such research co-ordination and integration is a clear international public good of a type found in many research arenas, but has extremely high integrative and knowledge chain dimensions and value as effectively applied to INRM research.

In every example cited for this type, the institutions are acting in a co-ordinating or facilitating role for a range of institutions and disciplines within a region or more broadly across regions, e.g. the Alternative to Slash and Burn (ASB) Systemwide Programme, which face similar NRM problems. Such co-ordination can only be done by institutions that have both the resources and the scientific capacity to make a significant contribution. They must be active partners participating fully, and have the respect of those groups in the region that provide input, support and expertise; that capacity and respect comes only from long experience and contribution within the regions.

Type 3 – Development at both field and landscape levels of management and institution-building principles and methods that have applicability in more than one country for suggesting the appropriateness of technologies and policies

It has long been recognized that the building and enhancing of both institutional and human resource capital can be an IPG. In this section, research on the types of institutions and the appropriate levels for intervention and management for natural resources management within the context of integrated systems are research topics in themselves. The geographical scale of influence of institutions which deal at various levels with NRM should be influenced by the ecosystem scale of NRM processes and factors which they manage. There is now a growing interest in research on the type and scale of institutions appropriate to the different levels and scales of production ecosystems and NRM problems. A fundamental assumption driving much of that research is that management and management-influencing empowerment and action should be at the lowest effective level. These range from the farm family to community-based organizations (CBOs), watershed-based, river basin or regional consortia, to multi-nation groups. A clear understanding of ecosystem dimensions, their scale and levels of independence or interaction is important for both institutional infrastructure and for policy formulation.

Theme 4, Integrated Basin Water Management systems, of the Water for Food Challenge Programme (IWMI, 2002) provides an example of the types of research being planned and conducted to generate IPGs in institutional capacity-building around INRM. The Programme states:

> 'Effective integrated management of water resources at basin level is complicated by the finding that use of water and land at one location affects how water is used at another location, often in counterintuitive or complex ways. Misunderstandings can lead to policies that adversely affect one set of users, while trying to improve conditions for others. There are at least two major dimensions to this: The consequences of upstream use on downstream availability, and how actions taken at one scale affect uses and users at other scales.'

Expected outputs include:

- Improved understanding of issues of scale, upstream-downstream interactions, and governance requirements, documented in publications.
- Effective technical and management strategies adapted to specific locations, addressing conjunctive management of surface water, groundwater and rainwater, as well as urban, and agriculture-ecosystem interfaces.
- A basket of tools for sustainable river basin management.
- Improved data and information for local, regional and global use.
- Capacity built to put understanding into practice and utilize tools.
- Capacity built to manage basin water resources more sustainably.
- A methodological framework for use by researchers and practitioners of integrated management.
- Assembly of tools and data for use in conflict management.
- Finally, and most importantly, the enhanced capacity for efficiency of resource use for improved livelihoods.

Other examples that could be given include the development of water user associations, sustainable forest resource management and the development of CBOs where there is an established and growing literature. The building of such institutional capacity, the provision of decision-support tools, and appropriate ecosystem data sets all provide background, insight and resources as IPGs for better management.

Type 4 – Contributions to technology development for INRM-based production systems that can be effectively used, with modest adjustments for site-specific conditions, in more than one country context.

The end result of most agricultural development is to introduce specific changes in policies, the production environment, or in plant or animal technologies and their management, in order to make them more productive, more efficient and more sustainable in terms of economic, social and environmental goals. The IPG dimensions of INRM science research provide the frameworks, and the process understanding and quantification to guide the selection and adjustment of technologies to local contexts, reducing the huge cost of agricultural development through completely empirical approaches. They are only a means to an end. The prioritization of problems, the selection of entry points, and the availability of specific technologies are then crucial. Stakeholder group interaction has a high transaction and sometimes opportunity cost, and will remain functional only as long as technologies are flowing and effective change is occurring; in other words the outputs and eventual outcomes are worth the cost, or in some cases, if the subsidies keep coming. The aim is surely to train stakeholders so that they become equipped to resolve many of their own problems and to take advantage of many new opportunities, with only minimal external institutional assistance at the application level. Most will (and should) continue participation in scientific networks for ongoing updates of key technologies and tools.

In each of the major projects cited above there was an attempt by stakeholders to define the universe within which they are working. Each case narrowed the options to a few that were thought to be key entry points and represented stakeholders' priorities. Such early determination of focus is important for project effectiveness. Nearly all CGIAR INRM projects include national institutions, CBOs and NGOs whose primary task is to solve local problems.

While overall research is aimed at producing IPGs, location-specific trials, done within the broader context of INRM strategic objectives, produce specific results at the 'bottom end'. The contextual setting and the 'fit' of specific technologies across gradients of change is often enriched through an iterative process of technology refinement and analysis of its adaptation and extension as the project progresses. If properly designed, with ongoing processes of integration, those results often have broad adaptability (and generation of IPG), as in the case of ICRAF-involved research in Zambia (Ajayi *et al.*, 2005). The project developed and tested a tree fallow rotation as follows:

The major plant species used were *Sesbania sesban, Tephrosia vogelli, Tephrosia candida* and *Cajanus cajan*.

> 'The development of fertilizer tree fallows was carried out in two broad phases: Phase 1 began in 1986, when ICRAF and NARS researchers conducted diagnostic surveys to identify farmers' problems and assess whether agroforestry practices could help them and were of interest to them. This followed a period of shrinking farm size and natural fallowing, declining soil fertility, and reduced fertilizer subsidies. The second phase began in 1997/98 when the dissemination of the technology to farmers was initiated and was followed by the current efforts aimed at scaling up/out the practice to several other farmers. In the 2002/2003 season, an estimated 180 000 farmers in the southern Africa region were planting fertilizer tree fallows' (Zambezi Basin Agroforestry Project Annual Report 2003).

A second example is given from the rice-wheat consortium research on reduced ('zero') tillage in rotations in South Asia (Laxmi *et al.*, 2005). In this example, a single major intervention, zero tillage in wheat, was introduced across a broad ecozone having many similarities of environment, but significant heterogeneity of local environments requiring considerable local adaptation. The similarities were sufficient to make the primary technology (reduced tillage) highly relevant, but returns and resource use varied with environment, including soil type. The resulting technologies, and the scientific base upon which they depend are a clear IPG.

As a final example, the nomadic grazing systems (which often interact with, or are in transition to crop-livestock systems) are the subject of intensive research in the Magreb-Mashreq project of CWANA (Central and West Asia and North Africa) (Thomas *et al.*, 2003). The social, political, economic and technological dynamics of these systems in change in both CWANA and sub-Saharan Africa are of research interest both for their strategic dimensions as well as local adaptation.

Type 5 – Scientific understanding of the nature of ecosystem problems, their driving factors, and their consequences/interactions with poverty and productivity, and understanding the principles of managing ecosystems

Process models. Both strategic and applied INRM research is capable of producing IPGs. The former is more to do with discovering principles and processes whereas the latter is to do with using those principles and process knowledge in developing IPG technologies. Data can also be useful for priority setting – identifying problems and opportunities, to understand how systems operate, what interventions work under what conditions (although this too becomes close to 'principles'), for targeting, for interpreting impact assessments, and for informing management decisions.

Scientific models (quantified understanding of the behaviour and relationships of NR factors, species and populations across gradients of time and space in response to management options) are being upgraded, adapted and calibrated to local and regional environments (Campbell *et al.*, 2003). A process model for minimum tree diameters at the time of cutting to maintain economic forest populations of the various high value species is shown for a forest in Borneo. This model can be broadly applied within an ecozone once it is calibrated, and across gradients with additional calibration, to serve as a guide, when combined with an economic model, for longer-term forest management policy. In this case, the economic model was adjusted for multipurpose forest use, providing income and livelihoods for forest dwellers as well as economic returns for the overarching forest management concession. As in most instances of ecosystem processes, the INRM research partners do not develop the models from scratch. They have adapted well-known process science to local high-value timber species within their forest environments. The process approach can be further extended to determining the resultant biodiversity and maintenance of species that contribute to forest multipurpose use and the well-being of rural communities and forest dwellers that depend on them.

The refined and recalibrated models developed by the Management of Soil Erosion Consortium (MSEC) as described in Case 1 (Maglinao and Valentin, 2003) are additional types. The new, user-friendly 'Predict and Localize Erosion and Runoff' (PLER) model, based on well-known and widely used runoff parameters, predicts soil loss across gradients with sufficient accuracy to delineate between major management alternatives such as cropping pattern and tillage intensity. It can thus be used as a first approximation of the environmental impact of landscape-level changes on cropping intensity. The model requires calibration at reasonably large regional scales. The ability to predict the effect of cropping pattern and tillage options on sediment loss and, equally importantly, on downstream reservoir sedimentation is extremely useful in the selection of alternative technologies. It is also important in the selection of incentive or regulatory policies to achieve desired natural resource services or ends (e.g. reservoir sediment loading and eventual lifespan). The model is most useful in larger river basins where sediment loading in downstream areas has a high economic cost, and the calibration and use of the model to provide quantitative estimates of management alternatives can be economically justified. Eventual adoption of alternatives by farmers is ultimately a matter of labour availability, access to the technologies needed and the economic incentives for their making the desired change. The ability to quantify outcomes is highly useful to policy planners who can provide the incentives required.

Soil and biomass carbon determinations and models are becoming precise and highly useful in the selection of cropping systems, plant and animal residue management and tillage options. The ASB Systemwide Programme has generated excellent data on carbon management across several continents (Ericksen, 1999). Carbon preservation, sequestration and stocks are becoming critical to the maintenance of productivity of soils in dry areas in particular, and to fertility management of soils across the semi-arid and humid tropics of Africa. The scientific methods, models and location of individual benchmark sites on gradients of carbon change are highly important to the understanding of soil productivity and of its degradation. The Tropical Soil Biology and Fertility Programme (TSBF) has been working and publishing in this area for over a decade, and its experience is very evident in the ASB. This area of science yields major IPGs, and their adaptation to local environments. It is a perfect example of the IPG nature of much NRM work. It is necessary to point out, however, that this type of process work must lead to results that are useful in determining the type and levels of appropriate technologies and management that farmers and communities can reasonably be expected to use. Many ecosystem processes can be expensive to understand and quantify, and may lead to non-applicable results.

Scaling up and scaling out. Broadening the impact of a limited set of on-the-ground research data points depends on many capacities. The original partnerships, including institutional organizations at the key levels and their involvement, as appropriate in the various steps of the process (vertical integration) are important. Horizontal scaling across time and space will ultimately depend on the capacity to extrapolate across gradients of change in the system drivers, many of which will have been mapped. The processes of change across those gradients are discussed below.

IPG LESSONS LEARNT

INRM research has been challenged to produce generalizable results and replicable methods that could form the basis for IPGs. As demonstrated in the previous sections, a recent set of INRM research has indeed generated a variety of IPGs that can now be more widely applied by a range of users.

In this section we review briefly the main challenges to INRM researchers concerning the production of IPGs followed by some general approaches for enhancing the IPG nature of research outputs, and the relevance and quality of science (Kassam *et al.*, 2004).

Challenge 1

Empirical (trial and error) findings are only site specific, unless the identical intervention is tested across multiple environments, with results subjected to rigorous statistical analysis, and then verified within probabilities. Such replication becomes virtually impossible with most NRM research, where interventions must vary with environment, and are highly interactive with the numerous ecosystem 'drivers'. This, to a large extent, is a universal truth for all types of research with farmers or communities. However, the concern of site specificity increases the more holistic or broad is the research, thereby encompassing a greater range of complex systems and interactions.

IPG approach. The more that a large complex system can be disaggregated into sub-systems within the context of process-based hypotheses, the easier it becomes to identify the similarities and thus implications across sites. These sub-site scales and systems themselves normally offer a range of variation (e.g. in soil types, education level of farmer) that form the basis for testing alternative hypotheses about interventions. It is equally important to understand the local conditions under which the research is taking place. Given that there may well be a limited number of replicates of a particular INRM intervention (or set of interventions), knowledge of the context is vital to understanding why certain results occurred or did not occur. The context includes ecological, economic, social, and political systems, dynamics and interactions. If done properly, case studies can be used to generate empirical lessons that become IPGs. The best way to achieve empirically based IPGs (e.g. principles of INRM) is to plan for this *ex ante*, including co-ordinating across different research centers and INRM research projects. Since the complexity and multiple system determinants greatly reduce the ability to implement widespread studies with common treatments, the expanded use of INRM tools and processes can optimize lessons learnt and the statistical relevance of data sets taken across gradients of change, and with similar but not identical experimental treatments by different researchers or farmer collaborators.

Challenge 2

The level of complexity in INRM research inhibits synthesis across sites, and sometimes even within a site. The multifaceted nature of problems and interventions in INRM research implies that synthesis across theme, discipline, site and scale will be extremely important. But this requires high standards of co-ordination, teamwork and time commitment.

IPG approach. Synthesis across sites is facilitated by co-ordination in research design so that some common objectives and methods can be established. This could apply to diagnostic methods, treatment of problems, or indicators of impact, for example. The more comprehensive the monitoring and impact assessment plan, the easier it is to explain results at a site and to compare them to those at other sites. Of course, this could be said of all research and development projects. But there are some unique aspects of INRM that makes this more complicated than usual. The problems to be addressed are manifested at multiple scales requiring multiple interventions. Thus, there is much more 'treatment' noise than in most other research protocols. Second, decisions are not made exogenously and the process of decision-making becomes its own dynamic intervention. Third, because of the demand-driven and responsive nature of INRM, priority problems and interventions may change over time and thus old baselines may become irrelevant and new ones become necessary. The dynamic nature of INRM means that the monitoring and impact system must also be dynamic.

Challenge 3

Attempts to solve a multitude of problems lead to lack of focus of research. In development, it is clear that progress requires multi-sectoral approaches that address the range of critical problems faced by the population across spatial and temporal scales. While research needs to address this complexity, there are increasing tradeoffs between science and development, the wider is the net that is being cast. A wider scope may mean that insufficient resources are allocated to the resolution of any specific problem.

IPG approach. The reality is that there is a multitude of problems in communities and landscapes so the question for researchers is always how much to tackle in any given research thrust and how much to ignore. INRM research is about increasing the level of complexity to become more relevant, more responsive to the needs of stakeholders and by doing so to provide a framework for more efficient and effective reductionist (limited-factor) research, which is still needed. For example, a number of INRM research projects have used modelling approaches to help understand the complexity of NRM-related problems and to help prioritize among promising intervention pathways. The adaptive learning nature of INRM research also emphasizes the early learning from failures that allows for a reallocation of resources to more promising areas.

Challenge 4

Overemphasis on participatory decision making can lead to reduced rigour in research. There is a danger in INRM research projects that devolution of decision making to local stakeholders will favour local development goals over broader research objectives (that can lead to larger development impacts in the long-term) and by doing so reduce the IPGs from INRM research. This may come about from weak adherence to planned research strategies and reduced input from scientists as to what might be tested or tried.

IPG approach. INRM research must be guided by a clear research framework. Although specific priorities and hypotheses will emerge over time, there is need for multiple levels of research questions and hypotheses that serve to provide structure to INRM research. Just as technology testing research has been easily accommodated within INRM, the same should hold for policy and institutional interventions. It may be necessary, for example, to test dissemination methods in order to make recommendations as to which of these are appropriate under different circumstances. It must be made clear which parameters are being tested (and therefore subjected to hypotheses) and which are not. The use of control/comparison tests and analyses should hold for any intervention having likelihood of significant interaction, ranging from technologies to information to processes. This in turn requires careful planning of sampling units, sample selection and monitoring. All this needs to be balanced against social and ethical considerations. Is it ethical to ask farmers to test widely interventions for which little is known, or at the other extreme, to test interventions that we predict will fail? It is critical to discuss these issues with all the stakeholders at the outset.

Challenge 5

Major support by research staff on process and technical matters in pilot INRM projects do not provide replicable outputs. We all know that the amount of scientific time allocated to initial INRM projects could not be scaled up to many sites for sheer lack of scientists and research budgets. Operational budgets associated with these projects are also often well beyond what might be expected from national budgets (e.g. through extension). These very facts raise concerns about the lessons learnt from the projects and therefore the IPG nature of the approach.

IPG approach. There is little question in the mind of INRM scientists that a chief goal of INRM research is to develop tools that are effective in INRM, are easy to apply and are low cost. The previous sections have highlighted a number of these, ranging from diagnostic tools to monitoring tools. These types of products need to become more accessible to potential users. That aside, INRM researchers do need to give more thought into the vision for how these approaches can be implemented at national scales. What human and financial resources are required? How can limited skills and budgets be best allocated to achieve national INRM goals? How are the answers to these affected by contextual variables? Analyses of these investment questions will themselves represent IPGs of considerable importance.

TOWARDS CREATING INRM-BASED KNOWLEDGE CHAINS

In conclusion, we are suggesting that the continuum of basic–applied science and its combination and integration with indigenous community-based knowledge is essential for sustainable management of natural resources within the context of production efficiency. This matrix of information and capacity constitutes a '*knowledge chain*' when embedded into an appropriate institutional matrix. The chain requires adequate inputs of knowledge from each of the key resource domains for each critical systems driver. Appropriate information tools must be available for the integration. There must be appropriate 'nodes of connectivity' for each type of knowledge, and a compatibility with the overall system. The ultimate goal is to make the range of research and experiential knowledge available for both upstream and downstream use, both within and between efforts within each domain. For example, social, economic, biological and natural resource process understanding should be appropriately available to all. It is not essential that all such knowledge be available for single model-building (although that might eventually happen). What is important is that the interconnectivity can occur at the level of qualitative understanding, and in a quantitative mode where necessary.

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