INDEPENDENT SCIENCE & PARTNERSHIP COUNCIL
CGIAR

CGIAR SCIENCE FORUM 2011

The Agriculture–Environment Nexus

Summary

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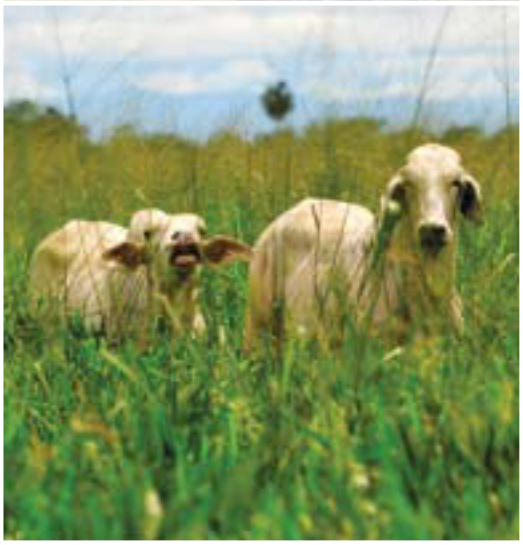

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

The Independent Science and Partnership Council (ISPC) of the CGIAR is committed to its role in mobilizing science for development through international dialogue on critical and emerging issues. It also works to foster partnerships between the CGIAR and collaborators worldwide. The CGIAR Science Forum offers an opportunity for scientists to come together and examine emerging challenges, identify key researchable issues, and establish strategic alliances to address them.

INTRODUCTION

If we are to support 9 billion people by 2050 we will need the very best innovative thinking to revitalise agriculture and make it both more productive and more sustainable. This will have to be achieved in a world of changing climate, where resources are continually being depleted, and the services provided by healthy ecosystems increasingly disrupted. The CGIAR will have to build upon half a century of achievement to meet the challenge of this doubly green revolution. The CGIAR Science Forum was therefore structured to discuss different aspects of the way agriculture and the environment are intertwined and their reciprocal effects.

The CGIAR Science Forum 2011 sought to identify the consequences of this interdependency and the science and approaches that will be needed for productive and sustainable outcomes in the future. The Science Fora are designed as interactive meetings with the main work at the most recent Forum carried out during breakout sessions, each focussing on a different aspect of the central theme. The content of those sessions are summarised here including: the priority research questions; the most promising science, technologies and innovative approaches; and in the context of the CGIAR reform process, what the lessons might be for the new CGIAR.

The findings of this Forum emphasise the urgency of increasing research investment to meet the agricultural challenges of the coming decades. This summary highlights some critical 'inflection points' where a new focus of research investment could lead to significant impact. The Forum recognised that the "environment" can no longer be treated as an "externality" and agreed that maintaining ecosystem services is essential if agriculture is to deliver what is expected of it in the future. The dearth of funding for basic research in agro-ecology has hampered progress: innovation will flow as our fundamental understanding grows. Better metrics to more accurately measure impacts, more supportive policies, and research to provide a clearer understanding of trade-offs are also essential.

The Forum reaffirmed the aspiration of the CGIAR reform process - to achieve an interconnected agricultural knowledge and innovation system where the complementary skills and competencies of advanced science, national research and development systems and the farmers themselves work together to address the challenges of feeding the world whilst conserving the environment. The need to mainstream the concepts of Integrated Agricultural Research for Development (IAR4D) was emphasised. The value of partnerships between environmental groups and agricultural researchers was emphasised - it is essential that the full environmental implications of different agricultural strategies are better understood.

Session 1: Resource scarcity and the ecological intensification of agriculture

Bas Bouman, of the International Rice Research Institute, introduced the session, highlighting the need to address the growing global demand for food through further intensification of current agricultural land use. Limited resources, such as water and land, will need to be better managed, as will external inputs. Misuse of external inputs has not only contributed to environmental problems, such as eutrophication and soil erosion, but also to a breakdown of natural biological control systems. Ecological intensification was introduced as a concept by Cassman in 1999 in recognition of the need to increase yields in ways that meet acceptable standards of environmental quality. Since then, work has focussed on agricultural intensification with minimal pollution and optimum use of limited resources and inputs, but it has not yet truly embraced the 'ecological' aspect of ecological intensification. Can ecological intensification be made truly ecological, by harnessing concepts of ecology and ecological engineering? Can productivity be sustainably increased, while protecting the environment and environmental services? What technologies, new and old, are available to us? Participants in this session sought to address these questions.

Shu Geng, of Peking University, presented a philosophical overview, urging that measures taken to further intensify agricultural systems and increase yield, must be designed with the aim of generating zero carbon emissions, zero waste and zero pollution. The goal is that intensive agricultural systems will transition to 'green' intensive agricultural systems. He urged participants to consider energy and the environment as two parts of the same thing. Agricultural production can be intensified, he contended, in ways that do not cause further degradation of the environment, if we begin by addressing the root of the problem by investing in renewable energy technologies.

Yingxu Chen, of Zhejiang University, presented as a case study the Lake Taihu Cleanup Project, documenting the development and application of two technologies that facilitated the remediation of land and waterways after extensive fertiliser runoff and eutrophication. The first innovation was a slow-release fertiliser (sulphur-coated and wax-sealed fertiliser combined with a slow-release agent). The second was an improved irrigation management system; an 'eco-irrigation system' that couples rainfall with crop-water requirements. Using these two technologies in combination significantly reduced runoff. This technology is now being used in 10 provinces in China, but although successful, issues remain about scale-up of the technology and about how to encourage farmers to use it. Participants in this session questioned whether this kind of technology – although effective at addressing environmental pollution from agriculture – is really going to help encourage sustainably intensive agricultural production systems. It was suggested that this kind of technology is actually leading agriculture in the direction of relying more heavily on inputs, rather than guiding it towards sustainability.

Gonzalo Zorrilla, of the Latin American Fund for Irrigated Rice at CIAT, discussed the case of rainfed and irrigated rice in South America, where the first steps towards ecological intensification has been to help ensure that good crop management practices are adopted more widely by farmers. Research indicates that the difference in productivity between farms in southern Brazil, Uruguay and Argentina, which achieve relatively high yields, and those with low yields elsewhere can be reduced by the extension of some key management practices (minimum tillage, early weed control, effective water management, etc.). Another change that has been introduced in these areas, and which has boosted yields, is the construction of water catchments by farmers to collect rainfall for use in irrigated rice fields. This water harvesting and shifting between rainfed rice and irrigated rice have delivered two- to three-fold increases in yields. He reported that these changes have delivered a documented reduction in inputs, lowered costs per unit and reduced the environmental impact of rice production in this region. However, participants in this session questioned

whether the negative downstream impacts of water harvesting in this way have been as well documented as the benefits. Concerns were raised by several participants about some of the ecological problems that have been noted as caused by these practices (such as soil erosion and problems associated with the rapid filling up of these reservoirs during the wet season). The session concluded that when considering whether changes in practices actually do meet the criteria for ecological intensification, a systems approach must be taken. A perceived win-win situation may in fact create losers downstream. This led to a discussion of the need to clarify and agree on what criteria define ecological intensification. This discussion was expanded later in the session.

Zhang Fusuo, of China Agricultural University, presented research on improving crop productivity and nutrient-use efficiency in intensive agricultural systems in China. A similar conclusion to the findings in South America, discussed earlier in the session, is that the most expedient route to improve both yield and resource-use efficiency in China is the extension of some existing good agricultural practices, which offer significant improvements on current sub-optimal crop and soil management practices in vast areas. Participants in this session, however, urged that these practices should first be examined to ensure that they do not impact negatively on environmental services. It was acknowledged that the integrated soil-crop management system that was presented, increases productivity and resource-use efficiency. Participants acknowledged its usefulness, but doubted whether improving nitrogen-use efficiency will foster ecological intensification of agriculture. *Aiwang Duan* of CAAS and *Junguo Liu* of Beijing Forestry University, also spoke of practices that improve nitrogen and water-use efficiency. Once again, these were acknowledged as useful, but the discussion that followed reinforced the need to better define criteria for ecological intensification.

Peter Carberry, of CSIRO, examined the concept of eco-efficiency in agricultural intensification and presented work that extended the concept. He argued that the debate about ecological intensification also needs to address economic risk (measured as the variability in economic returns, or the chance of failure) as one characterisation of system state, along with productivity and environmental states. Perceived or actual risk of economic loss is a major reason for lack of adoption of new technologies. He proposed a return-risk framework for diagnosing system state and opportunities to enhance eco-efficiency. He argued that achieving increases in global agricultural productivity through agricultural intensification depends on an assessment of the current performance of farm enterprises relative to their potential productivity, and the risk associated with intensification options.

Yulei Lu, of the UK-China Sustainable Agriculture Innovation Network (SAIN), discussed some of the projects and technologies that SAIN are developing. The overarching goal is to improve the sustainability of agricultural production and to build capacity for adaptation to climate change. These initiatives include developing estimates of future greenhouse gas emissions from agriculture in China; improving methods for nitrogen management; better integration of policies for water and energy use in agriculture; and developing a catchment management template to mitigate non-point source pollution in China. Participants acknowledged the drive towards sustainability, but suggested that ecological processes and wild species could be engaged in some of these endeavours as an alternative, and possibly more expedient way to achieve the intended goals. The willingness of farmers to adopt new methods was acknowledged as an issue, which echoed work presented earlier in the session by *Carberry*. The need to research this more thoroughly was conceded.

Gobin Liu, of Northwestern University, spoke of the successful efforts in soil and water conservation and the rehabilitation of ecosystems in the Loess Plateau of China. Deforestation and over-grazing, exacerbated by China's population increase, have resulted in degraded ecosystems, desertification, and poor local economies. A long-term project has encouraged the transition to more sustainable farming practices (such as keeping goats in pens rather allowing them to roam freely and erode the soils) and better watershed management, leading to both significant recovery of ecosystems and improved livelihoods. The necessity of

attributing a value to ecosystem health in economic considerations was highlighted. The problems associated with deriving a value for ecosystem services were acknowledged.

Geoff Gurr, of Charles Sturt University, introduced the concept of ecological engineering (i.e., manipulating the landscape by introducing elements which attract predators and/or parasitoids of pests, thus harnessing the power of ecology to reduce constraints on yields). Although there is nothing new about biological control, ecological engineering does go one step further in introducing changes to the landscape, such as planting companion species, which are designed to increase the prevalence of natural enemies. He emphasised that, because of persistent underinvestment, our knowledge and understanding of basic ecology in an agricultural context is 'in the stone ages' compared with our knowledge of molecular processes and biotechnology. A selection of practical examples of ecological engineering was presented, documented yield increases and cost savings that have been achieved. *Gurr* pointed out that these effective uses of ecological engineering have been developed despite our relatively low level of understanding of the underlying ecology. Vastly more powerful methods could be developed if we had a stronger foundation on which to develop them, using the power of ecosystems to enhance agricultural productivity in more sustainable ways.

The open discussion in this session concurred that since the introduction of the concept of ecological intensification, the emphasis has primarily been on increasing yield through measures such as improved water-use efficiency, better nitrogen-use efficiency and preventing agricultural pollution, rather than a true focus on harnessing the power of ecological processes in an effort to increase production in ways that do not negatively impact on the environment.

Several of the examples presented during this session were challenged as to whether they were truly ecological in their approach to agricultural intensification. Participants were challenged to examine whether these and other examples in the current literature are indeed examples of true ecological intensification, and represent a genuinely new approach, or are simply good agronomic practices that are neither new nor an ecological approach to intensification. The need for debate and agreement on what criteria define ecological intensification emerged clearly. It was acknowledged that the extended definition of ecological intensification that emerged from this discussion ('harnessing the power of knowledge of ecological processes to increase yields and enhance ecosystem services and sustainability') needs to be further debated and refined, but also that it represents a good start in re-focussing the emphasis of ecological intensification on the 'ecological' component.

The question of whether it is possible to increase the productivity of land, as well as the ecological performance of that land (i.e., whether it is possible to find a win-win situation) featured largely in the discussion. It was argued that there will always be trade-offs, and that these may not immediately be recognised, because of a lack of multidisciplinary analyses and a failure to take a systems approach (as in the case of the South American water catchments), but those trade-offs exist nevertheless.

The ubiquity of the prefix 'eco-' it was agreed, had rendered it practically meaningless.

In summary, the session heard of promising science and examples of emerging technologies that are being applied in intensifying agricultural production in ways that engage the power of ecological systems to boost the productivity of agricultural systems, while reducing negative impacts on the environment. Participants debated what the priority research issues are in this area. It was acknowledged that the challenge is to identify key researchable issues that have the potential to be up-scaled and transferable to different regions. Although no single universal public goods technology exists, some vital issues, if addressed, could accelerate practical advances in genuine ecological intensification of agriculture. Better metrics are needed to more accurately quantify ecosystem services and environmental impacts (measuring biodiversity, for example).

It was agreed that a major constraint is the long-term underinvestment in ecology research within an agricultural productivity framework, which has resulted in a dearth of knowledge. Innovations will flow once our fundamental understanding grows.

This session also concluded that better understanding of risk, and researching why some farmers are more open to change and trying ecological approaches, while others are averse to adopting even simple, available technologies, will be essential if real progress is to be made.

Engaging the private sector (which includes small farmers) and harnessing market forces is essential in the development and uptake of techniques that foster genuine ecological intensification of agriculture. Participants in this session, however, urged that public goods research organisations, such as the CGIAR, ought to lead the way in funding the foundational research needed, particularly in the development of metrics and in improving our understanding of basic agro-ecology. The private sector is unlikely to take these on. It was proposed that the CGIAR should work in partnership with organisations that have a comparative advantage in these areas.

The discussion concluded that there are proven techniques available to intensify agricultural production and boost yields in ways that do not deplete resources, nor lead to environmental degradation. Some promising innovations harness the power of understanding ecological processes. Referring to the success of these and the need for more research on the underpinning agro-ecology, one participant commented 'imagine what we could achieve if we actually understood how this works.'

Session 2: Sustainability Science

Jeff Sayer, ISPC member, James Cook University, introduced the session and highlighted some the challenges of addressing the "wicked problems" associated with ensuring food security while avoiding additional depletion of natural resources. "Wicked problems" being those where all the apparent solutions appear to lead to new problems.

Sonjia Vermuelen, CCAFS, opened the discussion with reflections on how sustainability science could achieve impact for wicked problems such as climate change, a hotly debated and controversial issue. There is no specific formula to "solve" wicked problems. However, collaborative, interactive and diversified teams, improved politics and behavioural change are essential elements in striving to address these kinds of problems.

The role of science, and of the CGIAR, in landscapes was discussed by *Jabury Ghazoul*, ETH Zurich, while *Tony Simons,* World Agroforestry Center, introduced the agroforestry perspective of the science of scaling up.

Patrick Dugan, WorldFish Center, reflected on the potential impact of large integrated research programs, from the perspective of aquatic-agricultural-systems. *Agus Buono,* Bogor Agriculture University, shared experiences and perspectives on the use of a dynamic crop calendar for increasing the resilience of rice production, faced with climate variability and change in Indonesia.

A review of the "impact stories" of the CGIAR suggests that most describe relatively small impacts from "component research". In many cases these were research endeavours that many other research suppliers could have achieved. The major impacts ascribed to crop improvement – the Green Revolution – were often in reality the result of interdisciplinary research where the context for the application of improved crops was provided by natural resource and social science.

The term "Sustainability Science" is used within the CGIAR to describe science that is inspired by the needs of beneficiaries. Sustainability Science seeks to draw upon different disciplinary skills and tools and to operate at multiple scales, 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 natural resource management targets within and outside the CGIAR, the following elements of a definition were suggested at the Science Forum session on Sustainability Science:

- Advancing scientific understanding of human-environment systems;
- Working across scales in space and time;
- Improving linkages and dialogue between research and stakeholder communities;
- Short feed-back loops, flexible and not constrained by disciplines; and
- Building capacity for linking knowledge with action to promote sustainability.

A number of principles were developed at the Sustainability Science sessions, which should apply to future research by the CGIAR and particularly in the CGIAR Research Programmes:

Measuring the impact of large-scale sustainability science endeavours 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 towards the examination of impacts on the livelihoods of the poor and on the environmental attributes that will enable their livelihood gains to be sustained. The motivation for impact studies needs to shift away from justification of research investments to donors and focus more on learning from and adaptation in an IAR4D context.

IAR4D requires new partnerships and alliances. However, pragmatism is needed to limit the size of IAR4D teams to optimal sizes. Too large teams are unwieldy and have proven to be a handicap. The transactions costs of very large-scale research for development endeavours are great. CRPs will need to function on the basis of nested hierarchies of teams with provision for meta-analysis of findings to generate public goods and allow for scaling up.

Changes are needed in science management to allow for – and encourage - participatory, integrative, inclusive, transdisciplinary and multi-scale research endeavours. New information and communications technologies, geographic information systems, remote sensing and simulation modelling provide valuable tools to support sustainability science – but it is important that these technologies are used as tools and do not become ends in themselves. Ecological and social systems are complex, dynamic and unpredictable; complexities should be communicated rather than reduced. Participants noted the need to see "simplicity beyond complexity."

The constraints imposed upon agriculture by increasing costs and diminishing availability of inputs such as land, water, fossil fuels, fertilizers etc will make ecological efficiency and intensification more important in the future and this will mean that sustainability science will become more important over time.

It is becoming more important to use a food system's approach and, considering the value chain from farm to fork, include issues of post-harvest losses and waste along the food chain. Food security is much more than food availability and 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 in framing problems and as information providers.

There are major new challenges emerging for sustainability science. Some of these relate to:

What is the role of biological diversity at plot, farm, landscape and eco-regional scales?

How will farm size evolve in coming decades? Is there inevitability in the move towards consolidation of farm size as economies grow and people move into services and manufacturing? Or, are alternative pathways possible and desirable?

Where will food be produced in the future? Will economic factors and climate change lead to major shifts towards new production areas in the Boreal region or in under-exploited parts of Africa?

Will farm landscape become more segregated or will the need to balance environmental and food production values lead to more integrated agricultural landscapes?

Potential changes in climates means that agricultural science is moving into uncharted territories – research will have to support the ability to produce food and maintain the environment under highly uncertain future conditions. Research can support adaptation but can also help to shape those futures.

How can research deal with different spatial and temporal scales? Sustainability Science needs research at various spatial and temporal scales. How you deal with scales is a research issue, and as such results should inform the design of research programmes.

There are many more risks and drivers of change than those linked to the climate. The future is not what it has been; markets, consumption patterns, economies and policies will change. Innovation will create new opportunities

Scientists can operate on long time scales – 10 to 100 years – but politicians deal in shorter periods of 1 – 10 years and farmers can rarely enjoy the privilege of looking beyond their next harvest.
Research might operate in 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 as well as the global issue of "feeding the world, reducing poverty and protecting the environment" are "wicked problems" – problems where all the solutions lead to new problems – we have to deal with cascading sets of issues, opportunities and problems. It should be recognized that in addressing these problems, there are rarely win-win possibilities: in practice, critical trade-offs between food security, livelihoods and environmental protection exist.

In general, scientists are not trained to operate within complex adaptive systems and the incentive structures for science are not at present necessarily well aligned with the innovative science that is required to address the emerging problems of feeding the world and maintaining the environment. Scientists must receive more recognition, and support for working in inter-disciplinary teams in a "sustainability science" mode.

In summary, the use of Sustainability Science is motivated by the observation that genetic improvement, natural resource management and social and institutional sciences cannot achieve their optimal impacts in isolation. Participants concluded that the most significant impacts of CGIAR science have been achieved when these three major branches of science have been combined in inter-disciplinary research programmes. The concept of Integrated Agricultural Research for Development – IAR4D – is one manifestation of the move towards more integrative approaches to addressing the CGIAR mission.

Session 3: Metrics, monitoring and certification to support sustainable intensification of small-holder agriculture

Kenneth Cassman, ISPC Chair opened the session by highlighting the importance of establishing robust and cost-effective metrics for monitoring and certification of food production systems to ensure that agricultural systems and their products are produced using practices that do not harm the environment or contribute to climate change and loss of biodiversity. The scientific challenge is to ensure that such methods are based on good science and are unbiased.

The CGIAR and its global research portfolio are well placed to provide global leadership for the underpinning science that allows development of standards and metrics for monitoring the performance of agricultural systems at the nexus of productivity and environmental services. This is especially true for small-holder producers in developing countries who might benefit from payments for environmental services (PES) provided by their farm, forest, or fishery. Areas where there could be harmonization of research methods and data collection include, but are not limited to: analyses related to climate change (carbon capture and storage), soil quality, GHG emissions and nutrient losses per unit of economic yield, impact on biodiversity, contribution to local food security and nutrition, system resilience and yield stability, and water productivity. Other benchmarks are needed for social and economic well being, which importantly impact baseline studies including village and household studies.

This theme is relevant to the CGIAR as it "builds out" a new research program through a portfolio of CRPs. CRPs are being developed separately, which highlights the need for common measures to ensure progress and the ability to adequately evaluate the impact of CGIAR research on natural resource management goals across sites, systems, and regions. This session was intended to bring together policy makers, private sector, NGOs and researchers to identify the science and research needed to promote metrics, monitoring and certification to support sustainable intensification of small-holder agriculture in developing countries.
Greg Traxler from the Bill and Melinda Gates Foundation spoke about the importance of metrics and monitoring. Investing in data (on which metrics and monitoring is based) is essential for effective priority setting and improved targeting. It helps us understand tradeoffs among development objectives, particularly between productivity and environmental goals**.** We need tools to see if we are making progress against objectives. What should be measured? He suggested the following types of outcome indicators: productivity-related (e.g., adoption, yield), household (e.g., welfare/income, food security and nutrition), environmental (e.g., soil health, water availability, biodiversity), and policy (e.g., price levels and variability). Key issues associated with the metrics include: the coincident collection of many indicators over many locations and over long periods; the alignment of indicators with research questions; research capacity to analyze data; comparability of data definitions over time and across geographies; and accessibility of data. He identified some key data challenges for the CGIAR:

- Getting agreement on key research questions to be answered
- Getting agreement on *must have* indicators
- Monitoring over time of *must have* indicators (a CGIAR role? where in the CGIAR?)
- Making data more accessible (better archiving and access to data? where in the CGIAR?)
- Better/ more realistic monitoring and evaluating (new approaches, link with other actors)
- Incorporating monitoring into decision-making to improve outcomes

The next speaker, *Timothy Searchinger* of Princeton University spoke about win-win metrics for climate change and agriculture. There is scope to improve productivity and at the same time lower emissions, e.g., in rice production. Progress in reducing emissions requires an emissions-intensity approach based on

emissions per unit of food produced. Thus, improved emissions estimation tools are required. Mechanisms are needed to increase transparency and to achieve consistency and steady scientific feedback for more sophisticated modeling approaches. That effort will also require broader, associated monitoring of factors that drive emissions and would benefit from a coordinated effort of world scientists. An area in need of improvement is the method for counting the implicit carbon costs of using land for food production. Land use is presently incorporated inconsistently and poorly into lifecycle analyses, and the failure to incorporate land use properly underestimates the value of productivity gains. Searchinger proposed a land-use measure (and standard template) that would focus on carbon opportunity costs of using a unit of land productivity based on native net primary productivity.

Jonathan Hutton from the UNEP World Conservation Monitoring Centre described his organization's efforts to measure and monitor the impacts of agriculture on biodiversity. As biodiversity is complex, multiple metrics of biodiversity exist; most have focused on "wild" biodiversity but there is a growing awareness of agricultural biodiversity (e.g. crop wild relatives). He presented various approaches to measuring and monitoring agricultural impacts on biodiversity from global to local scales including direct and indirect impacts. He also provided an overview on currently debated paradigms of land sparing versus land sharing approaches to farming, highlighting areas for future research. Hutton emphasized the different and competing views of what constitutes key dimensions (and metrics) of biodiversity, both within and between the agricultural and environmental disciplines. Lack of agreement on the most appropriate metrics for biodiversity impedes our ability to rigorously evaluate tradeoffs between productivity and biodiversity in agriculture.

Jeff Bennett from the Australia National University described a project with the Ministry of Forestry in China that assesses the environmental performance of alternative agricultural systems using a cost–benefit analysis framework. This involves paying farmers to change their operations to produce less food and fiber and more environmental services—ranging from biodiversity protection to downstream water quality improvement—in the context of land use change in the Yantze River headwaters in Sichuan Province. Merging financial and environmental assessments enables an overall assessment of changes that can be addressed using non-market valuation environmental techniques embedded in the conceptual framework offered by cost–benefit analysis, and this allows integration of biophysical information with community preferences for those outputs into a single metric of performance. Having a single metric provides a basis for choosing between those competing for access to environmental services payments. Transparency in this competitive process helps avoid community conflict. The application demonstrates the potential for a market-based auction process in the allocation of payments for environmental services at a local level.

Fred Luckey of Bunge North America described an initiative now being piloted – Field to Market, the Keystone Alliance for Sustainable Agriculture – that brings together a diverse group of producers, agribusinesses, food and retail companies and conservation organizations focused on (a) defining and measuring the sustainability of food and fiber production, (b) developing outcome based metrics and (c) providing tools to help growers analyze their operations and food companies to explain how natural resources are being managed. The Fieldpoint Calculator tool, for example, is used to calculate sustainability indices related to energy use efficiency or irrigation water use efficiency, or to calculate GHG emissions along the supply chain (to help identify opportunities for improvement). It is currently being tested in collaboration with maize producers in Nebraska andt will be extended to other crops in other regions over the next few years. The hypothesis is that farmers who receive information about how their management practices contribute to their environmental footprint, and how the magnitude of their footprint compares with other farmers in the region, will strive to decrease their footprint through adoption of improved management, if such practices are also cost effective.

Sandy Andelman, of Conservation International, spoke about recent efforts to build a global integrated monitoring system for agriculture, ecosystem services and livelihoods. Increasing food production, improving livelihoods and conserving natural resources requires monitoring in an integrated fashion at a system level. They have developed a framework for a small set of metrics for a global monitoring system that extends from raw data measurement to analysis, to decision making support. Issues related to moving from primary measurements to standard metrics and from plot to global levels were discussed. A number of synthetic indicators have been established and are being used, e.g., local food sufficiency, adequate water supply, biodiversity health, inclusive wealth, resilience, etc.

IWMI DG *Colin Chartes* reviewed some of the techniques that have been used to measure and monitor environmental impacts of agriculture. He focused on methods and metrics that consider ecosystem services such as hydrological cycling, soil and land health, nutrient cycling and habitat provision and their resilience. Innovative remote sensing technologies have the potential to integrate impacts and changes across landscapes and basins. While methods for measurement are a major step forward, a major problem in translating them into improved ecosystem outcomes is the misalignment between those who benefit from changed practices and those who pay for the changes. Schemes such as Payment for Environmental Services have been attempted in developing countries but results are mixed.

Mike Robson from FAO discussed some of the practical challenges in assessing and monitoring sustainable intensification by smallholders. Issues related to how to measure, who measures and aggregate monitoring were addressed in his talk. On the latter, he suggested that indicators are needed which sample the whole agro-ecosystem (e.g., water quality, diversity, quantity of beneficial species) and cover social/livelihood outcomes (e.g., child weight at 1000 days, school enrolment). The example of water quality in Senegal was discussed. He concluded by emphasizing the need for more evidence-based decision making, more investment in local capacity to better understand sustainability, undertake monitoring and analysis, and the need to frame locally-appropriate policies.

Rashid Hassan from the University of Pretoria and *Vibha Dhawan* from TERI in India provided some thoughts about metrics and monitoring for sustainable development from a regional perspective. Both emphasized that the CGIAR had a key role to play in helping countries develop metrics - scalable from local to global - linked to the new system-level objectives of the CGIAR (food security, poverty reduction, improved nutrition and health, and environmental protection).

The open discussion covered a number of issues. One related to the social capital of the CGIAR. Evidence-based decision making is weak in developing countries and much needs to be done. At the same time, there are many groups and organizations with science and environment-related expertise and so it is critical that the CGIAR use its limited resources most efficiently in: (a) linking better at the national level (including investing more in skill development for ex-ante and ex post assessments); and (b) helping develop and apply the most relevant metrics. One observer proposed it must effectively coordinate (e.g., at sentinel sites) and should act as a 'low intensity coordination mechanism'. Another observer emphasized a key role for the CGIAR in developing appropriate protocols, methods and practices, rather than in actual collection or monitoring data: the CGIAR's comparative advantage is more in utilizing science to develop appropriate indicators and metrics. This session also brought out the need for coordination across the entire spectrum of actors: private sector, CGIAR, UN agencies, universities, etc. The CGIAR could also, it was suggested, play a better role in defining and understanding major cropping systems and changes in their productivity, the environment, etc., as FAO data is too coarse to be used for benchmarking and impact assessment. Issues about scale and consistency featured prominently in the discussion. Impacts are observed locally and data connecting farm with larger scale are very poor. These need to be aggregated up to scale – and must be consistent across indicators to be useful.

Some major messages emerging from this session included:

- A strong scientific basis and appropriate methods are needed to underpin what and how we measure and monitor ecosystem service related variables—to enable analysis of tradeoffs between productivity and ecosystem service outcomes from agricultural R & D
    - but, developing standard metrics for some variables has proven difficult, e.g., biodiversity— due to complexity, little data and no agreement on definition.
    - simple metrics need to be developed "on the far side ofcomplexity" based on good science and understanding of the systems in question. The ultimate goal is robust and easily understood metrics that decision-makers can use.
- The CGIAR would appear to have a comparative advantage in:
    - developing protocols and standards for measuring and monitoring key performance variables of agricultural systems, e.g., helping establish a transparent scientifically sound but simple life cycle analysis template.
    - defining cropping systems and developing metrics for each on key environmental variables (ecosystem service related).
- Useful approaches are available, that are transparent, conceptually sound and empirically tested, for undertaking tradeoff analysis based on definition and specification of environmental production function + relevant cost information + relevant preference information (e.g., land use change bidding auction in Sichuan province) and new developments to facilitate measurement (remote data collection via GIS, mobile phones)
- Scale: indicators are measured at a particular location (farm level) but need to aggregate to higher, system (landscape or higher) levels, and must be consistent across indicators.
- Priorities must be matched to resources. Priorities should derive from key research questions (ex-ante); we cannot and should not measure everything. The demand for biophysical, economic, and sociological data is great but some will be difficult and costly to collect, so quality and coverage are issues. Must decide on big questions for which data and metrics are needed (e.g. productivity, human wellbeing, changes in resources use).
- Metrics and monitoring required at three levels:
    - To inform the CGIAR and donors about success (adoption & impact) towards Strategic Level Objectives (SLOs)
    - To measure changes in the environment related to agriculture
    - To assess/measure causal linkages between phenomena [regarding natural resources to achieve productivity increases sustaining the NR-base.]
- The CGIAR needs to:
    - invest more heavily in metrics development capacity/skills for *ex ante* and *ex post* measurements and define responsibilities for collection and management of data; data collection systems need to be feasible so that data can be updated regularly
    - support and link better to the national level measurement work – recognizing the importance of national data management and analysis (capacity building is also needed);
    - develop metrics for linking individual research outcomes to higher level SLOs;
    - work more closely with the private sector and other actors who are well connected to farmer base (good data on key variables of interest). Groups like Nestle and Bunge North America, for example, have invested significantly in the acquisition of farm-level data collection (which are available) and the development of certification standards and monitoring processes.

Session 4: Can intensifying agriculture save the forests?

Bill Laurance, Distinguished Research Professor with the School of Marine and Tropical Biology at James Cook University, gave a stark overview of the threats facing tropical forests. Agriculture, especially commercial agriculture, is the major driver of deforestation. Current and future agricultural land expansion is focused on the tropics, particularly for livestock feed and biofuels. Yet tropical forests provide critical global services to humanity in terms of biodiversity, recycling rainfall, stabilizing streams and rivers, protecting soils, and storing carbon. The opening of new roads in forest areas drives the process of fragmentation and subsequent forest loss, producing forest edge effects which reduces their ecological integrity. These problems even exist for protected areas due to the challenges of adequate enforcement over large areas.

Laura German, Senior Scientist at the Center for International Forestry Research, outlined findings from a series of comparative case-studies of the social costs of agricultural expansion carried out over recent years. Loss of land rights and livelihoods were reported for cases involving large-scale land acquisitions from international investors. German's research emphasizes the combined effects of a national policy that explicitly promotes foreign investors; a weak regulatory framework; and the imbalance in power between the investors and local people. The outcomes to date in a number of countries in Sub-Saharan Africa has been that local benefits have failed to accrue as anticipated. Countries with forest resources appear to be in a race to the bottom to secure the foreign direct investment and this raises significant questions about the real development impacts.

Maria del Carmen Vera-Diaz, Research Fellow at the Global Development and Environment Institute, Tufts University, reported on research on the relationship between factors driving soybean expansion at the expense of *cerrado* and forest habitat. Her approach is to model land rents as the main determinant of crop expansion in a Geographical Information Systems (GIS) framework. Vera-Diaz's research analyses the impact that new navigation mega-projects (e.g. creating new ports for easier export to Asia) and road improvements have on land rents, and then modeling the significantly elevated risks to forests as a consequence. In particular, road improvements are the most important driver of future soybean expansion in Brazil.

James Stevenson, Agricultural Research Officer with the CGIAR Independent Science and Partnership Council Secretariat, briefly reviewed the literature on the impact of agricultural intensification on the overall rate of agricultural expansion, explaining how this depends on a number of complex pathways of impact. GTAP-AEZ, a computable general equilibrium model linked to global datasets on land-use and agricultural yields, is able to model the net effect of these pathways. Stevenson's research generated estimates of the extent of global land-cover in the absence of the crop germplasm improvement that the world has seen in the past 40 years. Overall, the Green Revolution resulted in land savings of 18 to 26 million hectares, approximately half of which is averted deforestation. In addition, results were presented regarding the intensification of oil crops at the forest margin. In these cases, higher yields lead to additional forest conversion – the opposite result of the Green Revolution crops. Much work remains to be done to refine these models but these headline results are useful pointers to the likely scale of these effects.

Peter Minang, Global Coordinator of the Alternative to Slash and Burn (ASB) Partnership, outlined how agricultural growth in Africa was largely through land expansion with little intensification evident. Again the various pathways from intensification to land-use / land-cover change were outlined, but that intensification was necessary but not sufficient to protect forests. Minang advocated a strategy for land-sparing through multifunctional landscapes, and that a range of instruments including land-use zoning and

financial incentives (i.e. payment for environmental services) would offer potential for a future in which overall land-use would be optimized in a manner more consistent with desirable societal outcomes.

In the discussion that followed, a number of main themes for further research were identified. More research is needed that measures the actual impacts and trade-offs of investments involving large land acquisitions. Scenarios and trade-offs for development at local, landscape, national and global, would help us understand better who the winners and who the losers are, and to what extent, when small farms are consolidated. In addition the role of incentives and regulations in promoting acquisitions, and institutions and governance in mediating outcomes, would benefit from further careful comparative research of the kind presented by Laura German. For any such research to be effective, scientists would also have to understand policy processes in order to influence them, and a multi-stakeholder process would help promote action in the collective interest.

To make more progress on the issue of when and where land sharing (multifunctional landscapes) or land sparing (intensively managed areas of agriculture saving space for wild, pristine areas) is the right approach to meeting economic and ecological objectives, researchers need better information on current land use and the opportunity costs associated with changing it. The biodiversity and greenhouse gas emission implications of different landscape arrangements are also a rich future area of research. In addition, studies looking at the interactions of agriculture with other kinds of interventions (e.g. infrastructure, governance mechanisms) would help us understand when and where a particular strategy is most likely to be effective. Land use planning and zoning with an appropriate mix of incentives and regulatory systems may be a productive direction in some cases.

Participants in this session agreed that technology-induced productivity increases are critical but not sufficient as a strategy for slowing deforestation. Productivity improvement in the breadbasket areas is strongly land saving but what about productivity improvements at the forest margin? In some cases (ie. crops with elastic effective demand) increasing productivity results in increasing profitability, which drives further expansion at the margin.

Satellite real-time monitoring is an example of a technology that, when combined with a political regime that wants the data and will enforce the law (as was seen in Brazil in the period 2008-10), has the potential to make forest governance much more effective.

Much of the relevant work on these issues is happening outside of the CGIAR system, which emphasizes the importance of partnerships and networks in staying relevant and cutting-edge. Land-use and forest issues cut across new CGIAR research programs (CRPs) so it is importance that there is close linkage between CRP6 (forests) and the other CRPs. It is not how this will happen or what the incentives are to do it, but if research on these issues is to be a strong component of the new CGIAR, a broad cross-cutting agenda on institutions and governance of land and forest resources will need to take shape over the months and years.

Session 5 Agro-biodiversity: an important contributor to productivity and the key to sustainability, nutrition and rural incomes

This session explored the extent of our knowledge of the potential value and role of agricultural biodiversity in meeting sustainable production increase challenges and development needs, and the potential risks of its loss through production system choices or agro-ecosystem disruption.

Stephan Weise's (Bioversity International) presentation on *Making wiser use of agricultural biodiversity* focused on how agricultural biodiversity and greater reliance on ecological processes can deliver sustainable intensification for increased productivity. He introduced a research-for-development agenda which will focus on smallholder farming communities and will significantly improve livelihoods and nutrition, and ensure more sustainable and resilient agricultural systems through the improved use of biodiversity. Key elements of such a research agenda include:

1. Prototyping approaches to agroecological intensification through the increased use of agricultural biodiversity.
2. Piloting approaches for increased resilience and risk reduction with smallholder farmers through greater use of agricultural biodiversity and local forest resources.
3. Promoting the use of agricultural biodiversity to provide affordable, nutritionally-rich food sources which contribute to dietary diversity and improved nutrition and health.
4. Developing innovations across the value chain that permit the improved use of agricultural biodiversity for increased income, and supporting the equitable participation of the poor in markets.
5. Identifying, validating, and promoting biodiversity-based options congruently for improving nutrition, livelihoods, and system sustainability in representative agricultural ecosystems.

A stronger knowledge base is needed for harnessing the potential of agricultural biodiversity in three areas: (1) Nutritional health gains from diversified diets using a wide range of local plants and 'minor' crops and varieties; (2) Improving rural livelihoods through gaining greater access and value in markets to diverse agrobiodiversity-based products that also enhance food security across seasons; and (3) System sustainability and resilience resulting from a more diverse production base.

In his presentation *Agro-biodiversity: beyond mixtures and "ecosystem services"* R. Ford Denison from University of Minnesota, USA, contrasted large scale (global and regional) preservation of biodiversity with that at small level, on farms. He argued that global extinction of species is irreversible where as low within-farm diversity is not. There is a risk that demands for high level of biodiversity conservation at the farm level will undermine support for biodiversity conservation at larger levels. He discussed some local level practices that have been advocated for generating benefits due to biodiversity, namely crop mixtures and rotation. He concluded that the benefits of fine-scale biodiversity conservation have been overemphasised. While placing too much emphasis on the farm scale in the debate on biodiversity, the benefits from the global level biodiversity have been under-emphasized.

A comparison between mixtures and rotation suggests that while there may be benefits from both practices due to complementarity, in rotation management of single crops is easier and diversity increases over time. Mixtures can reduce flexibility and speed up disease spread between fields.

Regarding incentives for the large-scale biodiversity conservation, "ecosystem services" argument may not work for conserving endangered species. Denison argued that there is need to preserve rare species and rarely-grown crops not mainly for their current benefits, but rather for their future potential. Increasing the use of minor crops, for bet-hedging—insurance against broad crop failure—may not be attractive to individual farmers due to risk if productivity is low. Ways to overcome this could include breeding and agronomy to improve productivity; subsidies; or removal of perverse incentives.

In her presentation *Development opportunity crops*, Coosje Hoogendoorn from International Network for Bamboo and Rattan (INBAR), China introduced the Development Opportunity in Diversity Initiative; a multi-stakeholder platform. The platform was created to address future requirements for sufficient and nutritious food through cultivation of other than the major staples for developing balanced diets and for diversifying crop ecosystems thereby providing productivity where major crops may fail. CGIAR Centers and a broad range of other stakeholders are involved in the platform. Cultivation of the "development opportunity crops" (DOCs) is expected to improve (1) food and nutrition security, (2) incomes and (3) resilience of the cropping systems. These three areas form the three pillars of the initiative. Activities have been focused on case studies on three crops: breeding of mungbeans, marketing of Maca and research consortium on bamboo. Positive lessons emphasise the importance of holistic partnerships, high-quality adaptive research drawing from the latest research results, capacity building, international exposure, supportive policy environment and funding stability. Based on the experiences the speaker recommended collective action in research building on existing work, working across crops and forging new partnerships. She saw opportunities for engaging with the CGIAR's CRPs through planning, conducting systems research, using the sentinel site network and implementing research as "proof of application".

Li Long from China Agricultural University in Beijing, spoke about *Crop diversity for yield increase and disease management* and reported on research results from large-scale intercropping in China. Intercropping of tobacco, maize, sugarcane, potato, wheat and broad bean was tested – either by overlapping growing seasons or by mixing crop species based on differences in their heights – in 15,302 hectares of experimental fields in ten counties in Yunnan Province, China. The speaker presented results on productivity increases and how above and below ground interactions enhanced productivity, rhizosphere effects and effectiveness of N-use in cereal/legume intercropping. Some combinations increased crop yields for the same season between 33.2 and 84.7% and reached a land equivalent ratio (LER) of between 1.31 and 1.84. In the potato–maize intercropping system, the maize yields from intercropping were 147% in both experimental years compared with equal areas of the monocrops. The intercropped potato yields in these two years were 115 and 120% compared with equal areas of monocrops. Intercropping was also high favourable regarding level of damage from potato late blight. The speaker concluded that where suitable crops are associated, intercropping can enhance productivity and it can easily be applied in developing countries.

Sarah Simons from CAB International gave a presentation on *Invasive species and the threat to system sustainability*. She defined invasive species as plants, animals or microorganisms whose introduction and/or spread into new areas threatens agriculture, environment, health, trade, transport and, more broadly, economic development. She stated that invasive species currently constitute one of the biggest threats to food security, (agro-)biodiversity and ecosystem services, globally. As examples of invasive species she mentioned weeds, and gave an estimate that up to 40% of the food that is grown is lost to invasive pests and diseases. Globalization, especially trade, transport, travel and tourism, is increasing the spread of invasive species. She mentioned some readily available solutions such as international agreements that guide national policies. However, as this is not always effective in developing countries, she highlighted a local-scale solution promoted by CABI, Platwise, to improve food security and the lives of the rural poor by reducing crop losses. Plantwise uses existing knowledge on invasive species and agro-biodiversity and without extra use of land, water, fertilizers or chemicals strives to set up and run community-based plant clinics that deliver free plant health advice to smallholder farmers.

A panel with representation from an NGO, the private sector and a regional forum joined the audience in discussion. It was emphasised that focus needs to be on smallholders whose innovation is important as they are the decision making entrepreneurs and have access to important assets. Also dialogue is needed with the existing knowledge systems. Poverty focus needs to be in the core of the discussion as rural people need

income and employment. In some areas highest poverty indices correlate with highest biodiversity *in situ* and *ex situ* and genetic improvement and functioning seed systems are needed for exploiting a large number of species with potential value. There was a question whether poor farmers traditionally growing a large number of species have incentives to continue doing so when they have remained very poor despite the diversity. It was suggested that we should not rely too much on the small-scale farmers to conserve agrobiodiversity although they have knowledge on the use of diverse crops, especially in regions where farm size it likely to increase over time, due to a push from demographic factors and policies. To facilitate efforts to conserve the environment, more farmer education is needed on the value of the natural resources. Prioritization of the CGIAR's work depends very much on the scale of farming and therefore we need a vision on who are the farmers in 10-15 years and how are farm sizes going to change. The crops that were discussed are too small to warrant a program, and therefore linking the bottom-up approaches with the CGIAR research through CRPs should be carefully considered.

Session 6, Animal protein: increased production and a healthy environment in conflict?

ISPC Member Maggie Gill introduced the session noting the annual per capita intake of meat in developing countries increased from 9.9kg/cap/yr in 1963 to 28kg/cap/yr in 2003, with milk increasing from 1.9 to 33, eggs from 0.99 to 6.9, fish (seafood) from 5.1 to 13 and fish (freshwater) from 0.99 to 5.1. Increases in production to meet the increased demand were partly met by increases in productivity, but also by increases in numbers of livestock and numbers of fish farms. Attention was drawn to the negative consequences for the environment of such rapid expansion in livestock production by the publication of "*Livestock's Long Shadow*" in 2006, but the ensuing global publicity tended to focus on a few headline-grabbing statistics which, in some countries at least, eclipsed reference to the important contribution which livestock make to food security in regions with limited arable land. An earlier report of multi-donor studies (Livestock–Environment Interactions: Issues and Options, FAO, 1996) considered many of these issues but considering the dynamic nature of the livestock and aquaculture industries in response to growing demand for animal protein, a new look at the issues in this second decade of the 21st century is timely.

In the context of CGIAR Reform, research programmes should be structured to deliver outcomes, which usually benefits from integration between disciplines. The outcome addressed in this session was how to meet the increasing demand (in response to increasing incomes) and need (increasing recognition of the importance of animal source proteins for brain development in malnourished children) for animal protein, while maintaining a healthy environment. The session was structured to consider the provision of animal source protein from capture fisheries and aquaculture, alongside provision from terrestrial livestock industries as complementary and sometimes competing components (in relation to inputs) within the overall animal protein production picture. Both livestock and fish are produced/harvested in 'extensive' and 'intensive' systems and this session concentrated on those systems, while recognizing that 'mixed' systems are also important for livestock in particular. The session considered firstly the Interaction of 'extensive' systems with the environment –capture fisheries and grazing ruminants, and, secondly, the key pressure points between intensive systems and the environment, i.e. in relation to feeds, waste and interactions with wildlife leading to disease.

Steve Hall (WorldFish, Malaysia) spoke on "Fish and food security: the future role for wild capture fisheries in meeting world demand and need for fish". He noted that fish from marine capture fisheries is plateauing, whilst aquaculture production is growing rapidly. The importance of fish from freshwater capture fisheries is often overlooked (but they have immense importance in several developing countries). Such fisheries are affected by externalities. Thus the "Big question" for researchers and policy makers is to facilitate substantial conversations on what national governments and local communities want fisheries to be and to provide in the future?

Saverio Krätli (IUAES Commission on Nomadic Peoples) "Pastoral systems and the interaction with the environment: from problem to asset". In some countries, the contribution of pastoralism to the economy can be high (e.g. livestock provide 70% of agricultural GDP in Mauritania). Pastoral systems make use of human-animal-environment interactions rather than trying to diminish these sorts of interactions in intensive systems. One of the key differences with pastoralism is recognizing non-uniform distribution of resources in time and space. To effectively exploit pastoralism under increasingly demanding conditions, we need to identify different analytical tools to deal with non-uniformity.

David Kemp (Charles Sturt University) in his paper with collaborators on "Grasslands, environment, livestock and household incomes" considered the optimization of grazing systems in northern China. The key research and development question is how to balance household income and environmental issues?

Results show that strategies can be developed to decrease stocking rate while increasing incomes (focusing on young animals and appropriate market demand and timing). The project results have had an influence on policy and ways of addressing grazing systems more widely. A lesson learned from the approach was that it was better to focus on the desired development outcome and not to aim necessarily for the traditional indicator of maximum biological gain per hectare.

Robert Swick (University of New England) examined food-feed competition in his paper "Scientific opportunities to overcome the challenge of increasing demand for food and feed". 16-20% of wheat production is used for animal feed, but simple equivalences are misleading as this would not have been suitable for humans. Breeding advances have decreased time to market (and hence feed required) for broilers from 85 days to 35days. Fish show a relatively very efficient feed conversion ratio but there are continuing efforts to reduce the amount of fish meal and fish oil in the farming of the major aquaculture species. In general, protein sources are interchangeable between livestock and aquaculture feeds and so global production (of components such soya, maize, fish meal) and market forces play a large role in dictating industry strategies. Scientific opportunities for feed include: decreasing post-harvest loss, plant genetics, animal genetics, the use of appropriate feed additives (such as specific enzymes), other enhancers of gut health, and in feed formulation.

Hongmin Dong (CAAS, China) reported on the “Management of the waste from animal systems for the benefit of the environment” in China. The issue is substantial; total fresh manure excretion in China is 2.3 billion tones derived 34% from swine and 54% from cattle. By the end of 2010 there were 40 million biogas digesters in China with a total biogas production of 11.2 billion m^3. Carbon credits could drive greater uptake of this approach. However, new technologies are still needed to increase the value of animal waste (and its effective use and recycling). As part of this approach we need whole system assessment of environmental impact of different waste systems.

Bryony Jones (Royal Veterinary College - University of London) described "The effect of agricultural intensification and environmental changes on the risk of zoonoses that have a wildlife-livestock interface". She noted that 58% of human pathogens are zoonotic and 26% involve wildlife as well as domestic livestock. Factors which influence disease transmission include habitat change (such as forest clearing or the establishment of new intensified livestock systems), local biodiversity, host density and vector density. Although there is still a lack of evidence, there is a strong likelihood that higher density of livestock facilitates disease transmission. Predicting specific outbreaks of disease remains elusive, but the likelihood of epidemics accompanying agricultural expansion remains.

The session concluded with a discussion in which it was noted that: Livestock intensification presents challenges of competing feed uses, greenhouse gas emissions, waste disposal and, potentially, zoonotic diseases. Livestock and fish for aquaculture use feed resources, including those from capture fisheries (fish meal and oil) and crop agriculture, particularly maize and soybean. Planning is needed to encourage intensification based on the ‘best use’ of feed ingredients. Thus whilst the priority research question remains of how to improve production without harming environment, the session authors believe that the answer goes beyond straightforward trade-offs to the identification of integrated opportunities. We need to use new metrics and think about ‘point of production’ *versus* ‘point of consumption’ in assessments of production and its impacts. Clearly, science and policy interactions will be important.

Specific areas for component research include the maintenance of pastoral systems where they remain an important user of resources not available to other uses. We need to increase or optimize production of these systems. There is the importance of dealing with waste and breeding to improve efficiency in intensive and mixed systems. Assessing GHG emissions remains important for optimizing nutrition and grazing strategies.

However, speakers posed the question of where Government payments would come in for environmental services?

Both for freshwater fisheries and industrial capture fisheries - as for pastoral livestock systems - many of the issues affecting the maintenance of production and sustainable development lie outside the sector. To sustain these industries and practices, there is a need for dialogue on the value of resources and land uses with all stakeholders, including those from other sectors, so as to determine the appropriate use of land, resource inputs and their future exploitation.

This highlights the need for research on land-use planning and management research, to provide evidence to support the development of appropriate policies and the implementation of waste disposal and reuse of wastes, and disease surveillance, particularly in areas of agricultural expansion. For the CGIAR and its partners this will mean looking at potential industry developments from a multifunctional perspective. It will include the need to provide objective evaluations of production and the livelihoods that may be derived from these industries, including identification and quantification of potential environmental and social impacts from different undertakings. There are benefits of thinking of fish and livestock issues together. This range of multi-disciplinary analyses and projections are required for a more nuanced understanding of development options and so that more rounded advice can be provided to policymakers. The CGIAR needs to draw out lessons from past research and bring them together in a more integrated fashion. A corollary of this for the CGIAR reform process is that the balance of the approach, and the financial resources applied to them, may need to be reconsidered e.g. one third of total spending should be on research and perhaps two thirds on the 'glue' (of partner and stakeholder interactions and policy) to achieve the appropriate outcomes. There will be a need for professional expertise to open up the multi-sectoral conversations with stakeholders, which will affect the culture of the system and its approaches to research for development across the animal protein production sectors.