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INTERGOVERNMENTAL PANEL ON climate change

MEETING REPORT

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MEETING REPORT

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TECHNICAL ORGANIZATION: AGENDA AND THEMES

Lead Technical Coordinators:

Aziz Elbehri	FAO
Andy Reisinger	NZAGRC and IPCC

Scientific Advisory Committee:

Pramod Aggarwal	South Asia Regional Program for the CGIAR-CGIAR
Mohamed Badraoui	INRA/MAPM, Morocco
Victor Castillo	United National Convention to Combat Desertification (UNCCD)
Aziz Elbehri	Food and Agriculture Organization of the United Nations (FAO)
Cheick Mbow	ICRAF/START International Inc.
Luca Montanarella	Intergovernmental Technical Panel on Soils (ITPS) and IPBES
Hayden Montgomery	Global Research Alliance (GRA)
John Porter	Agriculture and Climate Change, Natural Resources Institute, University of Greenwich
Andy Reisinger	NZAGRC and IPCC
Laurent Sedogo	Executive Director WASCAL (West African Science Service Center on Climate Change and Adapted Land Use, Ghana)
Sonia Seneviratne	ETH Zurich Dep. of Environmental Systems Science Institut für Atmosphäre und Klima Zürich Switzerland
Jean-Francois Soussana	INRA, France
Lini Wollenberg	CCAFS-CGIAR/ University of Vermont

FAO Technical Support Group:
Martial Bernoux, Lorenzo Bellu, Marlos DeSouza, Alexandre Maybeck, David Morales, Anne Mottet, Simon Smith and Ronald Vargas

FAO Corporate-Level Coordination:
Martin Frick, Director, Climate and Environment Division (FAO)

REPORT AUTHORSHIP

Lead coordinating author: Aziz Elbehri (FAO)

Contributing authors: Arild Angelsen (NULS), Mohamed Badraoui (INRA-Morocco), Andy Challinor (University of Leeds), Harry Clark (NZ AGRC), Annette Cowie (UNCCD-SPI), Sena De Silva (Deakin University), Jon Erickson (University of Vermont), Stein Joar Hegland (WNUAS), Tim Hess (Cranfield U.), Ana Iglesias (U.P. de Madrid), David Inouye (University of Maryland), Andrew Jarvis (CIAT), Eduardo Mansur (FAO), Alisher Mirzabaev (U. of Bonn), Luca Montanarella (EC-JRC/ITPS), Daniel Murdiyarso (CIFOR), An Notenbaert (CIAT), Azaiez Ouled Belgacem (ICARDA), Michael Obersteiner (IIASA), Keith Paustian (University of Colorado), Daniel Pennock (University of Seskatchewan), Andy Reisinger (NZARGC/IPCC), Doris Soto (INCAR-Chile), Jean-Francois Soussana (INRA-France), Richard Thomas (ICARDA), Louis Verchot (CIAT), Ronald Vargas (FAO), Mark Van Wijk (ILRI), Reiner Wassmann (IRRI) and Robert Walker (U. Florida)

External reviewers: Patrick Mayfroidt (UC Louvain), Mark Smith Sanford (CSIRO), Guillaume Gruere (OECD), Philip Thorton (ILRI), Sonja Vermeulen (CGIAR), and Clare Sterling (CIMMYT)

Additional comments were provided by the following EM participants: Hayden Montgomery (GRA), Christopher Martius (CIFOR), Martial Bernoux (FAO), Delphine Deryng (Climate Analytics), Craig Hanson (World Resource Institute), David Reay (University of Edinburgh), Giovanna Velverde (Minister Counselor, Costa Rica), Lorenzo Bellu (FAO), Margaret Gill (University of Aberdeen), Alexandre Meybeck (FAO) and Riccardo Valentini (University of Tuscia)

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The sessions were chaired by: Rene Castro-Salazar (FAO), Craig Hanson (World Resource Institute), Petr Havlik (IIASA), Eduardo Mansur (FAO), Christopher Martius (CIFOR), Erik Patrick (IFAD), Riccardo Valentini (University of Tuscia), David Reay (University of Edinburgh), Richard Thomas (ICARDA), Giovanna Velverde (Minister Counselor, Costa Rica); and Robert Vos (FAO). The session rapporteurs included: Manuel Barange (FAO), Lorenzo Bellu (FAO), Martial Bernoux (FAO), Margaret Gill (University of Aberdeen), Adriana Ignaciuk (FAO), Alexandre Meybeck (FAO), Hayden Montgomery (GRA), Douglas Muchoney (FAO), Seo Niggol (Muaebak Institute of Global Warming Studies), Andy Reisinger (NZARGC/IPCC), Henning Steinfeld (FAO) and Olcay Unver (FAO). The meeting session notes and summary reports were prepared by Valentina Conti, Krystal Crumpler, Uwe Grewer, Elizabeth Laval, Felix Marttin, Anne Mottet, Marc Mueller, Carolyn Opio, Antonio Scognamillo, and Emilie Wieben from FAO. Session chairs, rapporteurs and note takers ensured timely communication of session note summaries to participants during the EM coordinated by Aziz Elbehri and Evelyne Van Heck.

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Preface

The landmark Paris Agreement seeks to strengthen the global response to climate change, in the context of sustainable development and efforts to eradicate poverty. Among the provisions of the Paris Agreement is an explicit link between climate objectives and food security. The Agreement recognized "the fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems to the adverse impacts of climate change". Stipulated under Article 2 is a commitment to "hold the increase in the global average temperature to well below 2 °C above pre-industrial levels" as well as "increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production".

At the 43rd Session of the Intergovernmental Panel on Climate Change (IPCC), held in Nairobi Kenya in April 2016 the IPCC decided the strategy and timeline for reports to be produced during its 6th assessment cycle. As part of this report, the IPCC agreed to produce a Special Report on "Climate change, desertification, land degradation, sustainable land management, food security and GHG fluxes in terrestrial ecosystems".

FAO welcomed the IPCC decision on the Special Report. It also reaffirmed its willingness to contribute its expertise in the areas of agriculture and food security. FAO proposed to organize an Expert Meeting (EM) on climate change, land use and food security on 23-25 January 2017 with the co-sponsorship of IPCC. The central aim of the EM is to place food security at the centre of the debate relating to climate change, land use systems and the required adaptation and mitigation responses in line with the Paris Agreement and the Sustainable Development Goals (SDGs). The second objective of the EM is to provide background support to the IPCC scoping meeting on the above Special Report, held in mid-February 2017 in Dublin.

One hundred scientists, economists and policy experts participated in this EM engaging in a high-level, globally oriented, and multidisciplinary scoping of the most critical issues that face land use and food security in the context of climate change. The three-day EM was structured around five themes: climate impacts on land, ecosystems and food; human-directed drivers of land change and linked to food security; emissions trends in AFOLU and mitigation options; adaptation and resilience in food and land systems; and policies for adaptation, mitigation and food and nutrition security.

The present Report offers a comprehensive synthesis from the EM proceedings and present a series of detailed conclusions and recommendations reflecting the collective view of the 100 participants with additional input from external reviewers. We expect the report to be a valuable source for the IPCC above mentioned IPCC Special Report, especially in relation to food security, as well to researchers and policy makers concerned with the policy implication of food security in relation to post-Paris climate action and Agenda 2030.

We thank the Government of Ireland and the Government of New Zealand for their financial support which enabled FAO to sponsor over 30 participants from developing countries to participate at this event.

Signed on behalf of FAO

René Castro
Assistant Director-General
Climate, Biodiversity, Land & Water Department

Kostas Stamoulis
Assistant Director-General
Economic and Social Development Department

Signed on behalf of IPCC

Youba Sokona
Vice-Chair of the IPCC

Jim Skea
Working Group 3 Co-Chair

Priyadarshi R. Shukla
Working Group 3 Co-Chair

Andy Reisinger
Working Group 3 Vice-Chair

Acronyms

AAA	adaptation of agriculture in Africa
AFOLU	agriculture, forestry and other land use sector
AI	agricultural intensification
AR4/5	Fourth/Fifth Assessment Report
AWD	alternate wetting and drying
BECCS	bioenergy with carbon capture and storage
CCAFS	Climate Change, Agriculture and Food Security
CGIAR	Consultative Group for International Agricultural Research
EM	Expert Meeting
GHG	greenhouse gases
GLASOD	Global Assessment of Human-Induced Soil Degradation
ICARDA	International Centre for Agricultural Research in the Dry Areas
IIASA	International Institute for Applied Systems Analysis
ILM	integrated landscape management
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
ITPS	Intergovernmental Technical Panel on Soils
LDN	land degradation neutrality
MRV	monitoring, reporting, validation
NDC	National Determined Commitments
PES	payments for environmental services
REDD	Reduced Emissions from Deforestation and Forest Degradation
SCS	soil carbon sequestration
SI	sustainable intensification
SDG	Sustainable Development Goals
SPI	Science Policy Interface
TEEB	The Economics of Ecosystems and Biodiversity
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme

Key messages and recommendations

CROSS-CUTTING MESSAGES

- Expanding knowledge and improving understanding of extreme climatic events and their implications across sectors, regions and time would help strengthen resilience and reduce the risk from cascading events across society.
- Single-issue solutions hold a high potential for unintended consequences and are unlikely to address the complex effects of climate change. We need to think of interrelated systems and inter-disciplinary approaches to tackle climate, land, ecosystem and food linkages, interactions and feedbacks.
- For climate action (adaptation, mitigation), we need to devise integrated frameworks and approaches that ensure scientific and technical solutions are co-designed with socio-economic and institutional assessments to enable the desired change.
- To achieve food and nutrition security, a food systems approach is required stretching over the whole food chain (production through consumption), all food security dimensions (availability, access, utilization and stability) and placed within a larger economy and broader ecosystem function (land, water, and energy).
- In developing regions, especially where food insecurity is high, climate policies and investments must target poor and food insecure people for adaptation and resiliency-building strategies.
- To secure a resilient food system under climate change requires a range of appropriate sustainability metrics to better support integrated and multidisciplinary scenario analyses combining socio-economic and ecological dimensions.
- Transforming the food system to address the twin challenge of climate change and food security requires an approach that addresses food production, distribution and demand and seeks to utilize and expand on existing synergies and co-benefits to manage interactions across temporal and spatial scales. This will also require governance and institutions to adopt such integrated perspectives, informed by robust assessments of the scientific evidence that allow institutions to navigate this complex space.

Theme 1. Climate impacts on land use, food and agriculture, and related ecosystems

KEY MESSAGES

- Climate change is expected to impact on crop production, livestock production, fisheries and aquaculture. There is robust evidence of negative impacts from heat and water stresses on crop yields but much less evidence is available for livestock feed, livestock production, fisheries and aquaculture.
- There is ample literature focusing on the effects of climate change on freshwater resources but there remain many uncertainties to be addressed, in particular the role of extreme and elevated CO_2 effects on terrestrial ecosystems and the resulting feedback processes to the global water cycle.
- Information on the effects of climate change on current and projected groundwater resources is limited and needs further research.
- We need to address in detail the impact of sea level rise and related climatic changes (costal currents, temperature, salinity, nutrients) on coastal water quality and coastal agriculture.
- There is a wide range of studies looking into climate impacts on soils but most overlook linkages to agriculture and food security, partly due to the very disparate data available. This gap is being addressed thanks to new developments in global soils data.

- The current literature on the climate impacts of pollinators on the one hand, and crops and animal pests and diseases on the other, is based on case studies and needs to be addressed more comprehensively. We need more extensive data on these aspects to integrate them into impact models and build the evidence on crop yields and their effects on food supply.

- Our understanding of the vulnerability and adaptive capacities of smaller food production systems remains limited and requires further data and quantitative research to examine, for instance, forage crops and mix systems. Particular attention should be paid to tropical and sub-tropical cropland, rangeland as well as inland fisheries, especially in Africa.

- Integrating impacts on productivity and land use and changes in land use are key to addressing the overall impacts on food production, taking into account changes in crop suitability.

- Two crucial dimensions of food security need special attention: utilisation and stability of food systems. In regards to food utilisation, there has been little focus on the impacts of climate change on the quality of food supply but there is a body of evidence suggesting a decline in protein and nutrient content of crops and dairy products as a result of increasing atmospheric CO_2 concentrations. In regards to food stability, agricultural shocks caused by extreme weather events are likely to play out through price variability and affect food supply variability. These issues remain an emerging field of study.

KNOWLEDGE GAPS

- In addition to expanding research to small crops, the role of extremes is still a key knowledge gap. Change in the frequency and intensity of extreme weather events and the resulting food price volatility are likely to become much more detrimental than the gradual climate change effects that have received most attention in the literature up to now, for very good reason. Climate model results and related crop model assessments are increasingly useful for evaluating extremes. Analysing the impacts of climate change through risks, or "food shocks" and their transmission across various sectors and assessing how they interact with specific vulnerabilities, is necessary for food security impact assessment, in all dimensions, including stability.

- Impacts on ecosystems (water, soils, forest and pollinators) indirectly influence food production and demand greater attention. We also need a comprehensive review of knowledge gaps in these areas. Furthermore, linkages with land use, food production and food security require further clarity and warrant more empirical research.

Theme 2. Human-directed drivers for land use, land use change, land degradation and desertification, and implications for food security

KEY MESSAGES

- We need a better and more systematic delineation between climate-induced drivers and human-directed drivers of land use and land use change to avoid incorrect attribution and to draw up correct policy recommendations. The climate-induced and human-directed drivers and their linkages with food security need to be understood and evaluated, including where possible, measuring the relative magnitude of the two types of drivers (e.g. pollination loss and pesticides vs climate change).

- To measure the effects of climate and human activities we need metrics and indicators that distinguish between direct and indirect, short-term vs long-term, and reversible vs non-reversible variables.

- We need more comprehensive and holistic modelling of AFOLU (agriculture, forests, and other land use) to better understand competition for land between food, biomass, carbon sequestration and biodiversity conservation; we also need to broaden models beyond a few individual demands to avoid suboptimal policy recommendations.

- We need a better understanding of the links and causality between climate events and human activities and their effects on land quality/productivity and ecosystem diversity.

- We need greater understanding of the human drivers behind desertification and land degradation, including human-land-water interaction.

Theme 3. Climate mitigation in agriculture and other land uses and linkages to food security

KEY MESSAGES

- Agriculture's share of GHG emissions is large and given the expected increases in food production needed up to the 2050s, a large amount of mitigation from agriculture will be needed.

- The priorities in reducing GHG emissions should focus on options that offer synergy to make food systems more efficient and also contribute to economic development and resilience. The latter is enhanced by augmenting economic efficiency (focus on short-term yields and profits, N-use efficiency) with risk management over the long haul.

- We need greater efforts to address emissions along the food value chain pre- and post-harvest and to explore the mitigation options associated with food waste as well as with food transport, storage, processing and packaging.

- We need to promote the use of biological nitrogen fertilizer in all farms of all sizes worldwide, particularly those growing legumes as it will lead to partial or total replacement of mineral nitrogen fertilizer, a major source of nitrous oxide emission.

- The growing demand for fish means we should assess the emissions and mitigation options for aquaculture and mangrove conversion to aquaculture.

- Mitigation policies should consider all four dimensions of food security: availability, access, utilization and stability.

- When tackling climate mitigation and food security, it is important to separate ruminant and monogastric and extensive and intensive livestock systems and to seek diet improvement in ruminants to reduce GHG emission intensity per kg product, while avoiding negative food security consequences (e.g., from feeding cereals to ruminants).

- We need to review and explore opportunities for carbon investment from communal rangelands that will contribute to low carbon and food security and to propose measures that reduce impacts of climate change on rangeland ecosystems.

- There has been too much focus on biophysical and agronomic solutions and practices and not enough socio-economic analyses to remove constraints for adoption of improved technologies. Progress in enhancing adoption of "proven" mitigation technologies by farmers requires integrated and multidisciplinary analyses with full engagement of stakeholders, especially smallholder farmers

KNOWLEDGE GAPS

- Spatial analysis of the feasibility of mitigation measures in the agricultural sector should take full account of the rural landscape where they are applied and allow compensation for GHG emissions at landscape level. It should also examine ways to achieve better resolution of priority efforts for mitigation.

- We need to examine incentives and the adoption patterns of mitigation practices linked to improved food security in high and middle-income countries.
- To support a Monitoring-Reporting-Validation (MRV) agenda on GHG mitigation, emissions from smallholder or suboptimal production systems in developing countries should be better evaluated and integrated into any productivity improvements.
- The effects of land management change, and in particular biophysical effects, are a major knowledge gap.

Theme 4. Climate change adaptation, resilience and linkages to food security

KEY MESSAGES

Rebuilding land and soil health

- We need to do a better job to link soil management with water quality and nutrients' leaching and move to better integrate critical soil health indicators, like soil carbon with other processes and practices.
- We need to promote best practices that offer clear economic gains as well as net long-term mitigation benefits.
- We need better instruments to account for payments for environmental services (PES) as part of any integrated soil-water-nutrient management package and to assess the potential role of the private sector.
- We need improved measurements that combine ecological and economic valuation of soil loss and design incentive programmes (e.g. through PES) that help minimize soil loss.
- We need to adopt integrated frameworks, such as the Land Degradation Neutrality (LDN) initiative, to maintain or enhance the land-based natural capital and the ecosystem services that flow from it through sustainable land management and interventions that restore degraded land.
- We need to adopt ecosystem-based adaptation approaches that are proven to be cost-effective and can lead to a multibeneficial strategy for adaptation.

Adaptation to water scarcity and equitable access to water

- We should integrate technical and economic assessments when measuring the impact of improved water use efficiency (maximizing "crop per drop") vs sustainable water use (optimized renewable use of water within a river basin).
- Economic analyses and institutional mechanisms are needed to improve governance and water access equity among different users affected by its scarcity.
- The costs of increased flooding and coastal soils salinization under climate change needs to be better assessed and options developed for agricultural systems adaptation.
- Integrated, participatory research will allow local or regional water assessments to develop frameworks to manage water, land, agroforestry and crops under different water demand, supply and pricing conditions.

Adaptation to pollination loss

- We need to quantify better the relative impact on pollination from climate factors vs human activities and production practices (pesticides, monoculture) under specific agro-ecological conditions. We should also identify alternative cost effective practices to minimize the loss of production and lower quality arising from insufficient pollination.

Rebuilding land productivity in rangelands

- We need better testing of dryland resistant plant species coupled with assessments of socio-economic and institutional constraints to adoption of alternative technologies, including water conservation techniques.
- Greater research is required to evaluate farmers' needs, objectives and constraints, integrated into socio-economic research to derive policies and innovative institutional schemes to improve adoption of proven technologies.
- We should devise integrated schemes that combine newly adapted species (plants and animals) with conservation agriculture, sustainable grazing techniques and water harvesting.
- More interdisciplinary research can promote dialogue across disciplines, especially between economists and ecologists and between environmental specialists and agriculturalists.
- Support community level responses and the building of mutual synergy on poverty reduction.
- Harness and mainstream indigenous knowledge and local adaptation practices and lessons learned in planning at all levels.

Agricultural intensification and diversification

- Promoting crop genetic diversity should be expanded and scaled up beyond basic research and moved into project development/deployment combined with market analyses to evaluate possibilities for greater adoption and for scaling up successful pilot projects.
- More economic research is needed to examine the impact of incentives on farmers' crop choices and agricultural practices with particular attention on those subsidies and technologies that support more diverse ecologically sound and climate-adapted production systems.

Adaptation and resilience options for livestock systems

- Examining the socio-ecological context of livestock systems is critical to identifying, testing and deploying resilience-supporting livestock technology under grazing or crop-livestock mixed extensive systems.
- Research and development of drought and disease resistant animal breeds and economic incentives to shift or mix species is another strategy to be explored under drylands conditions.
- Technology development has far outstripped successful farm-level adoption suggesting greater focus should be placed on socio-economic and institutional analysis to unpack the constraints preventing farmers' technology uptake.

Adaptation and coping mechanisms in aquaculture and inland fisheries

- Given their strong relevance for food security we need more research and meta-analysis in aquaculture and inland fisheries, especially designing optimal management initiatives that balance resource conservation with fish production.
- Additional research into aquaculture is also needed, especially in relation to floods and catastrophic risks with better integration into watershed management systems.

Adaptation with food security

- Where food insecurity is prevalent, adaptation planning and design must prioritize programmes tailored to poor people and communities' specific vulnerabilities, capacity to cope and opportunities to build resilience.
- National or regional-level adaptation programmes in agriculture and other land uses must integrate livelihood objectives and tackle food insecurity at individual, household and community levels.

Policy Theme 1. Resource management policies and food security

KEY MESSAGES

- Despite an increased body of scientific evidence on how to harness biodiversity within agricultural systems, we still lack the right policy and economic tools to make appropriate changes.
- Fluctuations in our food supply due to climate variability are not yet sufficiently incorporated into our food price models and analyses.
- We need better understanding of how climate-induced shocks to food prices and supplies are transmitted across sectors and borders.
- Payments for environmental services (PES) have worked in forest recovery only when market incentives are combined with regulatory enforcement and participatory approaches.
- To be successful in delivering multiple ecosystem services, PES need to be better designed and founded on properly framed meta-analyses.
- Explore economically viable options for environmental services' payments for pollinator protection.
- More socio-economic research is needed coupled with institutional innovations that overcome the low adoption rates of proven technologies, especially under low yielding, high risk environments.
- Devise integrated schemes that combine new adapted species (plants and animals) with conservation agriculture, sustainable grazing and water harvesting.
- Develop adaptable and practical policy schemes (including PES) to support these technological packages under rangelands conditions.
- Adopt a climate-smart water policy to better integrate water and supply scenarios within an integrated land-crop-energy strategy at a given hydrological unit.
- With scarcity, water use policy must make a clear distinction between water use efficiency at field (or farm) level and water use sustainability (watershed level or groundwater aquifer level).

Policy Theme 2. Policy options for food demand and sustainable consumption

KEY MESSAGES

- Addressing food demand and sustainable consumption requires a holistic approach based on robust data, scenarios and models that integrate food demand, dietary and nutrition preferences, food waste drivers and macropolicies such as trade.

- Interaction between land prices and competition for other land-based products and services, such as feed and fuel production and carbon sequestration, need to be comprehensively examined to inform the effectiveness of alternative policy instruments.

- There is an important data gap regarding: (i) how much food is lost at each stage of the food supply chain; (ii) how climate change may affect these losses; (iii) estimates of GHG emissions resulting from food storage and transportation; (iv) the efficiency and success of various food waste reduction policies.

- More in depth analyses need to look at the role of certification (including business-to-business certification) to better understand the role of socio-economic as well as psychological drivers that shape consumer choice.

- There is a growing literature on food chain carbon, water and other footprints and there is a need for comprehensive meta-analysis to draw robust conclusions and identify the most effective context-specific targets for intervention.

- We need better data on a range of environmental footprints and consumer behaviour analyses to devise policies to incentivize healthier and more climate-friendly diets.

- Food waste and loss reduction policies should offer guidance on food surplus management so that food stocks can serve as a buffer in time of production shock; countries and companies need to capture and report more data on food loss and waste.

- Clearly communicate science-based evidence in support of local production and consumption ("food miles") and urban agriculture and their impact on food security and climate mitigation.

Policy Theme 3. Pro-poor and climate-compatible socio-economic policies for smallholder resilience

KEY MESSAGES

Synergy: pro-poor climate policy and sustainability

- Policies to improve resource use efficiency with higher productivity may also contribute to mitigation (reduced emissions intensity) and better adaptation. Many policies that improve farmers' resource use efficiency and hence their incomes can also be beneficial in terms of climate mitigation.
- In climate policy, especially for developing countries facing food security challenges, the delineation between adaptation and mitigation has to give way to integrated approaches which must combine multiple environmental indicators that require working with a set of climate indicators (beyond GHG emissions only).
- When there are trade-offs in policy outcomes, we need cross-sectoral coordination for optimal outcomes to achieve the multiple stated goals (food security, climate mitigation, adaptation, pro-poor support, gender mainstreaming, resource management etc.); this may require compensating emissions in one sector (e.g. agriculture) by targeting emissions reductions in another (e.g. energy).
- Socio-economic policies assisting smallholders to build their resilience to climate change need to be comprehensive, cross-sectoral (crops, livestock, forestry) and multi-objective (food security, adaptation, and mitigation co-benefits).
- Socio-economic policies should promote equitable access to resources.
- Reduce risks and promote preparedness and recovery arrangements so as to ensure maximum synergies among poverty, development and investment efforts.

Pro-poor climate policy addressing employment and the dynamics of rural vs urban poverty

- Comprehensive, rather than piecemeal (or fragmented) policies with a long-term view are more robust but targeted policies focusing on some challenges in priority may in some contexts lead to more cost-effective result.
- Take a long view, projecting rural populations into the future and plan accordingly. The focus should be on those rural residents who are likely to remain rural in the coming years.
- Socio-economic policies targeting smallholders should aim to build resilience and reduce risks through crop, livestock, and fish diversification, including mixed cropping, as well as off-farm income opportunities.

Pro-poor climate policy and food security

- Food security must be a common goal across all climate policy interventions targeting small-scale holders. Good practices must be economically viable for small farmers if they are to become attractive mitigation options.
- Food security at the macro level is dependent largely on what is going on outside the agricultural sector. Economic development policies need to be considered as part of building agricultural resiliency.
- Climate policies with aggregate mitigation targets should proportionately be less burdensome on poor and food insecure groups or communities.

- The role of nutrition must be explicitly factored into policy design. Promoting nutrition is multi-dimensional and requires diverse solutions. Farm policy, including crop research and development, should expand beyond big crops and focus more attention on smaller, more adapted local crops and varieties that can contribute to resilience, adaptation and healthier food for the majority of people.

The long view: transforming the food system under the combined challenges of climate change and the environment

- In the long run, the challenges of climate change and sustainability require us to re-examine and introduce new ecological and economic tools, processes and values.

- Bringing ecological economics into the future food system requires expanding sustainability metrics to cover a range of ecological indicators (including renewable energy use intensity). We need to develop strategies to minimize (non-renewable) energy consumption per calorie of food produced.

- Achieving climate-compatible and agrifood systems requires expanding our metrics beyond productivity (currently measured per unit of land, or resource) to include ecological resource valuation, management and conservation. Because of the Jevons paradox, we need to accept regulatory mechanisms as necessary complements to productivity gains.

1. Direct climate impacts on land-ecosystems and food provision

1.1 Projected productivity changes and extreme events

1.1.1 Crops

In terms of global temperature and the yield response curves for crops such as wheat and maize, the main change in AR5 compared with the Fourth Assessment Report (AR4) is that a 1 or 2 °C warming to increase yields in temperate regions is no longer expected, although there is less certainty about when any change will occur. Adding current adaptation practices to these scenarios will improve yields by seven to eight percentage points, the change is not sufficient to reverse the negative climate impacts in hotspot areas. Regional assessments of the impacts on crop yields for major crops, such as maize and wheat, show that the magnitude of loss is higher in lower yielding regions (i.e. in proportion to yield). Overall aggregate impacts are fairly robust, considering the known model uncertainties. Moreover, there are no significant changes from recent data runs compared to AR4 or AR5. It is also known that crop production effects depend on land use which, in turn, is affected by climate, weather and policies, all of which should be better integrated into current models.

It is also essential to focus on the modelling of extreme events, and more studies are attempting to quantify and measure yield variability under such events. A great deal, however, remains to be done. The task at hand is very complex and requires innovative approaches to account for production anomalies and price shocks. Traditional models for measuring variability may not be adequate as the risks are difficult to characterize and quantify, in particular events that are less likely but can have enormous impact. One option is to first approach extreme events from the effects (e.g. food price hikes) and establish the paths back to climate variability. More complex approaches require seeking evidence of the links between environmental tipping points and the food system dynamics and examining how these events interact with a view to drawing plausible outcome scenarios and potential responses.

In terms of food security[1], it is critical to understand climate-induced food price shocks and their transmission across sectors and borders better. This may require combining climate assessments Myers *et al.* (2014) with the vulnerability of the food system; that is, a geographic approach (i.e. at the regional or local level), better mapping of the policy and institutional environment (including private actors) and a combination of quantitative and qualitative approaches to scenario assessments.

A nutrition perspective on climate impacts on food production has been limited but is central to assess fully the role of climate change on food security. Impact results are mostly reported in terms of weight loss but there is recent evidence of a decrease in the quality, i.e. protein and nutrient content, of crops grown under elevated CO_2.[2] Furthermore, these effects on forage quality are expected to impact on livestock and thus further alter food security. Climate change impacts and nutrition should also be explicitly addressed in the fisheries and aquaculture sector.

1.1.2 Livestock

Livestock is the most significant land user of land-based food systems and its contribution to the livelihood and food security of millions of people cannot be understated. There is also a large heterogeneity in livestock production, ranging from mixed crop livestock, pasture-raised livestock and rangeland systems to industrial livestock production. Climate change impact on livestock can be direct (e.g. heat stress, disease) or indirect (e.g. water, feed, biodiversity and loss of habitat). Climate change can also reduce genetic diversity and limit adaptive capacity. IPCC's AR5 acknowledges the paucity of quantitative evidence linking climate change to livestock and feed systems. There is relatively more local information but few global or regional assessments, although initial qualitative analyses are available. Furthermore, global warming is expected to alter the nutritional composition of food, including the protein value of livestock products as a result of changes in forage quality and the effects of heat stress on animals.

1 World Food Summit of 1996 codified the definition of food security as "a state when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996). FAO defines food security by differentiating four dimensions: availability of food, accessibility (economically and physically), utilization (the way it is used and assimilated by the human body) and stability of these three dimensions.

2 Myers *et al.* (2014)

1.1.3 Aquaculture

Climate change impacts on aquaculture and inland fisheries directly as a result of the rise in sea level, salinity of water, drought, floods, water scarcity and changing rainfall patterns, all of which depend on location. Climate shocks can cause substantial loss of fish stocks, extinction of species and loss of infrastructure, all of which lead to dependent populations becoming particularly vulnerable. There is far less research into climate impact on inland fisheries and aquaculture compared with major crops. Moreover, there is a need to better understand the links between climate impacts on inland fish species and nutrition. These issues should be included in vulnerability assessments which are of necessity context-specific.

1.2 Climate impacts mediated through soil, water and ecosystem services

1.2.1 Climate and soil health

A number of soil processes can be affected by climate change, resulting in erosion, soil leaching, soil organic carbon loss, salinization and nutrient loss. Climate warming can cause a loss of vegetation and lower the water table within the soil, thus increasing the decomposition of organic matter in the soil and promoting the release of soil carbon dioxide (CO_2) into the atmosphere. These effects differ across regions and are more pronounced in hotspots, such as peatlands where drainage can lead to a large loss of CO_2 as a result of the decomposing of soil organic matter. While an increase in CO_2 may enhance crop productivity, the extent to which this may occur depends on the limitations of soil nutrients.

Climate change can also exacerbate soil erosion by water. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in tropical croplands, it is estimated around 20 tonnes per hectare *per annum* of soil are lost, caused by heavier precipitation and drought, reducing canopy cover and increasing soil erosion. In Europe, studies on soil erosion show that higher precipitation is expected to increase between 15–35 percent (under the RCP4.5 scenario) and soil erosion will worsen in southern Europe, a region that is already vulnerable to it.

A critical element of soil health is its nutrient status. It is known that many soils around the world have a huge excess of phosphorus owing to continuous fertilization, notably in parts of Brazil, China, Europe and the United States. In many other regions, however, there is a serious phosphorus deficit which is expected to be exacerbated by climate change. Heavy precipitation causes phosphorus loss and increases the risk of eutrophication, impairing water quality and transferring phosphate to waterways. Land degradation increases erosion and phosphorus loss. Low soil moisture from climate change reduces the uptake of plant phosphorus; however, it is possible that a rise in the level of CO_2 could counter that effect by increasing the development of mycorrhizal and the uptake of phosphorus.

Extensive agricultural systems are more vulnerable to reduced soil health under climate change. Soils from dry lands, peatlands, delta, flat plains and mountain areas are subject to higher health risks. In dry lands, land degradation is well documented and is expected to become worse. Decreased precipitation leads to a reduction of canopy cover and changes local climates which, in turn, result in an alteration in the level of albedo and cause roughness, evapotranspiration and the release of atmospheric dust. As a further consequence, as erosion increases, nutrients are transported elsewhere and there is a loss of fertility. Global warming also has the potential to change the type of vegetation, shifting it from semi-arid grasslands to shrub land and precipitating the erosion of soil and local decomposition, followed by a loss of soil productivity and weaker soil health.

As a result of climate change, the negative impact of a decline in soil health on crop yields may occur sooner, including areas that are temperate and which practice intensive agriculture systems. In France, where long-term research has taken place, there is evidence of a substantial loss of soil organic carbon, 90 percent of which is caused by the climate scenario and 10 percent by a change in land use. Approximately 25 percent of the total carbon organic stock is lost to climate change. Similar findings have occurred in the state of New South Wales, Australia, although these results vary by location with some areas gaining soil organic carbon and others losing it. This evidence, however, is sensitive to assumptions regarding the level of CO_2 concentration in the atmosphere. When CO_2 concentration in the air is accounted for, some of the carbon is captured in the soil. This suggests a possible role for soils as carbon sequester.

Rising sea levels threaten coastal soil with large deltas in Asia and Egypt particularly vulnerable. Saline water intrusion damages soils in coastal areas and the combination of climate warming and increasing irrigation demand will negatively impact on the quality of water.

The above interactions between climate, soil and land use demand the integration of soil status into the yield gap analysis. Typically this has not been done, though a few studies are starting to fill this gap. In particular, a recent study from China assesses the role of inherent soil productivity (i.e. crop yield gap analysis) in tandem with crop management and climate variables. Another study, undertaken by the International Institute for Applied Systems Analysis, indicates that in the absence of land degradation within the equation, crop yields in temperate regions, such as Germany, improve by 13 percent owing to a global warming of 2 °C. When land degradation is taken into account, however, no significant yield improvement is observed.

1.2.2 Climate, hydrological cycle and water scarcity

Approximately 80 percent of the world's population suffers, to some degree, from water scarcity and many basins around the world are now considered hotspots and water stressed. Climate-induced changes in precipitation directly affect the amount of water entering water basins. Variations in temperature, radiation, humidity and wind speed affect evapotranspiration, resulting in dryer river basins. Most climate change projections show a highly variable spatial distribution of rainfall, with some regions as beneficiaries while others expected to have decreasing rainfall. Moreover, rainfall patterns are predicted to become more variable and extreme. Rising temperatures and enhanced CO_2 concentration are anticipated to raise the level of evapotranspiration to some extent across most latitudes, especially in the northern latitudes.

More intense rainfall indicates increasingly frequent streamflow runoffs and less filtration and groundwater refill. More water is flowing into rivers, but over shorter periods, leading to a greater variance in river regimes, which may have an impact on freshwater fisheries. Changes in snow melt timings as a result of rising temperatures also affect hydrological regimes, exacerbate the relationship between freshwater and groundwater and contribute to water quality degradation.

Modelling the hydrological impacts of climate change remains a challenge owing to the poor quality of water resource data. To date, only scattered observations at particular locations are available, often in the form of intermittent hydrological data series and with incomplete estimates, making it difficult to adequately create a methodology for the construction, calibration and validation of hydrological models. Modelling ground water is even more difficult and often ignored in these models. Given that groundwater is critically important for agricultural water supplies in many parts of the world, this absence causes a serious limitation. A further climate modelling challenge with hydrology is the non-matching scale between local and global. Since AR5, most regional studies project a decrease in water availability as a result of climate change well into the future. Projected food demand increases imply increased demand for irrigation, but global projections based on water supply offer divergent outcomes and irrigation acreage may decrease because of reduced supply.[3] In hotspot regions with acute water scarcity, reduced freshwater in areas that are currently irrigated may indicate that irrigation has to be abandoned altogether.

1.2.3 Climate impacts on ecosystem services: the case of pollinators

Over three-quarters of the world's leading crops rely in part on pollination, with pollinators playing an essential role in ensuring the taste and quality of food. Climate change, together with human-directed causes (Section 2) may result in a loss of pollinator ranges and pollination timing. These changes represent a serious threat to the future of food production.

Pollinators are a diverse group of species, over 200 000 worldwide, many of them wild pollinators and only a small subset managed domestically (e.g., honey bees). Global agriculture relies heavily on pollination and this dependence has increased more than three-fold since the 1960s with wild pollinators playing a far greater role than those that are managed.[4] According to a recent IPBES review, the worldwide economic benefit from pollinators in commercial agriculture is estimated to be over €550 billion *per annum*.[5]

3 Lefleve Xavier (2014); Marshall *et al*. (2015).

4 Inouye *et al.* 2016; see note summaries in Appendix 1.

5 IPBES 2016.

There is increasing agreement among scientists that climate change constitutes a threat to pollinators and scientific evidence to support this is slowly amassing.[6] The threat to wild pollinators for crop production is, indeed, serious. Many species are responding to climate change by shifting upwards and further north in terms of altitude and latitude, respectively.

Studies in Europe demonstrate that by 2100 pollinators are expected to transfer to new areas and that their distribution will diverge from those where fruits and orchard trees are optimally grown. This trend may result in smaller pollinator populations and, hence, smaller crop yields. The migration of pollinators, such as the hummingbird, also is changing as they reportedly migrate sooner than they did heretofore.

Climate change is also causing a timing mismatch between pollinators and crops with evidence that crop flowering and the activities of pollinators occur at different times as a result. For example, having spent the winter underground, bumble bees may emerge either earlier or later in spring so they are unable to pollinate wild flowers when they are in bloom. Studies in the United States reveal a changing phonology of apple tree flowering. In the past, the emergence of bumble bees to pollinate the flowers on apple trees coincided pretty well. But scientists are now predicting an earlier blooming of this flower, a change that will affect pollinators, creating a time gap in pollination and therefore negatively affecting yields. Another problem with flowering apple trees resulting from climate change is earlier flowering, making them susceptible to frost and resulting in a significant crop loss.

Evidence on crop-pollinator dynamics under climate change, so far, is relatively scant. Some studies have alluded to a crop-pollinator mismatch, although most do not. Ecologists, nevertheless, now confirm that there is evidence of a change, for example the fact that bumble bees are evolving in terms of peak numbers and that spatial and temporal developments are occurring and affecting crop pollination. Much less, however, is known about the physiological effect on partners. Crops and pollinators that are close to the thermal limit are seen to perform worse as climate temperatures rise. Pollinators are becoming smaller, live shorter periods and there are fewer plants and blossoms. More research is clearly essential to improve the understanding of such climate-induced physiological changes and the growing threats of reduced pollination services to food production.

Finally, an important gap in the literature is the identification and understanding of cumulative and combined impacts of climate change on species, habitats and communities. While pollinators become extinct, increases in temperature and a shift in moisture regimes are likely to increase the proliferation of various pests and diseases and induce changes in crop pathogens, which further threaten crop-pollinator dynamics.

6 There is also evidence that chemical use on farms is a major threat and may exacerbate the loss of pollinators even more than climate change.

2. Human-directed impacts on food and land-based ecosystems and their implications for food security

2.1 Multiple drivers of land use change: mixed effects on food security

The clear depiction of climate impact on land as a result of human-directed forces is important in terms of food security policy. It also calls for action to achieve mitigation targets, as well as adaptation and resilience objectives.

The human-directed forces of land use and its changes are multiple. These range from population growth and migration, to livelihoods (e.g. income, poverty), access to resources (e.g. land tenure, traditional rights to resource use), market forces (e.g. expansion of commercial agriculture, trade, usage, natural market developments, migration), technologies (e.g. genetic, mechanical), to income-induced alterations in food preferences and diets and economic drivers.

There are important and often complex interactions between many of these drivers whose ramifications are diverse, with sometimes unexpected outcomes in terms of land use and food security. The pressure on land in a country of outmigration, for example, may not be lessened as a result of the migrants' demands for food and rising incomes in a host country. As a result of their rising income, food demand from home countries increases both through trade (with the host country) and higher incomes for households receiving remittances. In fact, the outmigration country may experience a rise in food production and/or food exports. This example illustrates the necessity to adopt a land systems perspective that fully acknowledges the inherent trade-offs and is not tied to a single-indicator perspective, which by itself may not achieve sustainability.

Forest transition (i.e. reversal of agricultural land to forests) is determined by several converging factors. Viet Nam, for example, has reduced deforestation in its highlands through a combination of labour outmigration to more productive and profitable neighbouring rice areas and has provided government support for reforestation.[7] In China urbanization, combined with declining crop profitability, has caused farm outmigration in parallel with an enabling environment from the government to reverse cropland forests. The outmigration in India and Nepal from agriculture, together with a structural change in the economy over the past 10–15 years in terms of government subsidies, have opened new agricultural lands for reforestation.

In arid and semi-arid regions, land use change can arise from a direct production decline and at times lead to desertification. The indirect impact of land use changes is mediated through carbon stock loss, lower water and nutrient cycling and habitat loss. The socio-economic indirect impacts include a rise in food and nutrition insecurity, lower income and increased poverty. A recent study estimated the annual cost of land use changes, in terms of loss of environmental ecosystem services, at around US$230 billion annually.[8] In dry lands, net crop productivity loss has been recorded at between 10 and 30 percent in many areas, especially in parts of Africa, and in Australia, Central Asia, Latin America and the United States as a result of dry land degradation.

Given that a good portion of resource loss from human-directed drivers of land use change is not accounted for in the marketplace, land degradation will continue. In terms of regional impact, Africa loses the most, with estimates putting the annual deficit at 7 percent of gross domestic product, largely because of the loss of forests with high value biomes. Since markets fully internalize these costs (externalities), corrective action of any significance would require a combination of government policy and regulation, complemented with market instruments where appropriate.

In terms of food security, the impact of land use change is mixed not only with opportunities for synergies but also trade-offs. While cropland expansion can increase food production in the short run (e.g. from deforestation), it may come at a high biodiversity cost and ecosystem loss if the crops replace high value biomes (e.g. tropical forests or mangroves). While the potential to help for agricultural intensification is real, it may contribute to deforestation, a fact that is widely acknowledged.[9] Expansion of urbanization comes at the expense of cropland, with estimates of about 4 percent food production loss to urbanization annually by 2030.[10] Nevertheless, urbanization may offer a higher alternative income which improves access to food.

7 Meyfroidt and Lambin. (2008).

8 Nyonka *et al.* (2016).

9 Byerlee *et al.* (2014).

10 D'Amour *et al.* (2016).

2.2 Land degradation and desertification: between human drivers and climate change

The global soil assessment issued in 2015 by the Intergovernmental Technical Panel on Soils (ITPS), as part of the first Plenary Assembly of the Global Soil Partnership, lists several processes that affect land degradation, including soil erosion, decline of soil organic carbon and nutrient imbalance. A recent study documents the important role of temperature on carbon stock in boreal areas, concluding that one degree of additional warmth will result in a significant net loss of soil carbon into the atmosphere.[11]

Desertification is defined under the United Nations Convention to Combat Desertification (UNCCD) as land degradation in arid, semi-arid, and dry, sub-humid areas, climatically defined by their low values (<0.65) in an aridity index: the ratio of long-term mean annual precipitation to the potential evapotranspiration. Desertification results from climatic and human factors. Activities to combat desertification include sustainable land management and soil restoration. As climate changes, so likely will the aridity index values for affected areas.

The recent release of the World Atlas of Desertification by the European Commission[12] highlights a number of drivers that are putting at risk the production basis for food and it features the trends of several land degradation processes. According to this atlas, there is evidence that unsustainable activities by humans cause land degradation, reduce land productivity and extend desertification in several hotspots. Among the responses promoted by ITPS is the endorsement of the World Soil Charter by FAO member countries. This charter seeks to reverse the negative trends and approve voluntary guidelines for sustainable soil management while listing good practices that are directly applicable to all countries.

There are efforts to sustain the intensification of land through various objectives, including food production and meeting climate targets. For example, experiments are taking place in the United States to combine technical and economic approaches that integrate double cropping, reduce idle fallow, develop mechanization and improve degraded land. Likewise, Brazil aims to slow down deforestation in the Amazon through a range of incentives that include technological improvements, enforcement of existing regulations and engagement of those industries concerned (e.g. soybean, livestock). Examples can similarly be cited for other countries, which would be highly useful in order to evaluate the causes and impacts. The conclusion is that there is no single solution that is sufficient either to tackle the multilayered causes and determinants of land use change or to calculate the environmental and economic costs.

2.3 Land degradation in rangelands: causes and consequences

Since rangelands occupy nearly 40 percent of terrestrial surface and livestock from rangeland are the economic backbone for millions of rural people, they will remain an invaluable and irreplaceable source of food, nutrition and income. Rangelands are an important pool of carbon soil and soil-based emissions are relatively limited but not when measured on a ruminant animal basis.

Rangeland degradation is a serious and persistent challenge caused by the transition from pastoral to agropastoral systems, with continuous grazing and increased animal stocking rates often going beyond the capacity of rangelands.[13] Rangelands exhibit loss of diversity and reduced animal productivity, accompanied in some cases by increased desertification. In arid regions, abandoned cropland may be used for animal grazing and become part of rangelands, a process that may be irreversible because of human pressure. Once land changes from cropping to rangeland or vice versa it is difficult to reverse for various reasons including changes in land tenure (with the new owners unwilling to return the land to previous use), induced intensification from human population pressure (which may be reversed unless population declines, say from outmigration). Conversely, any clearance of rangeland for cultivation or mining purposes is a major driver in land degradation. Even if cropland is abandoned rangeland may not easily be restored if its ecological resilience is lost. Moreover, with increasing conservation efforts in tropical forests, rangelands are increasingly

[11] Crowther *et al.* (2016).

[12] European Commission. (2016). EC/JRC. (2016).

[13] There are differing views on this as shown in the substantial literature debate on equilibrium vs non-equilibrium systems (communication from an external reviewer).

targeted for conversion to cropland as they are seen as more or less valuable in environmental terms, in particular climate and biodiversity. Pressure on rangelands for conversion to cropland is likely to increase in the future.[14]

2.4 Human-directed pressures on water resources

Besides climate, there are many human-directed pressures on water resources. With growing population comes a higher demand for food and improved income levels for a larger segment of the world's populations. India and China alone account for close to one billion people in the middle income bracket. This brings with it a change and increase in wider food preferences, in particular, fruit, vegetables and meat products. More water is required for non-food crops, such as biofuels, timber and fibre crops. Besides the urban and industrial demand for water, it is essential for the environment and to support river ecology. Irrigated land is also lost through bad land management and degradation through salinity and water logging. It is clear that the human impact on water resources for agriculture is now far more significant than climate change and likely to remain so for the foreseeable future. Climate change, therefore, exacerbates a pre-existing issue.

Linked to the rise in water demand for irrigation and food production is the challenge of groundwater depletion. This is especially true in dry areas and because of climate change this demand is likely to increase even further, causing underground depletion as seen in California and India. This in turn, will limit the area that can be irrigated, thus creating food insecurity and increasing soil drought.

2.5 Forest loss and recovery and the role of agricultural intensification

Agricultural intensification (AI) does not always reduce deforestation, nor is it promoted solely for forest protection. There are varying factors that determine whether or not agricultural intensification can save forests. According to Borlaug, increasing agricultural yield will reduce pressure on land or the demand for more land, which becomes on the one hand an agricultural argument.[15] But on the other hand, the economic argument is that higher yielding technology makes agriculture more profitable, thus encouraging expansion and placing pressure on forest land and new technologies, while changes in behaviour influence market prices. The same argument applies to the transfer from crops to livestock, with the scope for improving feed efficiency leading to land intensification. Studies from Latin America in 2008 show that farmers tend to expand their land first before increasing their yields if the former is less expensive than the latter (Boeserup's hypothesis).

The outcome from agricultural intensification with respect to forests (i.e. whether trade-offs or synergies dominate) depends on the type of technology used, the input intensity and the level of change in yield. If the new technology is labour intensive, land expansion may be constrained in the absence of sufficient labour. Labour shortages may limit the adoption of conservation agriculture which is labour intensive. Likewise, market forces take effect through product price changes and labour costs (i.e. wages) that result from yield changes, potentially creating incentives or disincentives to expand production and, hence, land use. A question of scale arises, depending on whether the adoption of conservation agriculture takes place. While it may be a win-lose outcome at the local level, it is a win-win outcome at the global level. A study of oil palm shows that while technological progress in Indonesia and Malaysia has caused forest loss in these countries, the decrease in palm oil prices on the world market as a result of supply expansion has saved forests elsewhere.[16] In addition, agricultural intensification is more likely to result in a rebound effect when trade is open and intensification takes place in a region which has comparatively low yields to start with, such as for an African Green Revolution.[17]

14 Searchinger *et al.* (2015).

15 Borlaug, N. (2007).

16 Villoria *et al.* (2014).

17 Villoria *et al.* (2014)..

Certain intensive lowland technologies extract resources from upland agriculture and thus preserve forests.[18] A recent review by Byerlee and colleagues[19] demonstrates a marked difference in impact according to whether intensification is driven by technology or market-driven. On the one hand, technology-driven intensification generally deploys better technologies that are able to reduce cropland areas and, therefore, deforestation. Market-driven intensification, on the other hand, can justify land expansion and the loss of forests. In Viet Nam, for example, the commercial production of coffee has expanded to meet export demand at the expense of forested areas.[20]

Ultimately, changes in technology and the intensification of agriculture may or may not have an effect on deforestation. Nevertheless, where afforestation has succeeded, there is evidence of a combination of factors that include technical, economic and active policy engagement. The issue of agriculture intensification should thus be considered within the context of agricultural practices and not in isolation. It will significantly contribute to and complement other forest conservation measures, adding to their effectiveness and political feasibility. Some of the complementarities include: land use zoning; economic instruments such as those proposed by the previously mentioned TEEB/UNEP study; spatial targeting; and standards and certification. In particular, a comprehensive land based accounting for GHG emissions would take into consideration the potential synergy between agricultural intensification for food production and the offsets provided by forest ecosystem services, contributing to a better understanding of how much productivity can be increased without raising global level GHG emissions.

2.6 Mangroves: a severely threatened high biodiversity biome[21]

Mangroves are immensely important ecosystems and harbour a unique assemblage of aquatic terrestrial biodiversity. Mangroves are a major source of carbon stock with a net primary production among the highest compared with any terrestrial ecosystem. With more than 50 mangrove species and a multitude of fish and shellfish species these unique tidally influenced vegetation systems are biologically diverse. Their multiple ecosystem services are well documented and range from provisioning (fish habitat, wood, fuel, and food), supporting (nutrient cycling and land building) and regulating (pollution, salinity, carbon storage, wave, storm surges, and tsunami) services. With their unique root system and tidal range mangroves can also protect against soil erosion upstream and capture sediments downstream.

The large capacity of mangroves and other blue carbon ecosystems[22] in sequestering atmospheric carbon is due to their high carbon burial rates, which are around 20 times higher than any terrestrial ecosystems. Therefore, the carbon stocks in the mangrove ecosystem is as much as four times higher compared to other terrestrial ecosystem.[23]

Globally mangroves cover an area of around 14 million hectares in more than 30 countries, mainly in the tropics. Mangroves and other coastal ecosystems are facing tremendous pressure due to land use change for aquaculture, agriculture and infrastructure development. The world's mangrove has lost more than 40 percent in the past 30 years.[24] Mangrove deforestation potentially costs up to US$40 billion *per annum*.

The implications of mangrove deforestation are multiple. The most immediate one is GHG emissions. The rate is staggering as it is estimated to range between 0.02 and 0.21 Pg annually. This amount represents 10 percent of emissions from deforestation globally, even though mangroves account for just 0.7 percent of tropical forest area. Mangrove deforestation with regeneration has another disadvantage: the potential re-introduction of mono-species and substantial reduction of species diversity in all coastal settings. As a result, aquatic biota will be tremendously affected as the nutrient cycling is altered.

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18 Mayfroidt (2013).

19 Byerlee *et al.* (2014).

20 Meyfroidt, Vu, and Hoang. (2013).

21 Forest carbon dynamics from deforestation and afforestation are not addressed in detail at this expert meeting given the limited time and the broad agenda.

22 UNEP. (2014).

23 Alongi. (2014); Donato *et al.* (2011).

24 FAO. (2007).

Food security in the context of a coastal community is closely related to the sustainability of fish production. Unless ponds or farms receive high inputs, it is unlikely the current supply can be maintained. A new finding in Southeast Asia, which has most of the world's mangroves, confirms that food production and security are associated with mangrove conversions to aquaculture, oil palm and rice production.

Managing mangrove and other coastal wetland ecosystems, through conservation and rehabilitation, should consider the human dimension vis-à-vis multi-stakeholder objectives and biodiversity. Designing viable alternative livelihoods for the local communities that depend on mangroves for food, income and their livelihoods should be a top priority in any intervention aimed at preserving mangroves and their multiple ecosystem services, including carbon sinks. Working with the local community, embracing their agenda and understanding mangrove hydrology are all key ingredients to the success of mangrove restoration.

3. Greenhouse gas fluxes from agriculture and land systems: a scoping of mitigation options

3.1 Trends in greenhouse gas emissions from agriculture, forestry and other land uses

There are two types of emission associated with crop and livestock production: those that relate to land clearings to expand production for new markets; and those that relate to production and management practices. Most deforestation and the conversion of natural ecosystems take place as a result of agriculture expansion. Emissions from such activities amount to between 8.4 to 10.3 gigatonnes of CO_2 *per annum*. Gas emissions that relate to agricultural production are dominated by non-CO_2 gases, mostly from agricultural soils, enteric fermentation, manure management and rice cultivation. The AR5 uses four data sources for emissions relating to the agriculture, forestry and other land use sector,[25] and trends across these are consistent. Regional trends show a rise in gas emissions in South Asia, Southeast Asia, Latin America and sub-Saharan Africa, with the largest increase from soils and enteric fermentation. In Eastern Europe, Western Europe and North America, there is evidence of stabilization or a slight decline in agricultural emissions. Various opportunities to reduce net GHG emissions from land use present themselves, notably as a result of agriculture and livestock management, sequestration of organic carbon in pastoral systems and agroforestry.

There are several emissions hotspots in the world, typically tied to livestock (including enteric fermentation and manure management emissions), forests (including emissions from fires, deforestation and wood harvesting), and crops (including paddy rice, cropland soil, and croplands over drained histosols). Emissions are elevated around the Congo Basin (deforestation and livestock), in the Rift Valley (livestock) and in South Asia and Southeast Asia (rice paddies). In the southeastern part of South America and on the Indo-Gangetic Plain, there are crop-related emissions. Emissions intrinsic to soils are found in the Midwestern United States, Western Europe, parts of South Asia and part of East Asia, where fertilizer and manure applications are significant as a consequence of the rapid growth in meat and dairy consumption during the last four decades. While all types of meat consumption are increasing, monogastrics such as pork and poultry show the strongest rise. Unlike ruminants, emissions associated with monogastrics depend primarily on manure management.

There are also significant mitigation hotspots linked to cropping systems that may be geographically localised but nevertheless significant. One such example is the burning of cereal residues in Indo-Gangetic Plains where ca.90 million tonnes of surplus cereal residues are burned on-farm annually.[26] On a global scale, total crop residues burned are quite significant with implications not only for GHG emissions but also public health concerns. In India's Punjab province, according to one study, about 20 million tonnes of rice and wheat residues out of a total of 37 million tonnes are burned in situ annually, leading to a loss of about 8 million tonnes of carbon equivalent to a CO_2 load of about 29 million tonnes per year and a loss of about 1×105 tonnes of nitrogen, in addition to the loss of sulphur and the destruction of beneficial microflora in the soil[27] with major implications for soil quality and nutrient use efficiency.[28]

A number of new findings in land use and agriculture are evident. For example, a recent study[29] shows a high loss of soil carbon, especially at northern latitudes. The research also indicates that the soil carbon content in some tropical soils may be increasing, although the dataset applied in the model relates to the temperate zone. There is also evidence that the rate of carbon emissions differs depending on the period required to stabilize organic matter levels under the 1°C warming scenario.[30]

Organic soils, including peatlands, are known to have high CO_2 emissions. Approximately 25 million ha of peatland have been drained across the globe, 60 percent in boreal and cool temperate regions, 5 percent in warm temperate regions and 34 percent in the tropics, mostly in Southeast Asia. These soils contribute nearly a billion tonnes of CO_2 equivalent emissions (85 percent as CO_2). In addition, fire fertilization of these soils creates further emissions.

25 Two data sets are from the United States Environmental Protection Agency, Edgar and the FAO database.

26 This paragraph is based on a communication from Clare Sterling of CIMMYT, one of the external reviewers.

27 Singh and Sidhu. 2014.

28 Jat *et al.* (2014).

29 Crowther *et al.* 2016; ibid.

30 If carbon stabilizes immediately, it is in the order of 30–50 petagrams compared with 200 petagrams if the flow takes more than 30 years to stabilize

Aquaculture produces over 55 million tonnes of fish and shellfish annually, generating high amounts of nitrous oxide emissions. These emissions are predicted to make up approximately 6 percent of anthropogenic nitrous oxide emissions by 2030, representing a major new source of gas to monitor. Likewise, the expansion of shrimp culture has resulted in a significant loss of mangroves (approximately 38 percent) where massive amounts of carbon are stored in the sediments, more than any forest ecosystem in the world. This loss is the most rapid of any type of forest in the world, in some cases, in the order of 2–7 percent *per annum*.

A key characteristic relatively neglected in GHG emission measurements is the processing of food. To date there are very few studies that analyse emissions throughout the entire food supply chain. A life cycle analysis from the United Kingdom divides up the emissions along the supply chain assigning 40 percent to food production and 30 percent to transport, packaging and processing, both largely derived from the use of fossil energy, with production being less energy intensive than processing. These results are likely to differ depending on the type of food and how it is produced. As a general rule, food products derived from livestock will tend to have a greater proportion of life cycle emissions at the production stage, whereas horticultural products would have a greater proportion of lifecycle emissions from the transportation and processing end. But to date, there are no global reviews that fully quantify GHG emissions along the food supply chain, suggesting a critical gap in knowledge.

3.2 Mitigation targets of a 1.5 °C world require negative emissions

The Paris Agreement includes the Bio-Energy with Carbon Capture and Storage (BECCS) incentive, a new technology that removes carbon dioxide from the atmosphere by way of biomass conversion technologies and stores it underground. The inclusion of this factor suggests that it is, indeed, feasible to keep the world warming increase below 1.5 °C . Whether it is realistic to consider BECCS or not is yet unclear. Major research efforts will take place over the coming years to elucidate the problem. Proposed by the International Institute for Applied Systems Analysis as a result of biosphere analyses that revealed unexpectedly higher amounts of emissions as a result of forest fires and methane gas, among others, BECCS aims to sequester such gases. While BECCS is not a typical (or easily accessible) mitigation technology, integrated assessment modelers have relied on it to identify ways to achieve 1.5 o C warming worldwide.

What is clear is that in order to achieve 1.5 ° or 2.0 °C global warming, some type of negative emissions are necessary, and BECCS may provide an exceptional solution. One potential course of action lies within the land use sector whereby carbon sequestration can take place through wood burial or similar. Alternatively, the trend of increasing greening activities may be beneficial, although this may cause a reversal in emissions in terms of the magnitude of reforestation and ecological restoration. Finally, it is not clear whether BECCS would have potentially negative consequences for food security.

3.3 Soil carbon sequestration: potential and mitigation options

Soil carbon balance relies on the removal from the atmosphere of CO_2 by way of photosynthesis and its incorporation into the plant. A residue then forms, which enters the soil and returns into the atmosphere as CO_2 by way of heterotrophic respiration. Soil carbon sequestration (SCS) is simply the management of the soil carbon balance, which is effected by increasing the amount of plant residues that go into the soil and increasing the soil's organic matter. It is possible, through conservation agriculture, to reduce the rate of heterotrophic (soil) respiration which releases CO_2 into the atmosphere. The duration of SCS is finite as the soil's organic carbon balance tends to tilt towards equilibrium point. Once SCS has been saturated, little more carbon can be sequestered, despite additional amounts of carbon in the soil (with the exception of peat soils, which are organic).

There are various ways to achieve a rise in the soil carbon balance. These include conservation, no-till and converting land back to forests. The potential for GHG mitigation from soil carbon is the subject of debate in the literature. A white paper, issued by the Rodale Institute of Pennsylvania[31] reports that if the world's agriculture were to shift to organic methods, the amount of carbon sequestration would be equivalent to total fossil fuel emissions. The potential for carbon sequestration depends on the area of the land, as well as the practices that are adopted, some of which rate

[31] Rodale Institute. (2014).

highly but relate only to small land areas. Other practices are able to cover broad strips of land, although the gain in carbon sequestration is relatively small.[32]

To develop reliable metrics that allow for the quantification and verification of emission reductions and SCS is a major challenge. The difficulty in terms of land use is that the sources and sinks of soil produce a non-point source emission, and are spatially and temporally variable. Moreover, it is essential that these metrics be applied by decision-makers, including not only scientists, but also farmers and land managers. While the current knowledge base is extensive, particularly in developed countries, gathering information and establishing monitoring networks are essential to identify and measure soil carbon alterations. The technical capacity by way of remote sensing and soil mapping is much broader; however, the sources of relevant data should be centralized, together with improved scientific and technological models. Engagement with land users is critical to develop support systems that enable policy intervention, create carbon offset markets and manage supply chains.

3.4 Mitigation options in agriculture and land-based ecosystems

3.4.1 Rice production[33]

Rice is a crop that is flooded for much of the season, creating anaerobic conditions that lead to substantial methane emissions. GHG emissions can be reduced by: changing the water regime; reducing flooding periods; and a shorter season rice (i.e. 90–100 days compared with 140–160 days) that reduces the time flooring, resulting in fewer GHG emissions. Rice research at IRRI focuses on improved irrigation techniques that will reduce emissions, such as alternate wetting and drying. IRRI researchers are analysing ways in which to scale up alternate wetting and drying techniques and convince farmers of their benefits. While the technology is simple, its adoption has not been straightforward. The major challenge lies in the policy and institutional environment as well as market conditions, rather than in the technology. The absence of economic incentives for farmers to adopt a labour-intensive activity that requires pumping water, when water is available for free in many places, makes it difficult. Were there a cost for the water used in production, farmers would then have a reason to save it by embracing the technique of alternate wetting and drying. For now, the benefit of mitigation alone does not justify the practice enough for farmers to adopt it.

Another technology with potential mitigation advantages is the use of site-specific nutrient management to reduce the application of fertilizer in rice. IRRI has developed a mobile phone application, the Rice Crop Manager Advisory Service, which provides farmers with a personalized crop and nutrient management guidelines, including the type of nutrients to use, field preparation, crop establishment and pest management. The app has a module that estimates GHG emissions and offers a climate forecaster and certain warning systems on salinity in coastal zones.

Post-harvest techniques include mechanized alternatives to incorporating burnt straw into the soil to reduce methane and nitrous oxide emissions. Straw can act as fire fuel in cooking stoves, forming a biochar by-product that can be used to fertilize the soil and reduce methane gas the following season. Cooking stove technology, however, is under development and the uptake has not yet been wide.

IRRI is also exploring the gelatinization temperature of rice – this determines the cooking time for any particular variety. Rice varieties that take less time and energy emit fewer GHG. Creating such opportunities for abatement on the consumer side will expand the options for mitigation along the food supply chain.

3.4.2 Livestock and rangeland

Emissions from livestock are of two types: enteric methane (40 percent of total livestock emissions on average) and manure management (nitrous oxide and methane). Both sources are natural processes that are difficult to control and are expected to increase as a result of population growth and diets changing in favour of animal protein. In many developing countries, food security, poverty alleviation, climate change adaptation and general improvements in

32 It is estimated that between 4 petagrams and 8 petagrams of CO_2 equivalent *per annum* over approximately a 20–25 year period would be feasible as a total technical potential (i.e. equivalent to 20 percent of current global emissions in terms of carbon dioxide). The case for achieving this was published by P. Smith and colleagues in the 2007 Fourth Assessment Report.

33 Mitigation options from agricultural soils linked to crops other than rice are equally important but were not discussed in detail at the EM because of the limited time assigned to mitigation. However, the supplemental citation list in the Appendix includes a section on NO2 emissions from fertilizer use in other crops.

economic performance take precedence over GHG mitigation. In developed countries too, GHG mitigation is attractive to farmers only if it can be combined with improved animal productivity and farm efficiency. This includes improved methods of feeding, superior genetics, enhanced animal health, better fertilizer and alternative grazing practices. In New Zealand, dairy farmers have reduced emission intensity but production has outpaced those improved emissions, resulting in a net GHG increase from the sector.

It is evident that alternative innovative technologies are required to decrease net GHG emissions. Substantial research and pilot tests are being carried out by the Global Research Alliance relating to best practices for animal feed and nutrition, animal genetics and breeding and rumen modification. Substantial information is available on dietary changes to reduce methane (e.g. lipids, cereals, sugar concentration), all of which have a modestly positive effect, although the long-term effects remain unknown. The key challenge, however, verified by a small number of farmers who have adopted such measures, is the practicality and economics of the technology. To induce farmers to adopt innovative technologies with mitigation co-benefits, it is essential to demonstrate their economic benefits in the form of productivity and long-run profitability potential. Mitigation benefits in the form of reduced emissions alone are not enough to secure farmers buy in.[34]

There are limited options to reduce emissions from livestock in rangelands, unless animal stocks are limited which, in turn, will negatively affect household incomes, especially those of the poor. There are few options to reduce methane by the live weight gain of ruminant animals through better flock management or improved feed quality. One option is to reduce the breeding herd overhead (i.e. number of non-producing animals needed to sustain the herd) and introduce improvements to animal health, husbandry and forage quality to bring down mortality rates and increase fertility. Another option would be to restore degraded rangelands and as such increase the availability of feed and thus livestock productivity. Such intervention would need to go hand-in-hand with incentives to keep animal numbers low. A major source of GHG emissions in rangelands of the savannah is the burning of savannah grass, a tradition that is practiced to improve the quality of the land. This practice, however, produces methane and nitrous oxide and its control has the potential to mitigate them. A change in the mix of animals is an alternative that comes with co-benefits. Replacing cattle with sheep, goats or camels, which are more adaptive to drought conditions, may provide a win-win solution for informal livelihood protection and emissions sequestration.[35]

[34] Other potential technologies on the far horizon currently being explored include modification of the rumen environment as a means to control the microbial process within the rumen in order to reduce GHG emissions from enteric methane. Evidence shows that by using certain chemicals, the micro-organism processes that produce methane can be slowed down or eliminated. Another option is the use of a vaccine, given that animals are able to produce antibodies against the bacteria present in the rumen, suppressing their activity. Yet a further alternative is to breed low-methane animals, which takes time.

[35] ICARDA produced a two volume encyclopaedia on the indigenous breeds of small ruminants that easily adapt to environmental changes.

4. Adaptation and resilience in food and land-based ecosystems

Unlike mitigation, which has the advantage of a clearly defined metric (GHG emissions), adaptation to climate change is a more difficult concept to tackle, with many possible entry points, different scales and diverse options and outcomes. In this section, adaptation is discussed along specific themes covered in the EM with a view to drawing direct and indirect implications for food security as a cross-cutting concern. As a general observation, discussing the implications of adaptation for food security requires us to make different distinctions. The first is to separate out the different food security dimensions (availability, access, utilisation and stability). The second is to distinguish between adaptation impacts on aggregate metrics (food production, net trade, aggregate freshwater availability etc.) vs local-based indicators (or measures) affecting food security for individuals, households and communities, especially among the poor and food insecure

4.1 Restoring soil ecosystem systems

Soil provides a wide variety of ecosystem services that have an important role in the supply of food and provision of water and nutrients. They act to retain land surface, prevent erosion and transform and accumulate organic matter. The World's Soil Resource Report, released in December 2015 by the Intergovernmental Technical Panel on Soils, identifies ten major threats to soil functions and soil-mediated ecosystem services.[36] These threats are topped by soil erosion which, alone, will generate a global average loss of approximately 0.3 percent of annual crop yield and a total yield loss potential of 10 per cent up to 2050, a reversible gradual loss of productivity every year, worldwide.

Soil erosion impacts negatively on the quality of water which, in many regions, may be more severe than soil productivity effects. Land at risk of abandonment due to human-induced changes in soil function was documented in a 1991 study by the Global Assessment of Human-induced Soil Degradation based on data from the 1980s. A more current assessment should be undertaken, incorporating the land that is at risk under regional climate change scenarios.

In terms of soil management, no-till farming has been the most widely adopted practice to tackle soil erosion. In 2009, no-till farming covered approximately 111 million ha. Compared with conventional practices, it reduces the loss of soil by 60 percent in temperate climates and by up to 99 percent when combined with contour planting in both humid and sub-humid regions.[37] No-till farming also lessens the chance of runoff and is shown to have improved yields by 20 - 30 percent over the last 30 years in arid and semi-arid areas such as Morocco.

There are several reasons for the high uptake of conservation agriculture in North America. One reason behind the adoption of no-till is largely due to the rapid and massive adoption of genetically modified herbicide-tolerant soybeans (and later corn), starting in the mid-1990s. Another reason was economics and cost savings by using less fossil fuel. In Africa, there may be less push for adopting conservation agriculture, when viewed as a fossil-energy saving practice given the lower degree of mechanization in the continent. In Europe, conservation agriculture and reduced tillage are not actively promoted because of the extensive need for chemicals and herbicides to control weeds, particularly with glyphosate and related products. This comes at a high price and is not particularly encouraged by the European Commission. In Brazil, however, presently with approximately 17 million ha under no-till farming, adoption of conservation agriculture not only reversed massive soil degradation, but reduced production risks and increased flexibility in the timing of the operations. Both conventional and no-till farming need herbicides, but because mulching provides weed suppression no-till farming has great potential to diminish the use of herbicides. Nevertheless, more research is needed to advance conservation agriculture, particularly concerning weed management as the possibilities for organic no-till farming on any scale is a significant challenge.

Two conclusions arise regarding soil management practices to control erosion. The first is that no-till farming reduces the need for water and prevents soil erosion in temperate, tropical and sub-tropical regions. The second conclusion relates to integrated landscape management which, together with sustainable intensification, tackles soil erosion and manages water at the watershed level. Integrated landscape management is complex, multi-purpose and will depend on the active engagement and implementation by the individual landholder or farmer. Overall, no-till does offer benefits for climate adaptation, although its contribution to climate mitigation continues to be debated.[38]

[36] The ten threats are soil erosion, biodiversity loss, soil compaction, soil salinization, waterlogging, soil acidification, soil contamination, soil sealing, nutrient imbalance and soil organic matter loss.

[37] Moraes *et al.* (2016).

[38] Powlson *et al*. (2014; 2015); Sommer and Bossio (2014).

4.2 Adaptation to water scarcity and equitable access to water

While they are context specific, there are many adaptation options for water scarcity. On the supply side, water provision can be increased by investing in water harvesting and storage infrastructures. Opportunities also lie in better waste management practices and water productivity ("more crop per drop"). Boosting water use efficiency, however, may be counterproductive if the same amount of water is consumed simply because there is more of it (Jevons paradox). Therefore, a combination of raising water productivity and implementing good governance is required to cap the total use of water for irrigation. Since water has multidimensional properties, no single policy or economic stance will respond to the issue of water scarcity. The use of market instruments to manage water demand is still hotly debated and the challenge remains how to trade and price water both equitably and sustainably. The demand and supply of scarce water requires an interdisciplinary approach where both economic and non-economic instruments have a role to play. Moreover, there is a strong need for political will and inclusive governance, given the vital nature of water and the rising competition for a resource that is becoming scarce.

An important principle in water scarcity policy is the equitable distribution of the resource among primary users. The lack of sufficient water is exacerbated by climate change, calling for an institutional framework for its equitable allocation, especially in instances of drought and acute water shortage. Iglesias and colleagues[39] have developed such a framework that incorporates the need to assess climatic hazards and attempts to understand the underlying measures of vulnerability (i.e. resilience and adaptive capacity). Many overlapping policies will affect the ways in which drought and aridity are tackled, and in the case of structural water imbalance – in terms of supply and demand – the outcome may exacerbate desertification. A case in point is Lake Urmia in Iran. Once this framework becomes operational, other users including non-agricultural users, will need to be taken into account. Various indicators, therefore, are applied to include the drought vulnerability index (e.g. Mediterranean countries) and the social capacity to respond to drought. The framework distinguishes between permanent measures (i.e. water policy, technology) and those that are implemented during pre-alert (i.e. voluntary) and alert situations (i.e. including the necessary economic instruments and tariffs) required for quick and effective water distribution in an emergency situation. The methodology was applied to examine the distribution of water for various users in Iran.

Permanent measures include the value of information, technology (e.g. desalinization), aquifer management, policy (some are being developed in Europe to incorporate drought management into climate change) and economic instruments such as Spain's efficient water markets, to be replicated in Jordan. Overall, the critical steps necessary to develop a strategic plan in response to scarce water begin with: the establishment of a multidisciplinary team; evaluation of the risks and vulnerabilities; and identification of priority measures and how to include them into policy-making. Throughout the process, it is essential to engage actively with stakeholders, water users and other beneficiaries in order to achieve strategy objectives.

The Adaptation of African Agriculture initiative, launched by Morocco at COP22 in Marrakesh, aims to develop projects that combine the sustainable management of soil resources (i.e. improved soil fertility; increased soil carbon sequestration; conversion of annual crops into fruit trees and agroforestry); efficient water management (i.e. using proven methods); climate risk management (i.e. including agriculture insurance and early warning systems); and access by small farmers to best practices in agro-ecology and to finance.

4.3 Adaptation to pollination loss

The preservation and protection of pollination services under climate change is critical for global food security. As it is expected climate change will create a mismatch between pollinators and fruit trees and orchards, a consideration is to integrate natural areas (i.e. non-disturbed and non-tilled) within crop landscapes, encompassing the trees (i.e. ecological intensification). Natural areas also are necessary for the nesting of wild pollinators. Ecological intensification can prove to be economically viable as, for example, in Canada where the production yield of canola has increased and profits have improved by incorporating 30 percent of uncultivated land (where pollinators could thrive) with a strip up to 750 metres around the edges of the field.

[39] Iglesias *et al.* (2008).

More broadly, adaptation to the threats to pollination services posed by climate change requires a shift in crop management practices, from the farm level to the level of landscape. This implies the integration of ecological intensification (e.g. adding flower-rich field margins) to cropping and the strengthening of diverse farming systems (e.g. crop rotation, home gardening and agroforestry). Investment in the ecological infrastructure is also essential (i.e. medium-size patches of natural areas within or around farms and linear elements that bind them together). The benefits of landscape diversity can be drawn from comparisons between organic and conventional agriculture, the former demonstrates a 50 percent increase in the abundance of bees and organic bee richness compared to the latter.

It is important to provide an appropriate habitat and feeding resources for bees to ensure there are enough to pollinate crops, as evidenced by the critical role played by wild pollinators in food production. Many bumble bee species in Europe and North America are either threatened or considered an endangered species. Nevertheless, best practices may not succeed in the absence of alternatives to chemical pesticides and the biological control methods that will either reduce reliance on chemicals or act as a substitute.

4.4 Initiatives in addressing land degradation

Land degradation is a major concern for many land-based ecosystems around the globe and the continued loss of soil functions is associated with a decline in net land productivity and hence, a threat to the future of food provision and security. During Rio +20 Conference, the Land Degradation Neutrality (LDN) concept was proposed by UNCCD as a response to rising concerns about net land degradation. LDN aims to give form to a common understanding to "sustain and improve the stock of land and natural capital and the associated flows of ecosystem services in order to support the future prosperity and security of human kind". LDN promotes a dual-pronged approach of measures to avoid or reduce degradation of land, combined with measures to reverse past degradation.

The UNCCD Science Policy Interface (SPI) facilitated the LDN concept through a framework that seeks to understand the forces that affect land, assess the impacts and define responses to deliver land degradation neutrality by 2030, complementing Sustainable Development Goal 15.3. In terms of land ecosystem services, three indicators (land cover change, net primary productivity and soil organic carbon) were developed by the UNCCD-SPI to monitor LDN. Under this framework, LDN is considered achieved if the three indicators either improve or remain the same in 2030. In addition, site-specific indicators relevant to a particular location or country are included (e.g., presence of heavy metal contamination). Finally, given that some of the changes will take longer to occur (e.g. building soil carbon stock), process indicators have been introduced to measure actions taken.

There are several ways to reverse land degradation and the loss of ecosystem services, caused either by climate change or human-directed drivers. Sustainable land management can reduce or reverse land degradation, depending on the initial condition and intensity of practices. While some responses may be either technical or agronomic (i.e. agroforestry, integrated water and soil and nutrient management), others will require innovative economic instruments to mobilize the full force of markets in support of sensible environmental services and to internalize the cost of resources that enter and leave the land-water-food-energy system. (See later discussion on the advantages and disadvantages of payments for environmental services in Section 5.1.) Forging sustainable land use policies will necessitate a convincing economic case for valuing land and providing appropriate economic value to ecosystem services besides food production. An appropriate economic valuation of land and ecosystem services will yield valid incentives for land users and the private sector actors that are essential to scale up successful interventions.

To the extent that sustainable land management is at the core of the LDN it also contributes to climate change adaptation. However, the literature linking LDN to adaptation is scant apart from specific cases such as the greening of the Sahel in order to reverse its desertification and land degradation, which may be considered "climate-smart". Given that there are substantial areas of rangeland being degraded as a result of intensive grazing, it indicates how essential is sustainable grazing management and support for scientific evidence to develop best practices and policies. South America, for example, is experimenting with the simple subdivision of large areas in an effort to control grazing and halt overgrazing or undergrazing. Results show that such practices can improve animal performance and raise soil carbon sequestration. CGIAR's Climate Change, Agriculture and Food Security (CCAFS) is also testing – through its network of Climate-Smart Villages programme – a range of grazing and livestock feeding options that combine forage sources, the grazing system and various animal breeds.

Remedial actions to restore land degradation in the rangelands are quite varied. If the system remains fairly resilient, short-term protection measures (e.g. land scarification of the surface and water harvesting) may be beneficial and improve filtration. One option is to rehabilitate more severely degraded land but this is costly; another is to reallocate and change plant species within the system. A further option that has proved successful is to introduce new plants (e.g. cactus) that are more adaptable and resilient under harsher and drier conditions. Restoration also includes protection measures, such as building fences around rangelands and allowing them to re-establish. Such measures should be carefully designed to include social and land-use rights considerations.

Water harvesting techniques are critical in the restoration of rangelands and for improving land productivity. Water infiltration can be improved by simple methods such as scarifying the surface of land that captures rain water in dry lands and improves plant establishment. Various alternatives are available to create water harvesting structures, some of which are traditional techniques. Conservation has been surprisingly successful in dry land areas, generating significant and consistent yield increases over time as a consequence of improved water preservation. Such efforts in Central Asia have doubled crop production.

The need to combine bottom-up with top-down approaches while working from the middle, where real world challenges can be fully addressed, is evident. Furthermore, the variety of technical and economic responses (i.e. inter-disciplinary) should be integral. While there is no shortage of technical solutions, the most difficult undertaking is the uptake by farmers, which will call for recognition of socio-economic factors. Participatory approaches and inclusive decision-making is key to identifying and implementing win-win solutions for multiple stakeholders with divergent views. When scaling up successful pilot programmes, such as the introduction of new adaptable breeds, the joint participation of civil society and the private/industry sector is critical. Neither is able to respond to such challenges fully or sustainably on its own.

Innovative approaches and frameworks are essential to scale up pilot initiatives and combine land restoration with new economic and job opportunities for youth, especially in developing countries. For this to occur, a judicious combination of government policies and regulations, improved governance (i.e. multi-stakeholder participation in decision-making) and appropriate market instruments (i.e. incentives and disincentives) to effect change are indispensable. For the scientific community, this calls for improved dialogue across disciplines (i.e. between economists and ecologists) and the rapprochement of perspectives between environmental and agricultural economists, each of whom continue to work in isolation from each other.

4.5 Agricultural intensification, diversification and other practices

Sustainable intensification is defined as an increase in food production on existing farmland in ways that do not harm the environment while securing continued food production into the future. Examples of sustainable intensification include crop-livestock integration, conservation agriculture, intercropping systems, agroforestry and ways to improve water harvesting. Many sustainable intensification practices improve productivity and resource use efficiency and reduce yield variability, at least under current climate conditions. It is evident that the increase in productivity is substantial within an experimental setting, although its success largely hinges on available resources such as land, livestock, organic resources, crop residue and especially labour.

In sub-Saharan Africa, large household datasets indicate that the variables most associated with the uptake by farmers of intensification are farm (land), livestock and family size (labour). The same study showed that by doubling productivity, the most food-insecure households with limited resources are still less likely to respond proportionally. For mixed crop-livestock systems, a more efficient approach to raise the food security for poor households would be by way of off-farm incomes. For such poor households, only 2–7 percent will be relieved of food insecurity with a 50 percent increase in cereal yield.

In Africa, the gross margins for most small farmers decrease with the projected yield decline of major crops. In one particular study maize yield drops by 30 percent (to take the average climate crop yield impacts reported for Africa in the literature) under climate change[40] and predicted changes in market prices in the absence of adaptation are also taken into the equation. Were farmers to adapt and intensify, however, they may be able to compensate for the decline

[40] See Mark Van Wijk, Appendix 2

in yield. Similar trends are taking place with regard to sorghum-millet, although the loss in yield is smaller as a result of climate change. While many farmers may profit from market price developments, others who are more resource-poor are unable to fully compensate for the decline. Productivity gains from agricultural intensification may not be advantageous to the poorest farmers in sub-Saharan Africa, nor in other developing countries with similar production conditions. While the negative effects of climate change may be overcome to some extent by increased market opportunities for intensification by way of higher prices, this may not always be the case. To focus only on improving major crop yields in Africa within the climate change scenario will be a cost to the smallholder household.

Crop diversification and crop-livestock mixing are alternative approaches that can offer benefits in terms of higher productivity and resilience for small-scale producers. This includes resorting to multiple cropping, reintroduction of local varieties and expanding the genetic diversity within a landscape environment. Genetic diversity (plants and animals) is a key to adaptation and resilience in farming, whereby the crop diversity loss that agriculture has experienced around the world in the last century can be reversed. Expanding this diversity within a landscape that embraces the mixing of several crop varieties within the same field will reduce agriculture risks and deter crop failure, both of which are expected to rise under climate change. In Guangxi, southwest China, maize landraces survived the severe 2010 spring drought, while maize hybrids did not.[41] Crop genetic diversification requires placing greater value on traditional knowledge – a source for most agro-ecological farming practices.

An important empirical question is how to ensure that agricultural practices that enhance productivity and income for growers (e.g. conservation agriculture or agricultural intensification) also provide adaptation and/or mitigation benefits. Evidence from the field indicates that these practices fall into the climate-smart category within a specific context while varying widely from case to case. Based on research from CGIAR-CCAFS of the literature on climate-smart practices, it was found that there are rare cases that combine the three objectives (productivity, adaptation and mitigation) and few cases of productivity with either adaptation or mitigation.[42] The review found that studies that addressed both productivity and resilience counted for 56 percent of those examined showing synergies, while 40 percent showed trade-offs. The study also reported that practices with the highest potential for impact in terms of adaptation or mitigation (i.e. organic fertilizer use) tend to have low adoption rates. Conversely, simple practices such as intercropping have adoption potential, although at a lower rate of effect on climate change mitigation or adaptation.

4.6 Adaptation and resilience options for livestock systems

Livestock is important in terms of resilience, especially in the dry lands. Among the traditional strategies applied by herders is livestock mobility across zones in relation to feed availability. Likewise, adjustments to herd stocking rates can buffer against climate variability impacts on feed and biomass availability. Developing policies for livestock, however, requires context-specific evidence that integrates biophysical influences with socio-economic vulnerability assessments to ensure system sensitivity and the underlying capacity to cope are properly matched with the actual climate change impacts within the agro-ecological context.

There are a number of adaptation options that require validation within a particular context, from the socio-economic to the policy environment. Technical interventions to support adaptation include genetic improvement, animal health or better feeding interventions and improved feed quality. Adaptation interventions may also incorporate land restoration to increase production of feeds and forages. Interventions at the landscape level may include the diversification of production, shifting between plant species (e.g. Brachiara grass for sub-humid Eastern Africa)[43] or even production systems (e.g. a shift from cattle to small ruminants). The crop-livestock system combines co-benefits for adaptation and mitigation by way of the judicious exploitation of crop residues and manure. To ensure successful farmer uptake, however, both existing and new technologies that integrate better within existing farming and livelihood systems, undoubtedly require institutional and policy reforms, as well as market-based instruments such as insurance schemes and other appropriate financial instruments.

41 IIED Brief. December 2016.

42 Rosenstock *et al.* (2016).

43 A comprehensive review of drought-tolerant grasses suitable for dry land areas would fill an important knowledge gap. Likewise, no good review exists that quantifies the role of forage legumes and the implications for nitrogen production in the soil for grassland systems in tropical, sub-tropical and temperate areas.

4.7 Adaptation and coping mechanisms in aquaculture and inland fisheries

Aquaculture and inland fisheries are vulnerable to catastrophic climate conditions, often resulting in severe loss of stock and infrastructure. Moreover, adaptation responses to climate change and extreme events (floods and droughts) can only be context-specific and vary for each production cluster. In Viet Nam's Mekong catfish farms, the lower regions are affected by sea level rise plus changes to flow and the most feasible adaptation is to cultivate salinity-tolerant strains of catfish. Likewise, the Amazon Basin in Brazil and Peru is impacted by climate change and native fish ponds, such as those for exotic tilapia, may suffer from water scarcity, while others are hit by more frequent flooding. In this system, feasible adaptations may include appropriate spatial planning and insurance schemes for small-scale farms. These, however, are more short-term coping mechanisms rather than adaptation measures. Possible adaption or coping measures include: (i) reducing exposure of inland fishing to overfishing; (ii) encouraging exploration of hidden or unexploited species; (iii) and better planning and management practices that include biosecurity.

To address climate adaptation strategically, climate impact and vulnerability assessments are necessary, while fishing practices need to be integrated within water management strategies, taking an entire farming system perspective (e.g. rice-fish, rice-shrimp). Vulnerability assessment and adaptation plans for aquaculture and inland fisheries must be tailored depending on local and national scale. Also critical is the integration of the combined effects of multiple stresses on species, habitats and communities.

5. Policies for land use, sustainable food production and consumption and climate action

5.1 Policies that relate to resource management, climate responses, and food security

Policies that relate to land and other ecosystems to support food supply under climate change must target multiple, often overlapping and sometimes conflicting objectives simultaneously. Meeting policy objectives such as resource conservation, restoration of ecosystem services, land, water and food productivity and food security often require simultaneous and coordinated strategies and it is not always evident that the right approaches, frameworks and mechanisms are fully developed. In parallel to policymaking, a reliance on maximizing private profits also has limits as demonstrated by market failures and the increasing relevance of ecosystem services that fall outside the market system. Market failures in turn provide the impetus for policy action whether it be payment for environmental services or other forms of regulations. The use of payments for environmental services has been applied in many policy contexts; their effectiveness, however, is limited and they are more readily applied in some sectors (e.g. forest management) than in other emerging concerns (land restoration, soil health and soil carbon).

Overall land use policies and planning need to combine the traditional regulatory and territorial aspects implemented by governments and also supply chain governance interventions and emerging private-led mechanisms for sustainability. The range of actors and stakeholders is evolving in the context of climate change, requiring new forms of "trans-scalar land use planning".[44]

There is a large body of scientific evidence on how to better harness biodiversity within agricultural systems (i.e. agro-ecological farming), although the right policy and economic tools to make the change may yet be unavailable. With increasing climate variability, there are more fluctuations in world food supply, calling for a need to fully grapple with the implications of climate-induced shocks on food prices and supplies and how these shocks are transmitted across sectors and borders.

5.1.1 The case of payments for environment services: potentials and limits[45]

Payments for environmental services (PES) were introduced to provide the market valuation to natural capital as a policy instrument to ensure more sustainable use and conservation of resources and ecosystem services, as well as to improve land productivity and, as a consequence, food security. PES steps in when there is no existing market structure. PES is enforced through regulation and can be effective, at least in the short run, in effecting change (e.g. forest preservation) when strong regulatory, monitoring and enforcement tools are applied in combination with economic incentives and participatory approaches. One relatively successful case is Brazil's effort to slow down deforestation in the Amazon region. Part of the success is due to unconditional payments to poor households independent of what they did in the forest (which places them strictly speaking outside PES). However, the robust application of compliance and enforcement comes with restrictions on land use to avoid leakage and unreported deforestation. This has been followed by more driven initiatives such as deforestation-free supply chains and the application of certification schemes that relate to life cycle analysis. Costa Rica also offers an example of successful application of PES for forest recovery, the country has managed to reverse deforestation from 70 percent in 1997 to 48 percent deforested land more recently. In this case, afforestation was initially made possible through the creation of national parks in lower producing regions. Further gains in the afforestation effort, however, required the participation of livestock growers who control a third of all land in the country. The government of Costa Rica has adopted a landscape approach to land management based on strong inter-ministerial collaboration and has pursued other integrated methods, such as agroforestry.

With the exception of the few successful cases of forest recovery, PES have not been particularly effective. The reasons are many, one of which is the market valuation of ecosystem services that tends to be based on partial assessments. Many studies indicate that putting a value on a service, say, natural bee pollination, can trigger substitutions towards alternative options, thus nullifying the original conservation goal. For example, a study from China shows that hand pollination by significantly inexpensive labour outperforms natural bee pollination. This raises serious implications

[44] Rudel and Meyfroidt. (2014).

[45] According to the Millennium Assessment Report (2003), ecosystem services are defined as "the benefits people obtain from ecosystems". This ranges from food production to climate regulation. Environmental services are a subset of ecosystem services characterized by externalities. Programmes to implement payments for these services are variously referred to as payment for ecosystem services programmes, payment for environmental services programmes, or simply PES programmes.

about how best to assess ecosystem services that require a more integrated framework, taking into account that these services, once priced, can become substitutable for one another and therefore may not necessarily guarantee conservation. PES also needs to be contextualized due to spatial variation and large differences in what the services might be and, more importantly, what kind of activities they may compete with. PES must factor in the opportunity cost for farmers who give up an income-generating activity; they may not be attractive if the alternative is more lucrative.

PES may also suffer when there is insufficient attention to the institutional and market structure behind the service. Lessons from the first generation of PES show that there were issues relating to the targeting of payments to landowners who may not always be the primary group of people linked to the action being prevented (i.e. cutting trees). Moreover, too much focus may be placed on quantifying the service and the amount of payment to landowners, with less attention placed on the institutional structure and cultural aspects of land tenure. Understanding the ownership structure (i.e. cooperative versus individual ownership) is necessary to determine key differences in how these payments are made and used.

Among the underlying causes that could limit the long-term effectiveness of PES are the potential conflicts between conservation and development objectives; lack of participatory governance; and instances where the PES is designed to meet a single objective (e.g. GHG mitigation only). UN-REDD+ is a special case in point, highlighting some of the limitations with PES. A large number of pilot UN-REDD interventions have been documented, ranging from pure conservation to development, including alternative sources of employment, rural enforcement tenure programmes, education programmes and others. The view from the UN-REDD literature review is that the programme's success is quite variable. Successful cases are associated with time-tested methods of enforcement and regulation and through land use zoning. Another difficulty with UN-REDD is the economic rationale as it is not always easy to come up with the money required to compensate for the full opportunity cost, although there are conflicting views on this.[46] These projects are, however, mostly not jurisdictional REDD+ and another stumbling block for widespread implementation is the countries' REDD+ readiness. The Green Climate Fund recognizes this and intends to support efforts by national designated authorities and focal points to engage with the GCF in the early phases of REDD+.[47] UN-REDD programmes appear to work more effectively when designed as packages of interventions that cover development, income and food security for the rural population, in addition to the need to save the forest.

5.1.2 Policies relating to water resource and water scarcity

A climate-smart water system begins with climate-induced changes in hydrological processes and integrates the responses (i.e. water demand and supply) as part of a coalescent strategy that incorporates the food, land, energy, health and environment sectors. In terms of food, water is not only a production input through irrigation, in situations of water scarcity, water can influence trade policy and trade specialisation. Regarding scale, water resources are planned and managed at the level of the river basin or watershed, which may create the problem of farming often being decided at the farm-plot level. The need to integrate water use policy with water using sectors (e.g. farming, agroforestry, inland fisheries, energy, industry, domestic users) is well recognized, although the challenge lies in implementation and successful cases of integration are not numerous. A first challenge is scale alignment (i.e. river basin vs farm or field) and the second is institutional coordination. The latter may be a more difficult obstacle, especially in developing countries where development projects tend to segment along ministry lines and along individual donor-funded projects – often with uncoordinated and sometimes conflicting objectives.

With regard to water scarcity, water use policy must make a clear distinction between water use efficiency at the field (or farm) level and water use sustainability (i.e. water shed level or aquifer level for groundwater). Increasing irrigation technology can have a direct effect on water productivity, although that does not necessarily mean it improves water sustainability and water resilience. In addition, productivity at the field scale may be at the expense of sustainability and resilience at the basin scale. Water policies often fail in the long run when they focus too much on water use efficiency (or productivity) without taking the necessary measures to ensure water use sustainability. Water use efficiency in itself is challenging, owing to the inherent difficulties in establishing the proper water markets and identifying correct water pricing. In most situations around the world, water is much less expensive, if not free, compared to its true opportunity cost.

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46 Angelsen *et al.* (2016).

47 UNFCCC. (2016).

Only rarely does one encounter a case when putting a price on water use does result in a significant reduction in water use on a significant scale. One exception has been reported, in British Columbia, Canada, where stone fruit is grown under irrigation free of water conditions. Following a sudden introduction of mills to farmers' pipes and a small user fee for water, the volume of water used dropped by half after a year. In this case, farmers recognized that water had an economic value and their awareness of rising water scarcity under climate change prompted a behavioural change. This is not always the case, however. In most countries water continues to be underpriced and the fees charged rarely go beyond the cost of water delivery. For various reasons, there have not been many successful instances where water pricing has worked effectively. Effective water pricing should reflect either the full supply cost or the opportunity cost. Moreover, water, being a vital need, is highly regulated. The best option is a sort of hybrid between a market instrument and tariffs and quotas to deal effectively with water scarcity on the one hand and, on the other hand, incentives for optimal use of water resources.

Another challenge that faces water use policy is that of governance and equitable access to water resources by the poor as well as rural women. There are many key policy issues that relate to water governance, including multi-level coordination, information need, coherence, transboundary water management and groundwater management. The issue of transboundary water, is extremely critical given that large shares of water used for irrigation are transboundary resources (i.e. surface or groundwater), while water policies are regional policies that require cross-border coordination which is not always easy. Developing informed regional policies that can guide riparian countries and help them adopt coordinated approaches to the issues has to be explicitly addressed. The second governance challenge relates to managing groundwater owing to the private and dispersed nature of water use, it is often difficult to monitor and enforce regulation.

5.2 Policies for sustainable food consumption and diets and for reducing food waste and loss: food demand issues under climate change

5.2.1 Importance of adopting the food system approach in addressing climate and food security

While most of the literature on climate and food has focused on supply-side issues, the importance of food demand, consumption patterns, diets and nutrition to climate response is receiving increasing attention and deservedly so. Climate-compatible food policy must encompass production as well as consumption and trade issues. While food demand is of paramount importance to climate change adaptation and mitigation, the issue of food consumption not only must be addressed jointly with production because they are interlinked, but also to avoid contradictory conclusions and recommendations. For example, production subsidies not only can distort markets, they may also produce perverse incentives on the demand side, resulting in an unbalanced nutritional diet. Likewise, production subsidies may counter the aims of lower carbon food supply.

From a nutritional point of view, food production must be assessed not only for its volume, but also from its nutritional contribution. In many parts of the world dietary and consumer habits are changing,[48] not always for the better as attested by the rise in the numbers of overweight and obese people worldwide and the rise of nutrition-linked health problems such as diabetes, among others. Most reported dietary changes refer to a shift in consumption to more meat and dairy products in middle income consumers in developing countries, as well as an increase in the demand for fruits and vegetables in high income populations. In Brazil, there are dietary transitions at play, notably from meat to fish protein, making Brazil the second largest aquaculture producer in Latin America.

In many parts of the developing world, however, especially among poor and small-scale farmers, millions of people are food insecure and meet their caloric needs mostly through carbohydrates (e.g. rice, wheat) with known nutritional imbalances. For the poor, the price factor is a major determinant. Therefore food policies that introduce carbon certification or similar schemes must integrate the nutritional requirements of the world's poor. The "hidden hunger" from micronutrient deficiencies is a key concern, especially in Africa where a major shift has taken place in recent decades from local and more nutritious food products to a smaller range of imported foods (e.g. wheat and rice), often with unbalanced nutritional content.

48 Pradhan, P., Reusser, D. E. & Kropp, J. P. (2013). Embodied greenhouse gas emissions in diets. PloS one, 8(5), e62228.

There is a growing argument for reliable carbon footprint data along the food supply chain to support new food policies or private-led initiatives that aim to shift food demand for nutrition and climate change (i.e. understood as GHG emissions). In the scientific literature, a growing number of studies have been published that report engineering calculations of GHG savings if certain diets are adopted (e.g. Mediterranean, Western, vegetarian, more fish-based). One of the limitations of these studies is that they tend to be somewhat removed from plausible alternative scenarios while lacking a sociocultural or economic basis. Moreover, we have limited knowledge on how much change in diets we can expect from a given policy intervention (e.g. actual consumption changes arising from a carbon tax on food). Such comparative diet assessments tend to be reductionist and lack comprehensive nutritional analysis. For example, meat or dairy consumption, though a higher GHG footprint, comes with valuable micronutrients, whose deficit results in hidden hunger. More meta-analyses should be carried out to generate robust evidence before drawing firm conclusions. While there is the great benefit in encouraging people to consume products such as pulses, the literature on diets and its links to climate and food security needs further expansion.

While the carbon footprint is valuable and can inform policy and alternative consumption pathways, these life cycle assessments need to go beyond engineering calculations. It is essential to include the economic dimension; that is, to take into account the economic capacity of the poor to make a shift to alternative food systems if incentives are changed. Moreover, the carbon footprint should not be the sole barometer to measure food systems; it should be extended to other vital ecosystems affected by food production and consumption (e.g. nutrient footprint, biodiversity footprint). Recognizing the complexity of the task, this is certainly a field for further investigation of the existing literature as well as for future research.

5.2.2 Food waste and loss: improved framing of the problem

A recent study on food waste found that, globally, 20 percent more food is available in the market than is consumed.[49] There is also overconsumption and food overavailability in high income countries. Hence, it is essential to address food demand management as part of any strategy for climate-smart and sustainable use of resources. Research on food waste and loss is scant and there is a dearth of reliable data. More important, however, is that the real problem of food waste is one of framing. There is certainly an ensemble of factors that contribute to the chronic situation of significant amounts of food being produced and not consumed, ultimately translating into "wasted" water, nutrients, soil, trees and other vital ecosystem resources. Food waste is a regrettable side effect of efficiency, food subsidies, the value of convenience and the "cheap" food scenario. The problem, therefore, is above all economic, then social and, finally, technical. There is an absence of rigorous economic evaluation of food to determine its true cost, which should lead to proper pricing while taking into account the ecological footprint and the full cost. This should open the way for alternative economic scenarios where the pricing structure of food is redesigned in such a way as to correctly price food, water, nutrients and other ecosystems. As an outcome, one would expect a shift in consumer behaviour, less waste and perhaps even more nutritious food intake. To reiterate, the economic literature on this is apparently absent, making it a worthwhile area for scientific and economic research.

Meanwhile – and without much empirical evidence – there is an awareness that food waste is often linked to the threats of climate and sustainability on the food supply base. This recognition has unleashed initiatives that prompt and educate the public to waste. Such "campaigns", however, remain ad hoc and one-off and show that changing consumer behaviour through awareness campaigns, notably in Europe, does not have much staying power. Such behavioural change is unlikely to succeed in isolation. Food waste and loss reduction initiatives would work more effectively if integrated within larger policies and initiatives that also influence the decisions of farmers and elicit a behavioural change throughout the supply chain to the retailer. Another option is to internalize the cost of food waste reduction into the product price, which would also act as a more effective incentive to prevent food waste. These initiatives can only succeed if they are the outcome of a holistic economic-socio-technical framework.

Framing the challenge in economic and social terms can also be effective in encouraging change by the consumer. In Japan, the Ministry of Agriculture has promoted various measures to reduce food loss and waste under a combination of different tools, including education, knowledge, science and regulation and incentive measures, among others. It is difficult to create behavioural change in consumers and civil society, although an appropriate framing in the social-cultural context is potentially effective. In Japan, people view food loss and food waste not simply as losing the food; rather, it is viewed as the killing of animals and loss of plants for no reason, corresponding to Japan's strong negative

49 Hiç *et al.* (2016).

and religious sentiment. Another dimension is that, often, the poorest countries are the greatest importers of food and thus the issues of food loss and waste are more serious in terms of food security. As a consequence, authorities have framed campaigns for food waste prevention using strong social and religious arguments they believe will be more effective than if framed purely in terms of monetary value.

5.3 Socio-economic policies to support climate-resilience by smallholder farmers

Climate change requires policy responses on multiple fronts, including shoring up support for small-scale farmers and vulnerable communities that have a lower capacity to cope with the adverse effects of climate shocks. Policies that provide the social safety net for the poor can assist them to cope with climate extremes (e.g. floods) and develop the ability to recover and to adapt. In basic terms: How should policies be developed to include those vulnerable farmers who are subject to these shocks? How can policy be combined with practices that can sequester carbon? There are many other questions we should ask.

Socio-economic policies that aim to strengthen the resilience of small farmers, including through poverty alleviation and food and nutrition security provisions, are driven by the usual principles of providing the enabling environment to encourage improved resource use efficiency, facilitate equitable access to resources and information, as well as enhance empowerment and the agency of smallholders, including women. Policies to boost resource use efficiency and improve productivity may also contribute to climate change mitigation and better adaptation. Given the limited resources of governments, policies that involve financial incentives or investments to support smallholders need to link the climate benefits to the economic benefits as best practice.

There are many examples where policies that improve the resource use efficiency of farmers – and, hence, improve incomes – can be beneficial from the perspective of climate mitigation. In many farming systems in developing countries, small-scale farmers benefit from investments in technological innovation (e.g. mechanization) which, when combined with cleaner energy sources such as solar power, can enhance the benefits of productivity and mitigation. These technological innovations, however, need government support, especially in the absence of a sufficiently developed private sector. In developing countries, the government often plays the role of initiator to provide investment, often creating trade-offs as a result of budget limitations. In sub-Saharan Africa, one constraint to scaling up is the limited capacity of government to enforce activities at the grassroots level (e.g. water policy). One such example is offering incentives to those who shifted from using electric water heaters to solar water heaters. This ceased when farmers reverted to buying electric heaters as the less expensive option. The lesson from this case is that it is essential to tie a fiscal incentive to a technology to achieve user buy-in. Aside from win-win scenarios, there are also cases of “win-not much loss” options. For example, mineral soil with up to 150 kilos of nitrogen can be applied in abundance prior to the release of increased emissions, thus opening the way for agricultural intensification, something that is harder to do in sandy soils.

In addition to efficiency-enhancing policies for smallholders, policies must promote equitable access to resources. In the Sahel, for example, the food security programmes through which people can access land do not specifically target food-producing smallholders. This often results from a lack of participation (i.e. a weak agency) by smallholders and highlights the need to strengthen weak institutions (i.e. groups and cooperatives). The key goal is to enhance participation and empowerment. This implies an appropriation of the discourse by providing evidence to those who have been traditionally acted upon. Of critical importance for many developing countries is the need to strengthen extension services with the active participation of farmers and to identify the lead farmers.

Policies that offer climate and economic gains should correctly target smallholders because farmers are not one and the same and their situations differ, as do their long-term viability as farmers. Policymakers face the question of which segment of the rural poor to target in the design of their sociopolicies. Among small-scale farmers, especially in developing countries, a proportion of them is likely to be exiting farming, a certain number is staying put and another group is in the act of intensifying. Consequently, policy interventions will need to be differentiated to each group. Some studies make reference to these groups, considering whether or not it is a waste of resources to include them or whether or not to target the small-scale farms that show potential for viability.

In many parts of Africa, a large proportion of food production originates from smallholders.[50] Agriculture in Africa, however, is changing and as is observed in several countries that are reinvesting in agricultural land, large-scale farming is expanding. The patterns of migration are also altering rural areas, raising the question of demographics in the future in the face of good planning. While there are huge trade-offs from the status quo (i.e. ensuring that people remain in agriculture), would it be better to have them transition to other occupations? Some policy examples have shown the benefits of transitioning, at least in the short term. A further example occurs in China, where farmers seek complementary employment. Here, while farmers are able to make their own decisions, the land does not belong to them; rather, it belongs to the government. Many farmers experience land tenure issues due to the land being publicly owned.

The resilience of poor farmers to climate change and climate extremes depends largely on the integration of agriculture to other sectors to reduce economic damage of harvest failure at the household level. Policies need to address employment transition to offer alternative employment and study means to ensure livelihoods. Another important element of a pro-poor policy is the emphasis on economic aspects at the sub-farm level, to ensure the participation and empowerment of women and youth.

5.3.1 Integrated, cross-sectoral, multi-objectives policies are more effective

Socio-economic policies that assist smallholders to strengthen their resilience to climate change must be comprehensive, cross-sectoral (i.e. crops, livestock, forestry) and multi-objective (i.e. mitigation, adaptation, food security). To be effective, such policies should also be cross-scale to acknowledge fully that the relevant stakeholders and the trade-offs vary across scales, requiring actors to operate at these different scales, from local to global. One policy may be effective in one sector but not in another, an example being forestry and agriculture. Another example is that the underlying land tenure structure differs for crop farmers and mobile livestock farms, creating a policy dilemma given that one policy may be quite effective under one land tenure regime but not the other.

There is a fragmentation between adaptation and mitigation occurring in climate policy. The result is that policies relating to plantations for carbon do not incorporate food security objectives across sectors. It is not always necessary to look only for policies with multiple-win outcomes. But if it can be achieved cost effectively then it is worth pursuing. An example is given from Burkina Faso, West Africa, related to deforestation. Here, the people – aside from cereal growing – usually leave food-producing trees in what is referred to as a parkland, where the trees are protected beyond the forest. This ultimately becomes a significantly important safety net. The policy becomes even more important when taking into account the shea butter that is produced by the trees and the resulting sequestration of carbon. A drawback, however, is the fact that the trees end up felled once the land has been settled. On the positive side, the policy gender aspect is strengthened by the opportunity women have to sell the shea butter, providing an incentive to protect those trees beyond forest areas.

Cropland albedo management (e.g. through mulching, no-till farming or the selection of cultivars with higher reflectivity) is a recommended practice with potential win-win outcomes (i.e. adaptation and mitigation). Modelling studies demonstrate that a switch to no-till farming increases albedo, resulting in a decrease in temperature during heat waves.[51] No-till farming can therefore strengthen resilience and help farmers cope with increased variability in climate and yield (adaptation) while providing some climate mitigation benefits through soil carbon sequestration. Policy design, therefore, should consider such local biophysical effects in an effort to identify win-win outcomes.

Policy objectives may result in contradictory outcomes between food security and mitigation and thus prioritization should be at the sectoral level with harmonization taking effect at national level. National mitigation strategies, particularly with reference to the Intended Nationally Determined Contributions following COP21, provide such a case. Policy framed at the national cross-sectoral level may be more effective than that formulated on a sector-by-sector basis. An overall national mitigation strategy can call for a higher sequestration of emissions in agriculture – with food security as a higher priority – if other sectors take responsibility for the heavy lifting. For example, Brazil calculates that agriculture may increase emissions if bioenergy achieves the GHG savings objective. The challenge is that this type of inter-sectoral planning requires a high degree of integration across various sectors whose planners tend to work within line ministries. For many countries, this remains a major policy coordination challenge that needs redress through improved climate policy and governance.

50 Samberg *et al.* (2016).

51 Davin *et al.* (2014).

5.3.2 Comprehensive – not-piecemeal (or fragmented) – policies with a long-term view are more robust

In terms of climate change and food security, it is essential that policies are designed comprehensively, since the piecemeal approach is ineffective. A longer-term and all-encompassing view of the future is essential, within which each policy measure is tailored accordingly. Focus should be placed on the rural populations that are likely to remain so in the future. Some macroeconomic trends have been beyond the scope of the policy-maker, often driven by trade, investment or the internal dynamics that relate to migration patterns, all of which are transforming the food production sector. Food security at the macro level is dependent largely on the external dynamics of the agricultural sector. Economic development policy, therefore, must encapsulate the agriculture sector in its aim is to strengthen the resilience of smallholder farmers.

Finally, socio-economic policies that target smallholders should not only strengthen their resilience but also reduce the risks they face from climate change. They should promote the diversification of farming, mixed cropping to temper the impacts of climate variability and income stabilization, as well as ensure the availability of diverse and nutritious food production. It is essential that the dimensions of various livestock systems are taken into consideration, as well as the different types of farms. Mixing cropping with livestock is an essential diversification strategy in some farming systems. Such diversity calls for tailored interventions and objectives based on local circumstances. There is no one-size-fits-all solution to climate change; that is, not all measures and practices have win-win outcomes and so appropriate trade-off management should be incorporated into the policy design. In terms of biodiversity, crop rotation is key and should be promoted not solely for its benefit to soil health. In addition, socio-economic policy should encourage crop diversification, including at local level. The basis is to maximize the number of food crops given the availability of water resources and the local agro-ecology.

Of paramount concern in the food production and food security policy design scenario is food nutrition which is multifaceted and covers chronic undernutrition and metabolic diseases, such as overweight and obesity. By improving the shares of fruit and vegetables and promoting a more diversified diet, policies can potentially correct or prevent nutrition imbalances to some extent. In place of modelling agricultural systems for large crops, diversified agricultural systems should be encouraged. Once this has been taken into account, the climate change mitigation and adaptation objectives can be better determined. Ultimately, the landscape management level emerges, taking into account landscape, soil, water and biodiversity.

5.4 The long view: transforming the food system under the twin challenges of climate change and the environment

There is a crucial need to engage in a higher-level debate on the long-term win-win solutions to climate change. With only a narrow focus on agenda items, it is difficult to gain a broader and global perspective in order to understand the potential dynamics to effectively change the way food is produced and consumed. Minor adjustments and tweaks to policies in place will not achieve the desired objective of 2 °C world. The expansion of knowledge and understanding, as well as creativity and especially the sharing of knowledge, including that of failure (more often avoided than not), will be far more reaching.

The roles of ecology and economics together in the food system, and the natural resources that support it, should be rethought. This can be brought about only through a dialogue that takes into account the significant and fundamental transformation of the food system in the face of climate change and sustainability challenges.

In mainstream economics, the environment is considered a resource flow rather than stock, with technology as a process and the unit of analysis the margin (i.e. marginal benefit against marginal cost). This inevitably leads to a focus on efficiency, which generates a significantly strong bias that inputs – natural capital and human-made labour – are substitutes for one another and can be traded away at the margin. Accordingly, progress is deterministic and relates to the monotonic change of technology. Only when a market value is placed on natural capital can everything be compared. When taking into account natural capital as an ecosystem service, it becomes a major challenge.

If ecological principles are appropriately embedded in the equation, the question that arises is: How these would impact on an economic approach to climate change? In terms of ecological economics, humans are part of social, cultural and ecosystems and the economy is a subset of a larger sustaining ecosystem. Technology, therefore, becomes a social process with distribution a goal rather than a given; where justice is prioritized and incorporated into the climate economy system model. Such analysis offers a dramatically different set of responses than if one were to prioritize efficiency. The complementarity of inputs becomes evident as a necessity in terms of land, materials and energy globally, which are not substitutes. While the input of use efficiency can be improved, this also is limited by the barrier of complementarity. Behavioural economics contributes a better understanding of how groups think strategically. Institutions matter and the key challenge is to structure the institution so that it can make markets work more efficiently and effectively and to ensure that economic systems perform as expected.

By fully taking on board the science of ecology at the policy level, the economy becomes a biophysical system that operates on low-entropy matter and energy. If energy were the fundamental metric to measure the sustainability of the food production system, modern agriculture would become less and less energy-efficient over decades to come. More total energy levels are needed to produce food calories than previously. A study of the United States energy food system from 1910 to 1970 found that the total energy input to produce food calories increased over time. Throughout the process, the major energy trade-off is labour. As more energy is used, there is less need for labour. Reversing this equation may create an agricultural system that could be considered climate smart.

In summary, energy is one of the key metrics to consider within a reframed sustainable agro-ecological system. It is essential that a trajectory be sought, at the global level, to enable the decrease of energy input per food calorie output, the strengthening of food resilience and perhaps a solution to the overconsumption of food calories, as well as the redistribution of food. Sustainability should be a priority, given that productivity alone is not sufficient (Jevons paradox). Productivity gains should come hand in hand with regulatory forces and regulation that is equally applied to all can only create incentivization.

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Appendices

Appendix 01
Speakers' summary notes

Theme 1. Climate impacts on land use, agriculture and related ecosystems

PLENARY SESSION 1: CLIMATE IMPACTS ON LAND USE, FOOD PRODUCTION AND PRODUCTIVITY (DIRECT IMPACTS)

Climate impacts on crop yields, including extreme events, regional hot spots, crop suitability

ANDY CHALLINOR, UNIVERSITY OF LEEDS

Assessments of the impact of climate change on food security need to account for the diverse and complex interactions that ultimately deliver access to food. In particular, there are needs, some of which are beginning to be addressed, to:

- Be integrative, especially across traditional IPCC WGs. This can only be achieved by communication right from the outset, e.g. minimum one day author meeting to produce a framework approach.
- Capture the value of industry insight, including associated grey literature, on food shocks.
- Effectively combine quantitative and qualitative methods in order to asses risk.
- Produce global scenarios of food supply, demand and emissions that include land use and mitigation targets as constrained interactions across sectors, Paris targets and land availability.

The table below summarises knowledge gaps. Further notes on each topic are provided overleaf.

	WHAT WE KNOW	NEEDED NOW IF WE ARE TO ASSESS FOOD SECURITY
Yield and production	• Aggregated yield impacts known to be negative • Production depends on land use, which is affected by weather, climate, society, policy… • Aggregate adaptation benefits known (~7-15 percentage points)	• An integrated understanding of land use and food production (WG 2,3) • Associated scenarios to capture the range of possibilities, including further work on environment-diet-health and WEF nexuses
Extreme events	• Starting to be mapped out in more detail post-AR5. Needs to continue • Unknown unknowns > known unknowns?	• Understanding "food shocks" including risk transmission across borders and sectors • Integrated quantitative and qualitative approaches needed. • Role for "plausible future" analysis with stakeholder (policy?) engagement
Where and when	• First-order impacts known reasonably well; timings less clear • Interactions with vulnerabilities are critical	• When changes will happen under specific climate scenarios (WG 1,2) • Which changes will ultimately be significant. Work with specific sectors, as in crop breeding example – again, role for policy and stakeholder engagement

Yields and production need further work, but the interactions with food systems are especially important.

Note that some crops (e.g. wheat) have been shown to have greater agreement in aggregate temperature response than others, e.g. maize. Whilst it is therefore clear that there is more work to be done, the broader production and land use issues are more important. This is especially true given that food-based emissions are projected to either be the totality or large fraction of 2^{oC} emissions budgets. Changes in diet may be needed in order to achieve these targets.

Extreme events and food shocks also suggest a change in the way that assessments are carried out.

Extreme events, and their impacts on crops, are difficult to simulate. Climate models do not yet capture observed trends in extremes over time. Crop models have not always tested or reported the interannual variability of output yields, instead using it as an error bar on estimates of mean yields. However, this has changed in recent years. A study published in Feb 2017 confirms what is known about some of the observed effects of high temperatures on crops, and shows that models can capture some of the underlying mechanisms. More remains to be done at this process level.

IPCC AR5 chapter 7 noted that food price volatility can be triggered by extreme events, and that (non-equilibrium) economic models to capture this effect do not exist. Progress has been made since then, but much remains to be done to assess risks. Extreme events, and public and private sector responses to them, are now known to have serious knock-on effects through trade-induced cross-border amplification of climate-related food risks. These risks include food price spikes, food safety issues and interactions with conflict and migration, to name but a few. Interactions beyond food systems, e.g. energy systems (via biofuels) create the potential for food system failures, especially if there were to be a multiple breadbasket failure. These risks has not yet been adequately characterised, and can likely only be partially quantified.

The UK Climate Change Risk Assessment 2017[1] highlighted a number of relevant research gaps:

- Quantify the covariate nature of risk of multiple food production failures in world regions.
- Assess the risk posed by abrupt change and climate tipping points to global food production including an assessment of the likelihood, impact and geopolitical consequences of climate change and food insecurity.
- Characterise and quantify food system risks in supply chains, nutrition, and political instability due to extreme weather and climate change.

Hotspots of impacts are fairly well characterised, but there is less known on when impacts are expected Traditional projection methods ask what the range of possible impacts is for a given timeslice. Methods are now available to ask what thresholds of temperature or impact (e.g. crop yield) are important, and assess the time interval during which these are likely to be exceeded. This can be carried out for a range of scenarios and the analysis can include metrics for the sensitivity (or vulnerability) of the system studied[2].

1 https://www.theccc.org.uk/uk-climate-change-risk-assessment-2017/ccra-chapters/international-dimensions/

2 http://www.nature.com/nclimate/journal/v6/n10/full/nclimate3061.html

PLENARY SESSION 1:
CLIMATE IMPACTS ON LAND USE, FOOD PRODUCTION AND PRODUCTIVITY (DIRECT IMPACTS)

Climate change impacts on livestock and implications for adaptation: A summary brief

AN NOTENBAERT, JUAN ANDRES CARDOSO, JACOBO ARANGO, NGONIDZASHE CHIRINDA, MICHAEL PETERS, ANNE MOTTET

Introduction

This paper aims to provide an overview of the impacts of climate change on livestock and the implications for adaptation. It starts by highlighting the importance of the livestock sector to people's livelihoods and the natural resource base these livelihoods depend upon. It then proceeds by giving an overview of the different direct and indirect impacts of climate change on livestock production and the implications for adaptation to climate stresses.
The last section provides some more detail about using feeds and forages as a promising entry point for climate change adaptation and mitigation. The paper concludes with a few take-home messages.

Livestock and development trends

The livestock sector is very important for people and planet alike and can play an important role in achieving the SDGs. Including both ruminants and monogastrics, it has an estimated value of more than 1.4 trillion USD, supports about 1.3 billion producers, processors, retailers, indirect jobs and their dependants, and contributes 43% of agricultural GDP at global level. Livestock products provide 14% of the calories and 33% of the proteins consumed globally. Animal-source foods are important to nutrition and health and provide essential micronutrients, such as vitamin A, B-12, riboflavin, calcium, iron and zinc. In addition, livestock have high cultural and social value. The sector uses about a quarter of the terrestrial land area for grazing while one-third of global cropland area is devoted to producing animal feed. This makes it the biggest land user on earth. It further emits an estimated 14.5% of human-induced GHG emissions and uses 32% of globally available freshwater. Livestock can, however, also contribute positively to the natural resource base by providing several ecosystem services ,e.g. manure provision, soil carbon sequestration, erosion control (and soil health in general), biodiversity protection, draught power and energy production from livestock waste.

The livestock sector is very dynamic. The demand for livestock products has more than doubled in the past 40 years and is projected to continue to grow about 2.5% annually. Most of the growth is projected to occur in the developing world, where livestock production is taking place in a large variety of livestock production systems and agro-ecologies. Systems range from landless production over mixed crop-livestock production to rangeland-based systems and show a wide adaptability to heterogeneous climatic, ecological and socio-economic contexts.

Impact of CC on livestock

Climate change – with its projections of rising temperatures and CO_2 levels, changing rainfall patterns and the likely increase in climate variability and occurrence of extreme events - causes major impacts on livestock and on the ecosystems goods and services on which they depend.

Heat stress can have direct impact through behavioural and metabolic changes in the animals, such as reduced feed intake, increased energy requirement, decreased conception rates. While indirect impacts are felt through e.g. (i) a mismatch between increasing water demand and decreasing water supply, (ii) increased pest and disease pressure as a response to changes in pathogen development, vector distribution and disease transmission rates , oftentimes in combination with reduced disease resistance, (iii) biodiversity losses, both in terms of loss of habitats, plants and animals and in terms of a reduced gene pool for future adaptation, (iv) changes in quantity, quality and composition of feed resources and (v) changes in overall system productivity and livelihood patterns.

Arguably the most important climate change impacts are those mediated through the climate's impact on what the animals eat. Few global or regional assessments, however, consolidate information on expected climate change impact on feed resources. These are indeed complicated as a wide variety of feed baskets exist, consisting of different combinations of crop residues, planted forages, native grasses, grains and additives. Typically, feedlot-based ruminant and monogastric production depends thereby on a higher share of feed in the form of grains edible by humans or produced on land suitable for human food production, while extensive grazing systems often already show low efficiencies due to low primary production in addition to low nutritional density of the feed. Climate change impacts on crop residues, legumes and grasses are varied across feed items, regions and systems. They express themselves in terms of changes in overall biomass production and feed availability, changes in feed quality and changes in species and feed item composition.

Implications for adaptation

Regions identified as the most vulnerable to climate change, such as Sub-Saharan Africa and South Asia, are also regions where farmers and rural communities rely the most on livestock for food, income and livelihoods, and where livestock is expected to contribute increasingly to food security and better nutrition. Adaptation will be needed if households are to cope with the multiple (inter-related) stresses of climate change, population growth, urbanization, globalization, etc. This requires not only considerable -public and/or private- investment but also real change in on-the-ground behavior.

As the climate change effects are strongly influenced by species/genetic potential, health and nutritional status, technical entry-points for adaptation include genetic improvement, animal health interventions and improved feed strategies. Other adaptation options require changes at the landscape of system level. Examples include diversification of production and income, shifts in species and production systems, land use planning and sustainable land management, and protection of ecosystem services. Widespread adoption of such adaptation options (and combinations thereof) requires appropriate governance mechanisms, institutions and policies. Interventions enabling such include improving markets and trade, establishing early warning systems and contingency planning, providing livestock insurance, organising climate finance mechanisms and payments for ecosystem services.

The choice of adaptation options needs to take the local livestock production systems, farmers' socio-economic and cultural circumstances and the policy context into account. The prioritization of options and design of a context-specific investment portfolio entails an iterative –and ideally participatory- process of listing potential options, assessing adoption and out-scaling potential and estimating impacts.

Feed as a triple-win climate-smart intervention

Improved feeding provides a clear entry-point for enhancing:

1. Livestock production: Feed shortage, especially during the dry season, is one of the most important issues raised by livestock farmers across the developing world. Improved feeding strategies, increasing quantity and quality of the feed baskets, can increase production of safe and nutritious livestock products and the income of livestock keepers.
2. Climate change resilience: Feed availability and quality is often cited as one of the biggest risks for livestock associated with climate change. Improved and well-adapted feed crops and forages -grown under appropriate management- can contribute to the resilience of livestock production systems. They can reverse land degradation through use of animal manure, soil erosion control if planted for such purpose and general improvement of soil fertility, especially by legumes which have nitrogen fixing capacities or when integrated with other soil fertility management options.
3. GHG emission intensity: The provision of feeds and forages of higher digestibility is a well-documented mitigation option, specifically so for ruminant production in the developing world. To maximize the benefits of improved feed quality and to reduce the leakage effect (of farmers keeping more livestock because of their increased productivity and thus economic return), reductions in animal numbers also need to be part of the strategy.

As such, feed and forage interventions (e.g. improved germplasm, feed and forage conservation, establishment of fodder banks, supplementation, land restoration and reseeding of pastures) are amongst the most promising climate-smart options in the livestock sector.

Conclusion

The livestock sector is essential to people - providing employment, income, food and nutrition – as well as the planet. Livestock production is well adapted to different climates and provide greater resilience to smallholders in the face of climatic or disease shocks than do crops alone.

Climate-smart *Brachiaria*

Brachiaria is an African genus comprising about 100 species. Extensive germplasm collection in Africa followed by strategic research on the agronomy, forage quality and animal production, genetics, cytogenetics, plant breeding, and biotic and abiotic stress adaptation over the past two decades in Latin America resulted in the selection of vigorous and productive *Brachiaria* grasses, as well as the development of four commercial hybrids (Mulato, Mulato II, Caymán and Cobra) through breeding. *Brachiaria* grasses have become the most widespread and economically important forage grasses in tropical America, and their adoption is increasing in East Africa and South East Asia. An estimated 90 million hectares are planted with *Brachiaria* in Brazil only. *Brachiaria* grasses stand out for their ability to be productive and persistent under low soil fertility conditions, with some genotypes showing contrasting and/or intermediate behaviour in terms of their water use (i.e., "water saving" or "water-spending" behavior for their targeting to either long or intermittent drought periods respectively). In terms of climate change mitigation, *Brachiaria* grasses have a higher nutritional quality than many other commonly fed grasses and thus reduce the GHG emission intensity from enteric fermentation. In addition, they show a phenomenom termed "*Biological Nitrification Inhibition*" (BNI) which refers to a mechanism by which roots –in particular those of B. *humidicola*– naturally inhibit the conversion of nitrogen (N) in the soil from a stable form to forms subject to leaching loss (NO_3-) or to the production of N_2O, a potent greenhouse gas. This in turn has a direct environmental and economic effect (less N loss). Furthermore, *Brachiaria* grasses have the potential to increase carbon in soils (up to 6 ton ha/year) due to their large root systems, chemical characteristics of its roots (high C/N ratio, lignin and polyphenols), and root turnover (1/3 of total root system might be renewed annually). Green house and field experiments have also indicated that soil physical attributes are greatly affected under *Brachiaria* (i.e. increase of aggregate size and water infiltration).

Its productivity and sustainability is, however, threatened by climate and other –often interlinked- changes. A range of direct and indirect impacts are expected, indicating a clear need for increased adaptation action on the ground. Promising opportunities exist, with feed interventions as a notable potential triple-win entry point.

Livestock production and it's interaction with the natural resource base and the wider food system are of a highly complex nature. Further research and assessments are needed to inform robust evidence-based decision making.

PLENARY SESSION 2:
CLIMATE IMPACTS ON LAND USE, FOOD PRODUCTION AND PRODUCTIVITY (INDIRECT IMPACTS)

Climate impacts on land-based fisheries & aquaculture and links to food supply

SENA S DE SILVA[A] & DORIS SOTO[B]

[a] School of Life & Environmental Sciences, Deakin University, Victoria, Australia
[b] Interdisciplinary Center for Aquaculture Research, Universidad de Concepcion, Chile

The role of inland fish for food security and development

Although fish have been an important dietary component throughout our evolutionary history[1,2], its contributions to global food security came to light only recently[3,4,5]. This realization is linked to the significant increases in fish consumption over the years; globally 5.2 (1961) to 18.8 kg caput^{-1} yr^{-1} in 2013 and in LIFDC from 3.5 to 7.6[6,7]. It is estimated[8] by 2030 per caput fish consumption global, in China and SE Asia would increase to 18.2, 41.0 and 28.3, respectively and the world will require 30-40x106 additional tonnes of fish to ensure food security.

Global fish production for human consumption reached 146x106 tonnes in 2014, providing more than 3.1 billion people with 20-30 percent of animal protein intake apart from essential fatty acids, vitamins and minerals. Of the former 40 % were from inland waters, primarily inland aquaculture (47x106 tonnes)[8]. In many African, Asian and Latin American countries inland fish provide more than 50 % of the animal protein (e.g. Bangladesh)[9].

Fish are often affordable to the rural poor, and help earn foreign exchange to developing countries through trade of specific commodities. More than 90 % of the global inland fisheries and aquaculture (IFAq) production occur in developing countries and produce is not rendered. Global aquaculture employment lies between 27.7 and 56.7 million full and part-time[10].

Inland fisheries support tens of millions of livelihoods globally and contribute significantly to diets of billions in nutrition sensitive areas such as African Great Lakes, river basins of the Nile, Niger, Ganges-Brahmaputra, Mekong and Amazon[8]. The difficulties in obtaining and poor quality of available information have underestimated current production and hindered scientific management[11].

Inland aquaculture accounts for 35-40 % of fish consumed, contributed significantly to closing the gap between supply and demand. Aquaculture practices, often are small scale, organised into clusters and range from extensive to intensive, and some communally managed as in culture-based fisheries (CBF)[12]. The activity partially compensates for the fishery losses from overfishing and some extreme events.

Climate change impacts (CCI)

CCI in fisheries are often over imposed with direct human intervention such as overfishing and pollution of water resources[13]. Freshwater ecosystems are more likely to be adversely impacted than marine ecosystems. Populations of freshwater species have declined on average by 50 percent (whilst 30% for marine species) between 1970 and 2000[14].

1 Crawford, M.A., Bloom, M., Broadhurst, C.L., *et al*. (1999). *Lipids* 34, S39-S47
2 Cunnnane, S.C.,Stewart, K.M. (2010). Hoboken, New Jersey, USA: John Wiley and Sons Inc., 213 pp.
3 Kawarazuka, N., Běně, C. (2010). Food Security 2, 342-357
4 Běně, C., Barange, M., Subasinghe, R., *et al*. (2015). Food Security 7, 261-274.
5 De Silva, S.S. (2016). Food Security 8, 585-596.
6 HLPE (2014). http://www.fao.org/fishery/statistics/software/fishstatj/en
7 FAO (2016) The state of the world Fisheries and Aquaculture 2016: contributing to food security and nutrition for all. Rome 200 pp
8 World Bank (2013). World Bank Report No. 83177-GLB, 102 pp.
9 Belton, B., Van Asseldonk, I.J., Hakingh-Thilsted, S. (2014). Food Policy 2014:77-87
10 Phillips, M., Subasinghe, R.P., Tran, N., *et al*. (2016). FAO Fisheries and Aquaculture Technical Paper, No.601, 81 pp. Rome, Italy
11 Youn, S-J., Taylor, W.W., Lynch, A.J., *et al*. (2014). Global Food Security (2014), http://dx.doi.org/10.1016/j.gfs.2014.09.005. 7 pp.
12 De Silva, S. S. (2003). Aquaculture, 221, 221-243.
13 Cochrane, K., De Young, C., Soto, D., T. Bahri (eds.). 2009. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. pp. 151-212.
14 http://www.fao.org/3/a-i5707e.pdf

Direct climate change effects include extreme weather events, rising water temperatures (influencing oxygen content, stratification intensity and higher oxygen demand for poikilotherms), changes in river flow patterns, extensive draughts and floods, increase salinization of coastal river basins (e.g. Mekong)[15]. The possibility of direct man-induced changes (e.g. dams) exacerbating CCI on inland fisheries and aquaculture (IFAq)[16] are a major reality (e.g. Mekong[17], Amazon Basin[18]).

Hydrology changes could impact on the reproductive cycle of species, and effect recruitment and consequently production[19]. In Lakes Tanganyika and Lake Malawi deep waters have warmed 0.2–0.7°C over the past 100 years, increased thermal stratification, and prevented upwelling affecting fishery productivity with yet unknown consequences on food security[20].

Aquaculture in Vietnam, Lao, Bangladesh, Myanmar and China[21] are ranked very vulnerable to climate change. The catfish farming in Vietnam, with a work force of nearly 200,000 and exports worth over US $ 4 billion[22]is made vulnerable from sea level rise and salinization[23]. Shrimp only and shrimp-rice alternating systems in deltaic areas of Bangladesh, major foreign exchange earners, are under threat[24].

CBF, a developing country practice in small water bodies, is predicted to yield 10 million tons of fish. This cost-effective strategy, enhances production many fold over that from natural recruitment[25],[26], and improves food security in rural areas. CBF is dependent entirely on the rainfall patterns and therefore vulnerable to CCI.

Adaptation strategies (AS)

AS to counteract negative impacts on inland fish production should be a coordinated watershed effort. Strategies for fishery communities include the development and adoption of alternative livelihoods, integrated monitoring and early warning systems[28] to prepare fishers for extreme events or to face sharp changes in the catches of target species. More flexible fishing gear and methods to harness unexploited species offer an option[27] but will have to be regulated to ensure maintenance of ecosystem services and sustainability of the resources; developing management plans according to an ecosystem approach to fisheries (EAF) could increase resilience of systems.

In aquaculture AS need to be developed and implemented according to specific farming systems and contexts.

Key governance aspects of adaptation, valid to all types of aquaculture include the spatial planning of aquaculture considering climate change related risks (especially extreme events and sudden circulation pattern changes in tropical lakes). Biosecurity frameworks and better management systems put in place to minimize risks, such as escape of cultured alien species, genetically improved strains. Implementation of integrated environmental monitoring and early warning systems at the watershed scale with stakeholder involvement are essential8,[28] to improve stakeholder understanding of climate change related threats.

Current farming systems already offer some adaptation opportunities; species resilient to temperature changes (e.g. carps, tilapias), and saline tolerant strains of some.

15 De Silva S.S, Soto D. (2009). *FAO Fisheries Technical Paper*, 530: 137-215.

16 Tello, G. (2013. FAO Actas de Pesca y Acuicultura No 29. Roma, FAO. pp. 103–181.

17 Mekong Commission (2011). Mekong River Commission Secretariat, Vientiane, Laos PDR. 254 pp.

18 Finer M., Jenkins C.N. (2012). PLoS ONE 7(4): e35126. doi:10.1371/journal.pone.0035126

19 Vass, K.K., Das, M.K., Srivastava, P.K., *et al*. (2009). Aquatic Ecosystem Health and Management, 12; 138-151.

20 Rosenzweig, C., Casassa, G., Karoly, D.J. *et al*. (2007) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. CUP, Cambridge, UK, pp. 79–131.

21 Handyside, N., Telfer, T.C., Ross, L.G. (2016). Fish & Fisheries. DOI:10.1111/faf.12186, 23

22 De Silva, S.S., Phuong T.N. (2011). *Reviews in Aquaculture*, 3, 45-73.

23 Nguyen, L.A., Vinh D. H., Bosma Roel, *et al*. (2014) Ambio, 43; 1059-1068.

24 Ahmed, N., Diana, J.S. (2015). Ocean and Coastal Management, 114; 42-52

25 Pushpalatha, K.B.C., Chandrasoma, J. (2010). Journal of Applied Ichthyology, 26, 99-104.

26 Phomsouvanh, A., Saphakdy, B., De Silva S. S. (2015). Aquaculture, 439, 29-38.

27 Amarasinghe, U. S, Ajith Kumara, P.A.D., De Silva Sena S. (2016). Food Security, 8; 769-781.

28 FAO (2016). FAO Fisheries and Aquaculture Proceedings No. 45. Rome, Italy

Polyculture of two or more species (carps or carps and tilapia/catfish) predominate in major inland aquaculture producers like Bangladesh, China and India; highly diversified and recognized as resilient culture systems. These enable saving on feed and other external inputs are more resilient to mono-culture systems, and economically viable.

AS should involve minimal dislocation of farming communities and major overhaul of practices e.g. species changes related acquisition of expertise and costly infrastructure developments. For example, the most desirable adaptation for sea level rise impacts of catfish farming in the lower Mekong Delta is the development of salinity tolerant strain(s)[29]. Such approach has already involved relevant investment in research but will require significant implementation efforts.

AS to climate change in aquaculture cannot be considered in isolation. When challenges of feeding nine billion people (by 2050) are considered the issues raised are competition for land, water and energy and the over exploitation of fishery resources[30],[31]. A primary strategy to CCI in the tropics will be to minimize water use and in this context rice-fish/ shrimp farming provide options of generating synergies from combined farming systems[32],[33]. Implementation of an ecosystem approach to aquaculture allows to develop landscape based participatory management plans that address the socioeconomic, environmental and governance objectives while using risk assessment to design management measures[34]. Aquaponics is another promising option by supplementing food security, farmer incomes, reducing nutrient in effluent and efficient use of water[35].

Recommendations

An era where a further decrease from the marine capture fisheries is predicted[36], making the contribution of IFAq even more important for global food security.

Water is becoming a precious and limiting resource and most of the CCI revolve around the "water cycle" therefore is imperative to develop adaptive approaches that combine farming systems to improve efficacies for food security. Specific recommendations that link inland fisheries and inland aquaculture to this domain are:

- More in depth studies are needed to better understand direct and indirect CCI on inland fisheries; there is a need to incorporate climatic events and land use pattern of catchments and develop quantitative models to enable to understand the interactions and facilitate planning and management and streamline IFAq in the National Adaptation Plans and in watershed planning.
- Aquaculture practices that use a combination of species that feed low in the trophic chain should be encouraged, resulting in minimal GHG emissions per unit food fish.
- Adaptations should involve minimal dislocation of farming communities and changes to existing practices.
- Initiate R & D on farming systems that could work in combination e.g. rice-fish, rice-shrimp and develop adaptive measures that are "water saving " through aquaponics and other forms of integrated farming.
- The global community must give the deserved attention to the impacts of climate change on in inland ecosystems, fisheries and aquaculture.

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PLENARY SESSION 2:
CLIMATE IMPACTS ON LAND USE, FOOD PRODUCTION AND PRODUCTIVITY (INDIRECT IMPACTS)

Climate impacts on forest ecosystems and their pollinators, and impacts on food supply

INOUYE, DAVID W., STEIN J. HEGLAND, AND SIMON G. POTTS.

The vast majority of cultivated and wild flowering plants benefit from animal pollination. Approximately 200,000 species of animals serve as pollinators. More than 75% of leading food crops and ca. 35 % of crop volume depend on the ecosystem service that pollinators provide, and this dependency is growing as shown by the >300% increase in volume of agricultural production dependent on pollinators since 1961. The global economic value of these crops is €211 – 518 billion/yr. Natural ecosystems are also dependent on pollinators, as almost 90% of wildflowers rely at least in part on animal pollination, and their pollination helps to maintain biodiversity and ecosystem functioning.

Both managed and wild pollinators are vital to agriculture, as some crops are not serviced well by honey bees, the predominant managed pollinators. In many cases benefits to quality and/or quantity of crop production result from wild pollinators' activity. Bumble bees are now being commercially managed too, and while both managed and wild colonies can be excellent pollinators, wild populations of many species are now at risk, with some species thought to have gone extinct in the past few years. In Europe, 26% of bumble bees are threatened and the United States has recently classified one species as threatened.

Pollination service is under threat due to climate change, habitat destruction, agricultural intensification, increased pesticide use, and other anthropogenic activities. Climate change may cause spatial or temporal mismatches between flowers and pollinators and affect the physiology of these mutualistic partners. Insect pollinators are relatively mobile and have been shown to be expanding ranges in latitude and altitude, presumably in response to the changing climate. But there is concern because if the spatial distribution of the crops and pollinators lose significant overlap, pollination deficits may result. A study of orchards in Great Britain makes this point as the projected distributions of trees and pollinators will have significant areas of non-overlap by 2050. Projected shifts of suitable areas for cultivation of *Coffea arabica* coffee and of cacao will result in some major producing areas losing production as suitable climate zones move up in altitude or change latitude.

Changes in the phenology of plants and pollinators are occurring in both wild and managed ecosystems, and we are just beginning to observe potentially negative consequences. In some cases previously synchronized interactions are being disrupted, as one partner's activity period loses overlap with the other's. At a minimum this will result in re-organized ecological communities, and at worst, in the potential loss of some species. A study of the phenology of apple trees and their pollinators makes this point. We can expect to see increasing examples of spatial and temporal mismatch of pollinators and the plants they visit.

Pollinator services from wild bees, which provide the most efficient and important pollination service worldwide, can be preserved and increased by increasing the amount of natural areas within and around farmed areas. This will provide the combination of nesting sites and floral resources necessary to maintain pollinators, and if these natural areas are in proximity to cultivated areas, the crops will benefit. There are now multiple examples of such benefits documented for coffee plantations and for mass-flowering crops in agroecosystems.

The recent IPBES report on Pollination, Pollinators, and Food Production provides some important, relatively inexpensive, and effective policy recommendations to help support pollinator populations. If widely adopted they could have significant impact on future food security.

Theme 2. Human-directed drivers for land use, land use change degradation, and desertification, and implications for food security

PLENARY SESSION 3:
HUMAN-DIRECTED DRIVERS OF LAND USE AND LAND USE CHANGE, LAND DEGRADATION AND IMPLICATIONS FOR FOOD SECURITY

Human-directed drivers of land use change: implications for food security, economic and resource costs

ALISHER MIRZABAEV AND JOACHIM VON BRAUN

Introduction

Land use and cover changes (LUCC) will have critical impacts on the trajectories of future climatic changes and the functioning of food systems (Wheeler and von Braun 2013). Forests serve as the biggest terrestrial carbon sink, containing about 46% of global carbon stocks in their vegetation and the soil beneath them (Noble *et al* 2000). Similarly, grasslands, account for 20% of the soil carbon stocks (Ramankutty *et al*. 2008). According to remote sensing data, the cropland covers 23% of the global land area (Nkonya *et al*. 2016), though containing only about 5% of global carbon stocks (Noble *et al*. 2000). It has been shown that deforestation and other forms of land use change account for almost half of CO_2 emission in Sub-Saharan Africa (Canadell *et al*. 2009). Moreover, increasing demands for food and biomass due to growing populations, incomes and more diversified and competing uses of biomass in emerging bioeconomy sectors are likely to further intensify pressures for global LUCC. Already the annual global cost of lost ecosystem services of land due to LUCC was estimated to equal 234 billion USD (Nkonya *et al*. 2016). Therefore, an improved understanding of drivers of LUCC is essential for more accurate forecasting of the LUCC impacts on both future climate and the food systems, and of potential policy measures to facilitate the achievement of Sustainable Development Goals (SDGs) under changing resource constraints due to LUCC.

Drivers of land use change

Drivers of land use and cover changes are numerous, complex and interrelated (Nkonya *et al*. 2016), with often context-dependent characteristics (Mirzabaev *et al*. 2016). They can be classified into two categories: proximate and underlying. Proximate drivers comprise of immediate human actions that modify land use and land cover. Underlying drivers are the root factors shaping human behavior causing land use changes, formed by a complex of human-directed social, political, economic, demographic, technological, cultural factors, as well as by biophysical conditions (ibid.). If proximate drivers operate at the local scale, underlying drivers usually operate at larger scales, including global (Lambin *et al* 2003). Among the underlying drivers, biophysical drivers are the natural factors leading to land cover changes, such as climate variability, topography, soil types and others. Biophysical factors interact with human causes to lead to land-use changes.

Changing resource constraints due to past LUCCs modify resource prices and economic costs thus creating endogenous feedback loops that modify future LUCCs. For example, deforestation in the highlands of Vietnam leading to soil erosion and decreasing the profitability of the then prevalent slash-and-burn crop cultivation occurred at the same time when lowland rice production was experiencing significant productivity gains through the application of labor-intensive technologies. As a result, new resource constraints and profitability considerations led to the re-allocation of labor to lowland rice production allowing for the highland deforestation to reverse (Lambin and Meyfroidt 2010). Moreover, significant deforestation and loss of forest ecosystem services also prompted the Vietnamese government to establish new reforestation programs (ibid.). Similarly, the interaction of rapid urbanization due to socio-economic development, governmental afforestation and reforestation policies, and climate change impacts on the profitability of crop production were found to be the major drivers of land use changes in China over last two decades (Liu *et al* 2010). Growth in international coffee prices, certain characteristics of fiscal policies, lack of transparent property rights, inconsistencies in forestry legislation were found to be among the major drivers of deforestation in Sumatra region of Indonesia (Verbist *et al*. 2005).

As we see from above examples, the drivers of land use changes usually do not operate in isolation but are combined in context-specific interactions, thus potentially leading to heterogeneous outcomes depending on the context. Lambin *et al* (2003) indicate that despite such diversity, the drivers of land use change could be classified into some generalizable patterns or typical pathways. The critical challenge is thus to identify dominant pathways and associated causes of land use changes. This is the basis, for example, for the syndrome approach, which describes typical patterns of human-environment interactions.

Implications for food security, economic and resource costs

The impacts of land use changes could be classified into environmental and socio-economic (Briassoulis 2000). Land use changes influence global climatic changes through carbon emissions or through carbon sequestration (Meyer and Turner 1996), alterations of the global water cycles, land degradation, biodiversity and habitat loss and other effects. The food security impacts of land use changes may result from reductions in the area of agricultural land through decreases in available water supplies, land degradation, urbanization, and in general, poor management of land resources. Depending on their scales, land use changes could have local, regional or global environmental and socio-economic impacts. Interconnected nature of global climate and food systems requires careful attention to the global indirect land use changes due to potential displacement of land use changes (Meyfroidt *et al*. 2013).

LUCCs modify the capacity of land to provide ecosystem services both in terms of the total value of ecosystem services and their composition. Often, LUCCs involve a trade-off between different ecosystem goods and services. For example, deforestation for cropland expansion may reduce the total value of ecosystem services that humans derive, but could significantly increase the provisioning goods and services, in the form of additional food and fodder production. Resulting improved food availability positively contributes to food security, but could also lead to significant carbon releases to the atmosphere thus contributing to global warming. Similarly, urbanization could expand at the expense of prime agricultural land thus potentially reducing agricultural production (d'Ampour *et al*. 2016); at the same time, urbanization could allow for increasing incomes, thus providing with opportunities for improved food access. Such trade-offs of different land use changes need to be studied through systems-based approaches, such as, for example, Water-Energy-Food Security Nexus (Ringler *et al*. 2013).

In order to minimize negative impacts of land use changes, there is a need for developing land use policies and planning that will ensure that high-value biomes, such as forests, are protected and continue to provide ecosystem services both to local and global communities. The conversion of forests into grazing lands was found to be the major driver of deforestation in the Amazon region (Nkonya *et al*. 2016). In Central Asia, conversion of grassland to barren lands and shrublands was found to be the major type of detrimental LUCC (Mirzabaev *et al* 2016), while in Sub-Saharan Africa, the conversion of grassland to cropland was the leading cause of land degradation due to LUCC (Nkonya *et al*. 2016). One of the major reasons for the conversion of grassland to cropland in SSA is the low livestock productivity. Strategies for addressing the conversion of grassland to cropland involve increasing livestock productivity, which may be more effective than enforcement of land use policies aimed at preventing LUCC.

Lack of integration of the total value of ecosystem services into economic decision-making frameworks remains, however, the major reason behind LUCCs that lead to the net losses of ecosystem services provided by land in many parts of the world (von Braun *et al* 2013). Presently, provisioning services of land, such as food, have market values, but many other supporting and regulating ecosystem services do not have market prices. The payment for ecosystem services (PES) mechanisms that saw large investments in carbon markets should be given a new impetus to address the loss of ecosystem services through land use and cover change (LUCC). However, deforestation often occurs in areas without secure tenure regimes, hence a combination of incentive and disincentive-based mechanism might be needed to effectively reduce deforestation (Börner *et al*. 2014, Lambin *et al*. 2014). Moreover, empirical evidence also shows that sustainable forest management is likely in forests managed by local communities (Poteete and Ostrom 2004). Similarly, protected areas that involve local communities in the management and who, in return, receive direct benefits have been more successful (Coad *et al*. 2008).

An improved understanding of the drivers and impacts of land use changes requires more interdisciplinary approaches to studying land use changes. Geography-based studies without economic frameworks integrating human behavior may lead to misleading outcomes (Irwin and Geoghegan 2001). Similarly, economics-based studies need to integrate geographical and natural science frameworks for improved spatial disaggregation and explicit modeling of land use changes (ibid.).

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PLENARY SESSION 3:
HUMAN-DIRECTED DRIVERS OF LAND USE AND LAND USE CHANGE, LAND DEGRADATION AND IMPLICATIONS FOR FOOD SECURITY

Synergies and trade-offs between forestland management and food system

ARILD ANGELSEN[1]

Introduction

A long-standing debate concerns the impact of improved agricultural technologies and higher yield on agricultural land expansion into natural habitats (including forests) with subsequent biodiversity loss and greenhouse gas (GHG) emissions. Is higher yield (i) land saving, as growing demand for food and other agricultural outputs can be met by the same acreage (the Borlaug hypothesis, based on a simple global food equation), or (ii) does the potentially higher profitability of crop and livestock production stimulate land expansion (the Jevons paradox)? The answer to the question depends on the technology in question, the farm and farmer characteristics, the biophysical and institutional/ policy environment, the market conditions, as well as the scale of adoption and of the analysis (Angelsen and Kaimowitz, 2001a).

The potential of achieving win-win outcomes formed part of the basis for the promotion of Green Revolution technologies and – more recently – of climate smart agriculture (CSA), and – as a subset of that – conservation agriculture (CA). CSA and CA has gained prominence among donors, NGOs, national ministries, international research centres and agricultural extension agencies as a potentially viable means to increase agricultural productivity and food security while delivering climate benefits, both *on-site* and *off-site* by reducing pressure on natural habitats. They are also linked to the call for sustainable intensification (SI) of agriculture, to avoid "the risk that land is cleared for agricultural production elsewhere to compensate for locally lower yields" (Garnett *et al.*, 2013, 33).

The AR5 IPCC also points to CA principles and sustainable intensification as a major avenue for both climate mitigation and adaptation in agriculture (Niang *et al.*, 2014; Smith *et al.*, 2014). This debate is also linked to the question on land sharing vs. land sparing, that is, whether optimal production and conservation benefits are achieved by integrating the two objectives at the same land or by landscape specialization (Phalan *et al.*, 2011; Kremen, 2015).

These linked concepts of CSA, CA and SI raise at least three major issues: (i) adoption; (ii) impact on yield, farm incomes and food security; and (iii) impact on GHG emissions and other environmental outcomes. This note focusses on the latter. There is, however, a lively debate on adoption rates, e.g., of CA in Sub-Saharan Africa. Despite almost two decades of sustained CA promotion among small-scale farmers in SSA, the extent of its adoption among smallholders remains mixed and contested (Giller *et al.*, 2009)2009. Ngoma *et al.* (2016) find, using nationally representative data, for Zambia that less than 5% of the smallholders (on less than 3% of total cultivated land) practice minimum tillage, while other estimates have reported as high as 71% uptake. CA practices tend to be labour intensive, and family labour supply is limited and farmers often cannot afford to hire in labour. The investments in CA can pay dividends over the medium-long term in terms of higher crop yield, but the high initial costs – including own labour – make some reluctant.

The yield effects from CA and other forms of SI are, in general favourable. Evidence from experimental plots suggests that CA may improve maize yields in the medium to long term but that short term benefits are variable and negative on average (Thierfelder *et al.*, 2015)2015. A meta-analysis of CA yield impact points that the effect depends on a number of factors, such as rainfall and drainage and the level of inputs (including fertilizers) (Rusinamhodzi *et al.*, 2011).

The impact on GHG emissions can be split into *on-site* and *off-site* emission, the latter being linked to direct and indirect land cover change. Improved soil carbon sequestration resulting from reduced tillage and enhanced build-up of soil organic matter can reduce emissions and enhance removals. According to some estimates, improved practices, such as minimum tillage, can reduce emissions by as much as 1.1-4.3 $GtCO_2e\ y^{-1}$ by 2020 (UNEP, 2013). Others questions, however, the methods used and argue that the estimates are overstated (Powlson *et al.*, 2014; Powlson *et al.*, 2016). The remainder of this note deals with the impact of new technologies and higher yield on agricultural land expansion,

[1] I am grateful for very useful comments and literature suggestions from Tobias Kümmerle, Hambulo Ngoma, Ben Phalan and the expert meeting participants to the first draft of this summary.

resulting in higher emissions from deforestation and forest degradation. In the tropics, 83% of new agricultural land is from forest conversion (Gibbs *et al.*, 2010).

Technological change and deforestation – conceptual issues

The economic analysis of the impact of improved technologies and higher yields can proceed in two steps. First, a farm-level analysis of how individual farmers respond and thereby how output supply and input demand will change; and second, the market (general equilibrium) effects of those supply and demand changes, and the resulting land use changes both locally and globally (i.e., outside the region experiencing technological change). Three characteristics are critical for the land expansion outcomes (Angelsen and Kaimowitz, 2001a):

Type of technologies: The labour, capital and other input intensities of the new technologies is critical for the forest outcome. Most farmers are capital and labour constrained, hence if labour- and/or capital-intensive technologies are adopted, they tend to constrain land expansion. Looking beyond the individual farm, the adoption of labour-intensive practices can drive up rural wages, and dampen agricultural profitability and expansion.

Farmers seek to adopt technologies that enlarge their opportunities, and might therefore be reluctant to adopt labour intensive technologies, unless their profitability or other characteristics are much more attractive than current practices. The paradox arises, therefore, that while labour-intensive practices can restrain agricultural land expansion, farmers "will only be willing to adopt such land-saving practices when land has become scarce and most of the forest is gone" (Kaimowitz and Angelsen, 2008, 6). In sum, farmers do have strong incentives to adopt technologies that boost yield and raise profitability, but this could provide incentives to intensify production and expand less, *or* to expand crop or pasture areas.

Output markets: Yield-increasing technological progress increases food supplies, contributing to keeping food prices low. This might reduce farmers' income ("treadmill effect"), but benefit (poor) consumers. The magnitude of the price effect depends on two factors (Angelsen, 2007; Hertel, 2012): the demand elasticity in the market, and the market share of the sector experiencing technological progress. The price-dampening effect can be low either because the total market demand is inelastic, or because its market share is low, or both. Demand for food is generally assumed to be inelastic, i.e., supply change leads to a large price change. Many agricultural products are, however, not food stuff (e.g., cotton and rubber), they are not staple food stuff (e.g., cocoa and coffee), or they are subject to demand from multiple markets, such as for food, livestock feed and biofuels (e.g. maize and soybeans). Further, farmers selling products at large national or global markets are less likely to face downward pressure on prices when they increase their supply. "Innovations in regions commanding a small share of global production, with relatively low yields, high land supply elasticities and low emissions efficiencies are most likely to lead to an increase in global land use change emissions" (Hertel, 2012, 1). He notes that conflicting results of technology impacts on land expansion are mainly due to differences in demand elasticities.

Other market conditions are also relevant, for example, to what extent there is a well-functioning labour market (including migration) to supply more labour for the adoption of labour-intensive technologies, thus avoiding any brakes on expansion due to labour shortages and higher local wages.

Scale and sector of adoption: The output market share is also linked to the scale of adoption. The more widespread the adoption, the larger, *cet. par.,* the supply increase and the price-dampening effect. The scale of adoption - and of the analysis itself - is therefore critical. Thus "situations that are win-lose at the local level may be win-win at the global level" (Angelsen and Kaimowitz, 2001b, 400). The Green Revolution is a form of technological progress in intensive agriculture, which has saved large amounts of forests. The effect works principally through the output markets by keeping the prices of rice, maize and other food crops lower than they would have been without the Green Revolution. Technological progress in intensive agriculture can therefore be expected to slow down expansion of extensive agriculture (into forests), in part though output market effects. Thus efforts to spare forests, should focus on innovations which are appropriate for established areas and not for frontiers.

Labour market effects also pull in the same direction, as exemplified by intensified lowland rice production pulling labour out of upland rice cultivation in the Philippines (Shively and Pagiola, 2004). There are exceptions to this. In a study from Sulawesi (Indonesia), Ruf (2001) finds that Green Revolution technologies were linked with more forest clearing in the uplands for cocoa planting through two effects: (i) the technologies implied a mechanization of lowland rice production (hand-tractors), which freed up labour, and (ii) the increased profitability provided funds for investing in cocoa production in the uplands.

Empirical evidence

An early synthesis of case study evidence by Angelsen and Kaimowitz (2001a) provided mixed evidence on the impact of improved technologies on deforestation. The forest impact varies depending on the factors discussed above. They conclude in the following way: "The basic Borlaug hypothesis – that we must increase agricultural yields to meet growing global food demand if we want to avoid further encroachment by agriculture – still holds. Still, that by no means guarantees that specific agricultural technologies that farmers adopt will help conserve forests. The current trend towards more global product, capital and labour markets has probably heightened the potential dangers. Technologies that make agriculture on the forest frontier more profitable and that displace labour present particularly strong risks, while technologies that improve the productivity of traditional agricultural regions and are highly labour-intensive show the most promise" (Angelsen and Kaimowitz, 2001b, 402).

A comprehensive review by Villoria *et al.* (2014) reach similar conclusions, largely confirming theoretical results, but noting that data and empirical results are lagging behind our theoretical insights. Technological progress at the global level is likely to take pressure off forests, yet low-yield, land-abundant regions are likely to experience further land expansion. Globalization has improved markets access and technology transfer and diffusion. These processes can drive deforestation in new frontiers, exemplified by new soybean and cattle expansion in Southern Africa (Gasparri and Waroux, 2015).

Byerlee *et al.* (2014) suggests that there is a crucial difference between technology driven and market driven intensification; the former has generally reduced cropland use and deforestation, while the latter has been a major case of agricultural expansion and deforestation. Their definitions are important: "technology-driven intensification occurs when technical change in a crop allows for more output of land for the same level of input", while market-driven intensification "results from a shift in product mix to higher value crops due to new market opportunities, or a shift in input mix in response to relative price changes" (page 93). Technological change in the presence of favourable market conditions (growing demand and rising prices) does provide strong incentives for land expansion, as exemplified by a series of commodity booms throughout history (e.g., Ruf, 2001).

National and global level analyses are either done by econometric or by simulation models. Ewers *et al.* (2009) use country-level data for the period 1980–2000 to test whether increases in agricultural yield have serendipitously spared land for nature. If "perfect land-sparing" yield change were occurring (as in the simple global food equation), the land-yield elasticity should be –1. They find a much lower elasticity: –0.152 (t = –1.78) for developing and –0.089 (t = –0.57) for developed countries. Similarly, Rudel *et al.* (2009) find that "agricultural intensification was not generally accompanied by decline or stasis in cropland area at a national scale during this time period [1970-2005], except in countries with grain imports and conservation set-aside programs" (page 20675).

A central effort among simulation models has been the GTAP (Global Trade Analysis Project) (Baldos and Hertel, 2012b) and the SIMPLE model (Baldos and Hertel, 2012a), and the GLOBIOM (Havlík *et al.*, 2014) . Hertel (2012) gives a theoretical description and numerical illustration, and several more specific applications have been implemented. Stevenson *et al.* (2013) estimates that Green Revolution research saved 18-27 million ha from being brought into agricultural production (and a significant share of this gain being forest). Their simulation results are, however, "order of magnitude lower than predicted by the simple global food equation that does not take account of feedback loops through prices of products, consumption demand, and land-use decisions" (page 8365). Villoria *et al.* (2013) investigated the impact of yield increases in oil palm production, either in only the two dominant producers Indonesia and Malaysia, or globally. If only Indonesia and Malaysia experience technological progress, they observe a modest effect in terms of area expansion locally, but the opposite in other regions. If the change is global, emissions from deforestation are reduced both locally and globally.

Keeping track of indirect land use change (ILUC) is inherently difficult; econometric models cannot capture many of the effects, and simulation models are based on strong assumptions. A causal analysis framework for land use change (Efroymson *et al.*, 2016), whose core is a strength-of-evidence approach, could provide a fruitful route to integrate the multiple sources of evidence that exist in the form of case studies, statistical analysis and simulation models.
The forest outcomes of technological progress in agriculture can be mixed, but the likelihood of win-win outcomes can be enhanced through policies. "Technology-driven intensification by itself is unlikely to arrest deforestation

unless accompanied by stronger governance of natural resources" (Byerlee *et al.*, 2014, 92). These policies would include land-use zoning, economic instruments, strategic deployment of infrastructure, certification, and sustainability standards (Phalan *et al.*, 2016). There are few, if any, examples of where such policies have been designed with the explicit intention of promoting a land-sparing outcome. Designing and testing the success of such measures should be a key focus of agricultural programmes aiming for zero deforestation, as well as those seeking to expand the area available for restoration of native forests (Latawiec *et al.*, 2015).

Summary

First, the Borlaug hypothesis might hold at the global level, and in particular for yield-increasing technological change that produce for markets with inelastic demand.

Second, technological changes at local or even national level show mixed outcomes on forests, depending on technology and market characteristics. Simply assuming a particular outcome can lead to unintended climate effects of policy interventions.

Third, technological progress can also lead to more deforestation, due to the higher profitability, when market conditions are favourable for expansion, or when technology diffusion leads to the emergence of new deforestation frontiers.

Fourth, although technological progress alone cannot guarantee forest conservation, it can be part of a carefully-designed policy package that ensure win-win outcomes (local income and food security, and forest conservation with biodiversity and climate mitigation benefits).

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PLENARY SESSION 4:
HUMAN-DIRECTED IMPACTS ON WATER SCARCITY, BIODIVERSITY AND IMPLICATIONS FOR FOOD SECURITY

Freshwater availability and water scarcity: Projected effects on agricultural water scarcity

TIM HESS, CHLOE SUTCLIFFE & DAVID HARO, CRANFIELD UNIVERSITY, UK

Irrigation is key for global food supplies, and its importance is set to grow in future as demand for food increases, whilst the reliability of yields from rain-fed agriculture is projected to decline due to climate change. The global population is predicted to increase to 11.2 billion by 2100 (United Nations Department of Economic and Social Affairs Population Division, 2015), and to meet requirements food production will need to also increase (Alexandratos & Bruinsma 2012). Yet, even contemporary water resources in many global regions are already overstretched and two thirds of the global population are living under conditions of severe water scarcity for at least one month during the year (Mekonnen & Hoekstra 2016). For example, presently, aquifers where extraction is estimated to exceed recharge include the Ganges and the Indus Basin in South Asia, the Californian Central Valley Aquifer System in the United States, and the North China Aquifer System and the Tarim Basin in China (Richey *et al*. 2015). These are also areas where the timing of water supplies for agricultural production is an equally important consideration for sustainable agricultural production, with seasonal water shortages that coincide with peaks in summer demand causing concern in many important agricultural areas.

In the absence of climate change, water scarcity is projected to grow considerably due to beinggrowing human pressure on water resources (Gosling & Arnell 2016). The hydrological impacts of climate change may either mitigate or exacerbate the water scarcity (Haddeland *et al*. 2014). It is therefore essential that the potential impacts of climate change on water availability for agriculture are well understood so that adaptive water management measures can be put in place (Döll *et al*. 2014) .

Water availability for irrigation is determined by precipitation, and there is strong agreement between climate models that global mean precipitation will increase linearly as global temperatures rise (IPCC, 2014). However, there will be major changes to the geographical distribution and timing of rainfall and snowmelt, and scaling down to the regional level, there is much less certainty about how future precipitation will be distributed (Schewe *et al*. 2014). Climate change will also impact water resources via other mechanisms, including the effects of temperature and atmospheric CO_2 concentration on evapotranspiration from plants, and changes to the partitioning of excess rainfall between surface runoff and groundwater recharge stemming from changes in rainfall timing, intensity and soil surface conditions.

Climate change impacts on the hydrological system and water availability will undoubtedly be far-reaching, but it is difficult to predict with confidence what the outcomes will be at the regional scale because of high uncertainty within downscaled precipitation projections and the additional uncertainty stemming from the incorporation of hydrological models (Haddeland *et al*. 2014).

A review was carried out of 40 articles and conference proceedings published since the IPCC Fifth Assessment Report (published in 2012 and 2013). There was greatest coverage in Europe (9 articles), followed by South Asia and East Asia (both 6), the Middle East (5), North Africa (4), sub-Saharan Africa (4), South America (3), Central America (2), Southeast Asia (1) and Australasia (1). Five articles with global coverage were also identified. There was notably greater coverage of projections with regard to surface water impacts (33) than those which expressly concerned estimations of groundwater (7).

Global precipitation and therefore runoff is expected to increase overall as a result of climate change, and there is strong agreement that discharge will increase at high northern latitudes, eastern Africa and on the Indian peninsula, and that reductions in water resources are to be expected in mid-latitude regions including the Mediterranean and large parts of North and South America (Schewe *et al*. 2014). However, regional projections remain highly uncertain in many areas in terms of both the magnitude and even the sign of the change. Despite a mean intensification in global hydrology, the studies mainly concurred that climate change would, in most locations, result in reduced water availability due to amplified temporal-spatial variability of water supply (Leng *et al*. 2015) , including in areas where production from irrigated agriculture plays a major role in global food security.

Three continents stand out as hotspots for hydrological impacts on agriculture as climate change progresses; South Asia, East Asia and North America. These are areas where water resources for irrigation are already highly stressed; where human impacts on the water cycle are equal to, or exceed, the impacts that can be expected from moderate climate change (Haddeland *et al*. 2014); where aquifer withdrawals for agriculture equals or exceeds recharge values (Richey *et al*. 2015), and where the impacts of climate change will have far reaching implications in terms of affected populations and global food production.

The Indus Basin in South Asia is considered the basin most affected by human impacts on a global comparative scale (Haddeland *et al.* 2014). Streamflow is projected to increase in some areas (Mahmood & Jia 2016; Mathison *et al*. 2015; Narsimlu *et al*. 2013; Pechlivanidis *et al*. 2015; Roy *et al*. 2015) but the timing of increases is critical, with some studies projecting increases to occur entirely in monsoon season and reductions to occur at other times (e.g., Narsimlu *et al*. 2013). This may serve to reduce the utility to agriculture of the extra streamflow and increase the risk of flooding (Mathison *et al*. 2015). In South Asia implications for irrigated agriculture depend critically on abilities to harvest increased water resources where they occur, yet high uncertainty in projections means that investing in large-scale infrastructure projects carries with it heavy risk. One global study identified uncertainty in projections as being particularly high for South Asia and East Asia (Gosling & Arnell 2016), and another projected that freshwater scarcity in the regions identified here as hotspots (Western United States, China and West, South and Central Asia) could force between 20 and 60 Mha of cropland to change from rain-fed to irrigated agriculture by 2100 (Elliott *et al*. 2014), hence decisions around how to undertake management of water resources in preparation for future climate impacts must be taken very carefully in order to avoid maladaptation. Ultimately the reduction in available water for irrigation is likely to translate increasing food prices on the global market (Haddeland *et al*. 2014).

Multi-model ensembles are increasingly used within climate and hydrological studies to produce a range of climate projections that provide an estimation of the degree of certainty according to model selection. However, instances wherein studies seeking to project the hydrological impacts of climate change have incorporated both climate and hydrological ensembles were scarce within the literature identified by this review, with recent studies on the whole tending to employ multiple climate models, but only one hydrological model. Where studies used both, large uncertainties were identified as coming from both GCMs and GHMs (Schewe *et al*. 2014), with greater uncertainty being attributed by one study to the GHM ensemble outputs (Elliott *et al*. 2014). Further uncertainty in terms of model outputs can arise from the use of different measures to define water scarcity between projects (Gosling & Arnell 2016). Most of the hydrological models used did not include any estimation of the effect of CO_2 concentrations on evapotranspiration rates (Döll *et al*. 2016). There is thus some suggestion arising from the findings of vegetation models that hydrological studies may be overestimating probable irrigation requirements and scarcity (Elliott *et al*. 2014), and one ensemble study using an eco-hydrological model that did include this effect projected a decrease in global irrigation demand of around 17% (albeit with large increases in certain areas) (Konzmann *et al*. 2013). Future studies should seek to interrogate these discrepancies. Additional advances in hydrological impacts modelling could be achieved by developing a more nuanced understanding of the seasonality of impacts and by increasing the coherence between different studies in terms of both the measures of water availability and terminology for describing water resources that are used. All these issues speak to the need for advances in hydrological modelling to increase the robustness of outputs concerning climate change impacts on water resources, as well as for greater interdisciplinary efforts to identify low regret adaptation options that are suitable under conditions of uncertainty.

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PLENARY SESSION 4:
HUMAN-DIRECTED IMPACTS ON WATER SCARCITY, BIODIVERSITY AND IMPLICATIONS FOR FOOD SECURITY

Degradation of mangrove ecosystems and implications for greenhouse gas emissions, biodiversity and food security

DANIEL MURDIYARSO

Globally mangroves cover an area of around 14 million hectares, distributed in more than 30 countries, mainly in the tropics. With more than 50 mangrove species and multitude of fish and shellfish species these tidally influenced vegetation are biologically diverse. Their enormous ecosystem services ranging from provisioning (fish habitat, wood, fuel, and food), supporting (nutrient cycling and land building) and regulating (pollution, salinity, carbon storage, wave, storm surges, and tsunami) services are well documented.

The capacity of mangroves and other blue carbon ecosystems in sequestering atmospheric carbon is due to their high carbon burial rates, which are around 20 times higher than any terrestrial ecosystems (McLeod *et al*. 2011). Therefore, the carbon stocks in mangrove ecosystem is high as four times (ca. 1000 Mg/ha) compared to other terrestrial ecosystem (Donato *et al*. 2011, Alongi *et al*. 2014, Murdiyarso *et al*. 2105).

Mangroves are often highly productive and harbor a unique assemblage of aquatic and terrestrial biodiversity. The net primary production of mangroves ecosystem is the highest compared with any terrestrial ecosystem.

Sustainable value change of fish product from the coastal landscape is associated with food security in aquaculture systems. The issue may range from the access to land, distribution and quality (nutrition) of fish products.

Mangroves and other coastal ecosystems are facing tremendous pressure due to land-use change for aquaculture, agriculture and infrastructure development. The world's mangrove has lost more than 40% in the past 30 years. Mangrove deforeatation potentially costs up to US$ 40 billion *per annum* (Pendleton *et al*. 2012).

The implications of mangrove deforestation is multitude. The most immediate one is GHG emissions. The rate is staggering as it is estimated to range between 0.02 and 0.12 Pg annually (Donato *et al*. 2011). This amount is 10% of emissions from deforestation globally, despite accounting for just 0.7% of tropical forest area.

Although biodiversity as many facets, mangrove deforestation with regeneration has the potential of re-introducing mono-species. This will substantially affect species diversity in all coastal settings. Aquatic biota will be tremendously affected as the nutrient cycling is altered.

Food security in the context of coastal community is closely related to the sustainability of fish production. Unless the ponds or farms receive high inputs, it is unlikely that the current supply can be maintained (Lebel *et al*. 2002). A new finding confirms that food production and security is associated with mangrove conversions for oil palm and rice production (Richards and Freiss 2015).

Managing mangrove and other coastal wetlands ecosystem through conservation and rehabilitation should consider human dimension vis-à-vis multi-stakeholder objectives and biodiversity. Working with local community, embracing their agenda and understanding of mangrove hydrology are key ingredients for the success of mangrove restoration.

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Theme 3. Climate mitigation in agriculture and other land uses and linkages to food security

PLENARY SESSION 5:
EMISSIONS FROM AGRICULTURE AND LAND USING SYSTEMS AND FROM FOOD CONSUMPTION

Trends of GHG emissions resulting from food systems (crops, livestock, land-based aquaculture, processed food)

LOUIS VERCHOT

Over much of the 19th century and the first half of the 20th century land use and land-use change was the dominant source of greenhouse gas emissions to the atmosphere. Near the middle of the 20th century, land based greenhouse gases accounted for about 50 percent of all emissions. The major reason for the decreasing importance of land based emissions was the exponential growth of fossil fuel emissions. In absolute terms, land based emissions have had periods of growth and decline since the beginning of the 20th century. Emissions declined during both of the world wars and during the 1970s. We are now in a new phase of declining emissions that began in the mid-1990s and appears to be accelerating. Today, land use and land-use change is responsible for about 25% of global greenhouse gas emissions and in absolute terms, emissions are declining by around 12 percent per decade.

There are two types of emission associated with crop and livestock production: those associated with land clearing to expand production to new areas; and those associated with production and management practices. Most deforestation and conversion of natural ecosystems is done to facilitate the expansion of agriculture. Emissions associated with these activities are on the order of 8.4 to 10.3 Gt CO_2 y^{-1}. FAO reported that the rate of deforestation has been decreasing recently: in the 1990s, deforestation rates were 0.18% annually, but since 2010, this rate has been around 0.08%. It is worth noting that deforestation rates in the Brazilian Amazon region, have been on the rise over the past two years and PRODES data suggest that in 2016 deforestation was about 60 percent higher than in 2014. The continued decline in global land clearing for agriculture depends on reversing this trend. In other regions, subsistence agricultural activities are responsible for about 40 percent of deforestation and as much as 35 percent of forest degradation. Livestock grazing has been responsible for forest degradation and deforestation, particularly in Asia and Latin America.

Emissions related to agricultural production and management practices are predominantly nitrous oxide (N_2O) and methane (CH_4). The IPCC Fifth Assessment Report reported on data from three sources with global emission estimates between 5.2 and 6.3 Gt CO_2e y^{-1}, which is about 12 percent of global emissions. Emissions are from six primary sources: enteric fermentation (CH_4); fertilizer application to soils (N_2O); manure management (CH_4 and N_2O) and rice cultivation (CH4), crop residues (N_2O), and biomass burning (CH_4). Enteric fermentation and emissions from agricultural soils represent about 70 percent of these emissions; paddy rice cultivation are about 10%; biomass burning is about 9% and manure management makes up about 8 percent. Emissions from all categories are increasing. Regional breakdowns of the datasets show that emissions from these sources are increasing mostly in developing regions. Emissions in North America and Western Europe are stable or declining as production becomes more efficient in these regions. In developing regions like South and Southeast Asia, Africa and Latin America, emissions from both enteric fermentation and agricultural soils are increasing rapidly. Rice emissions are also a major contributor to increasing emissions in South and Southeast Asia.

One of the key economic trends that is likely to drive future emissions from agriculture is changing diet preferences. Meat consumption has almost tripled in the last four decades and has increased by over 30% in the last ten years. Dairy consumption is up by over 70 percent in the last four decades. Some of the greatest consumption increases are seen in Asia. While all types of meat consumption are experiencing increases, monogastrics like pork and poultry have seen the strongest increase. Production of these animals in Asia is shifting away from small farms and backyard production to specialized household or local community production and modern intensive farms, especially in areas close to big cities.

Organic soils are an important subset of agricultural soil emissions. These soils represent a relatively small portion of the agricultural area globally, but because of the high carbon content of peat and muck soils, they emit large quantities of carbon per hectare. These soils cover around 3% of the land area, but they contain at least 30% of all soil carbon. In order to grow crops, these soils are drained, which decreases CH_4 emissions, but as the previously anaerobic organic materials are exposed to higher levels of oxygen, they mineralize and carbon is lost as CO_2.

Over 25 million hectares of organic soils have been drained worldwide for agriculture use, which is about 7% of the total area. Of the drained areas, 60 percent is in boreal and cool temperate regions, 5 percent is in warm temperate regions, and 34% is in the tropics, mostly in Southeast Asia. The majority of these drained lands are being used for crop production. Emissions from these agricultural areas are estimated to be almost one billion tonnes CO_2 eq annually. Carbon dioxide accounts for around 85 percent of these emissions, with the balance made up by N_2O emissions. The use of fire to clear land, particularly in Southeast Asia, creates additional organic soil emissions. Emissions of N_2O also increase significantly as organic matter is mineralized and fertilization of these areas can exacerbate this situation.

The outlook for emissions from organic soils is uncertain. There are no global assessments of the drivers of peatland conversion and no projections for temperate and boreal conversion. In Southeast Asia, expansion of industrial and smallholder oil palm production is likely in the future, driven by markets for both edible oils and biofuels. Indonesia has adopted a policy which sets a goal for biofuels to constitute 25 percent of its national energy mix by 2025. Biodiesel from crude palm oil will be a significant part of the strategy to achieve this goal. In 2010, about 22 percent of plantations in Indonesia were on peat soils, so meeting the national goals require expansion of palm oil production. While the economics of meeting these production targets suggest a continued role for peatlands in future production, the government has recently created a federal agency to better regulate these regions.

Assessment of emissions related to aquaculture was new to the 5th Assessment Report. Production of fish and shellfish in aquaculture systems exceeded 55 million tonnes in 2010 and accounts for nearly half the fish consumed by humans. One of the major emissions impacts of this production is N_2O, with emissions predicted to increase to about 6% of anthropogenic N_2O emissions by 2030. Aquaculture also leads to significant mangrove destruction which results in large losses of carbon from both the biomass and sediments. Mangrove forests store between 500 and 1000 tC ha^{-1} and much of this carbon is lost when they are converted to aquaculture. Global estimates suggest that between 20% and 35% of mangrove area has been lost since 1980; loss rates are around 1% per year and some estimates are as high as 2–8% per year. Urbanization, coastal development, and unsustainable harvesting is responsible for a large portion of mangrove destruction. However, clearing of mangroves for shrimp culture is responsible for as much as 38% of global mangrove loss and other forms of aquaculture account for an additional 14%. Aquaculture ponds may also be responsible for carbon sequestration in sediments, with estimated accumulation at the global scale on the order of 17 Mt y^{-1}.

In the absence of a comprehensive global assessment of the food system that quantifies the emissions related to processing of food, case studies present useful information. One analysis of the UK food system shows that production accounts for about 45% of total emissions. Food transport, packaging, and processing accounts for about 31% of emissions and food use and disposal accounts for 24%. In the US, the highest levels of energy use in the food industry are associated with animal slaughtering and processing, wet corn milling, and fruit and vegetable preservation. AR5 reported that these processes account for 19%, 15%, and 14% of total energy use, respectively. A global assessment in the dairy sub-sector focused on butter, concentrated milk, and milk powder and estimated annual emissions of over 128 $MtCO_2$. Efficiency gains in some countries could eventually lead to reductions on the order of 9 to 14 $MtCO_2$ if measures were implemented to lower specific energy consumption significantly in at least half of dairy plants worldwide. These case studies illustrate that there are efficiencies to be gained with energy use in food processing through improved technologies and processes. Additional efficiencies need to be built into national energy systems.

This presentation and the ones that follow show that while many of the largest issues related to agricultural emissions were well captured in AR5, there is sufficient new scientific material to contribute to an expanded understanding of these issues in a special report on climate change, desertification, land degradation, sustainable land management, food security, and GHG fluxes in terrestrial ecosystems.

PLENARY SESSION 5:
EMISSIONS FROM AGRICULTURE AND LAND USING SYSTEMS AND FROM FOOD CONSUMPTION

Grassland/rangelands based livestock production systems: Options and trade-offs between productivity and GHG emissions reductions

AZAIEZ OULED BELGACEM[1], MOUNIR LOUHAICHI[2] AND MOURAD REKIK[3]

Rangelands comprise over 40% of the landmass of the world and provide valuable grazing lands for livestock and wildlife and contribute to the livelihoods of over 800 million people including poor smallholders (Ben Salem et al., 2011). They are critical to the carbon (C) cycle (Ogle et al., 2004) storing about one-third of the terrestrial soil C pool (Jobbagy and Jackson, 2000) over an area of approximately 3.3 billion ha. The large extent of rangelands, coupled with their propensity to store carbon in soils, suggests considerable carbon sequestration potential and thus opportunities for climate change mitigation.

Most of rangelands are under pressure to produce more animal-source food by grazing more intensively, particularly in the dry areas, which are more vulnerable to climate change and expected to still supply most of the meat and milk needed. As a result of past practices, somewhere twenty percent of the world's rangelands have been degraded by overgrazing (Sundquist, 2007).

Approximately 20% of the grazing lands of the planet are degraded and this percentage is expected to rise until 73% in dry areas (Dregne et al. 1991). Degradation of rangeland has tremendous consequences on the environment mainly, soil erosion, degradation of the vegetation cover, emission of carbon, loss of biodiversity and alteration of the water cycle. According to Ojima et al. (1993) and Sampson et al. (1993), non-sustainable land use practices such as inappropriate plowing, overgrazing of domestic animals, and excessive fuelwood use are the root causes of the degradation of rangeland ecosystems.

Ouled Belgacem and Louhaichi (2013) have demonstrated that global warming is expected to further contribute to the process of rangeland degradation as a result of overgrazing and mis-management and may have significant adverse impacts on range species under high CO_2 emissions scenarios. Already threatened rangeland species are likely to come under greater danger and present a very high vulnerability to climate change. On the other hand, species with low range value and broad ecological niches were favored by the impact of climate change and seemed to be able to survive under future environmental conditions of their adaptation range.

Rangelands are of great interest in terms of sequestering carbon from the atmosphere as a means of mitigating climate change, with estimated sequestration rates of ~ 0.6 gigatons (Gt) CO_2 equivalents yr^{-1} (Gerber *et al.*, 2013). It has been estimated that they account for a quarter of potential C sequestration in world soils (Follett and Reed, 2010). Despite this, they are neglected in terms of inclusion in mitigation strategies.

Increasing carbon stocks in the rangelands will improve water infiltration and cycling, increase productivity and hence biodiversity both below and above ground. Furthermore, rangelands support some of the world's poorest people (Ben Salem et al., 2011) and livestock is growing as a sector, with very important contribution in the GDP of the countries with significant areas of rangeland (World Bank, 2007). This will not only improve the livelihoods but also mitigate the negative impact of climate change. Livestock and rangeland ecosystems have a major role to play in mitigating climate change and mainly, supporting adaptation and reducing vulnerability.

Across these different land use systems, farmers and livestock keepers use a wide range of management practices to primarily achieve profitable gains (food security, livelihoods, income, etc.) but also to improve the "condition/health" of the grazing lands. Most, if not all, of the management practices aim predominantly to a) reduce and combat land

[1] International Center for Agricultural Research in the Dry Areas (ICARDA)- Arabian Peninsula Regional Program, Dubai – UAE. Email: a.belgacem@cgiar.org
[2] International Center for Agricultural Research in the Dry Areas (ICARDA), Amman – Jordan. Email: m.louhaichi@cgiar.org
[3] International Center for Agricultural Research in the Dry Areas (ICARDA), Amman – Jordan. Email: m.rekik@cgiar.org

degradation, b) restore/rehabilitate the land, and c) improve land productivity for livestock production. Therefore, all have a potential impact on carbon stocks in soils and biomass. Among management practices, controlled grazing management practice is considered beneficial in conditions of poor vegetation cover, overgrazing and degraded soils. It is considered as the most promising sustainable land management practice to restore degraded rangelands. Ouled Belgacem et al (2008) have shown that the reintroduction of the traditional management practice called "G'del" or "Hima" system under new arrangement has permitted a considerable increase of the rangeland production in forage units equivalent to more than 352 tons of barley in two years in a 4000 ha communal rangeland in southern Tunisia. It was also demonstrated that in 17-year protection from grazing under semi-arid conditions of China, the increase in C and N stored in soil contributed to more than 95% and 97% of the increases in ecosystem C and N storage. The exclusion of grazing had the potential to increase C and N storage in degraded semi-arid grassland and that the recovery of ecosystem C and N was mainly due to the accumulation of C and N in soils (Qiu et al., 2014).

Rehabilitation of degraded rangelands through reseeding and planting well adapted range species will provide additional benefits to local communities and economies and offer a very attractive opportunity to sequester carbon. Water harvesting techniques such as bunds or micro-catchments have been shown to increase forage production and therefore have potential to increase both above and below ground C in areas with erratic rainfall (Ouled Belgacem and Louhaichi, 2013).

Although rangelands would store an important pool of Carbon, they are a relatively small contributor to the word's anthropogenic greenhouse gas (GHG) emissions. The greatest emissions associated with rangelands likely come from livestock either directly through enteric fermentation and/or manure management or indirectly from feed-production activities, deforestation and overgrazing, etc. (Ben Salem et al., 2011; Ouled Belgacem and Louhaichi, 2013). In fact, livestock contributes to 80% of all agricultural non-CO_2 emissions (Tubiello et al., 2013), which makes it responsible for about 12% of all (GHG) emissions (Westhoek et al., 2011).

Climate change represents a special "feedback loop", in which livestock production both contributes to the problem and suffers from the consequences. Reduction of GHG emissions in the rangelands sector primarily involves the reduction of methane production by livestock, and increasing storage of carbon, which is dependent on improving rangeland health where needed. On the other hand, several assessments agree that increases in the demand for livestock products, driven largely by human population growth, income growth and urbanization, will continue for the next three decades at least (Thornton, 2010). The production will increasingly be affected by competition for natural resources, particularly land and water, competition between food and feed and by the need to operate in a carbon-constrained economy.

Livestock is an invaluable and irreplaceable source of nutrition and livelihood for millions of poor people and is one of the fastest growing agricultural sectors. Therefore, climate mitigation policies involving livestock must be designed with extreme care. It was reported that even within existing systems; autonomous transitions from extensive to more productive systems would decrease GHG emissions and improve food availability. Most effective climate policies involving livestock would be those targeting emissions from land-use change. To minimize the economic and social cost, policies should target emissions at their source—on the supply side—rather than on the demand side.

As mitigation options, reducing livestock numbers will surely reduce emissions but it will negatively affect the net cash income. However, changing the time of lambing, culling unproductive ewes, reducing stock in overgrazed areas, and managing fire frequency led to a significant reduction in GHG emissions without substantial effect on net income (Howden, 1991). Grazing the mix (sheep, goats, dromedaries) of animals may be both ecologically and economically efficient. Changing animal distribution, establishment of shaded areas, development of water sources, or fencing can improve carbon sequestration through some increase in plant cover and improved health of the root system through lighter intensity of grazing. However, the main way to reduce significantly methane emissions is the improvement of the quality of the diet such as providing protein supplements (Dordrecht et al., 1995).

In conclusion, a great deal of research evidence shows that improved grazing management could lead to greater forage production, more efficient use of land resources, and enhanced profitability and rehabilitation of degraded lands (Louhaichi et al., 2013). The tightening linkage between ecosystem services and human well-being in the world's dryland systems acutely demonstrates the need for a new, integrated approach to diagnosing and addressing sustainable development priorities, including maintenance of the supply of critical ecosystem services.

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PLENARY SESSION 5:
EMISSIONS FROM AGRICULTURE AND LAND USING SYSTEMS AND FROM FOOD CONSUMPTION

Climate-smart agriculture in rice production systems: From concept to implementation within the regional context of Southeast Asia

R. WASSMANN; B.O. SANDER

Climate-smart agriculture (CSA) denotes the merger of adaptation (adjusting to climate change) and mitigation (reducing Greenhouse Gas emissions) into one comprehensive approach. This concept and the term "CSA" are now widely used as a new paradigm by many institutions and initiatives. However, at this point only few examples exist where CSA has actually been implemented at significant scale.

Rice production represents a particularly relevant example for demonstrating the scope of CSA. This can mainly be attributed to the importance of this crop for food security and the fact, that rice is also a significant source of the Greenhouse Gas methane. In terms of adaptation, improved rice varieties are the key for coping with direct and indirect impacts such as floods, droughts and salinity. In addition to more resilient rice plants, short-maturing varieties can be adopted in order to avoid climate stresses by adjusted cropping calendars and also reduce methane emissions due to shorter flooding periods.

Moreover, several crop and water management practices can form integral parts of CSA in rice production. "Alternate Wetting and Drying" (AWD) is an irrigation technique originally developed for saving water and coping with water scarcity. This practice also reduces emissions by 30-70 % as has been shown in several field studies in Southeast Asian countries. Mechanization trends in rice cultivation include climate-smart practices such as laser leveling and direct seeding that reduce water needs and emissions.

The presentation will discuss implementation of CSA practices in rice production through several case studies that encompass different rice growing environments and drivers of impacts:

- Sea level rise causing higher flood and salinity risks in mega-deltas where irrigated rice is the predominant crop (e.g. in Southern Vietnam) => CSA options: improved varieties with combined flood and salinity tolerance and adjusted cropping calendar
- Variability in the onset of the rainy season in regions dominated by rainfed rice (e.g. Southern Laos) => CSA options: direct seeding in combination with drought-tolerant varieties
- Strong winds during weather hazards such as typhoons (e.g. Philippines) => CSA option: rice varieties with high lodging resistance
- Water scarcity due to El Nino events that are often exacerbated by competing water demand from other sectors, e.g. in the vicinity of large cities such as Manila => CSA option: AWD reducing water demand

Due to the specific drivers of climate change, these cases require distinct adaptation strategies. At the same time, the dynamic changes in the rice production systems also offer synergies for increasing resource use efficiency and thus, for mitigation.

Theme 4. Climate change adaptation, resilience, and linkages to food security

PLENARY SESSION 7:
CLIMATE CHANGE ADAPTATION, RESILIENCE, AND LINKAGES TO FOOD SECURITY

Sustainable intensification as adaptation: potential and limits

MARK T. VAN WIJK

Sustainable intensification of agricultural production (i.e. increasing food production from existing farmland in ways that have lower environmental impact and which do not undermine our capacity to continue producing food in the future (Garnett *et al*. 2013)) has been promoted as a means to meet growing food needs in developing countries. Examples of interventions that are seen as sustainable intensification are crop – livestock integration, conservation agriculture, intercropping systems and improved rainfall water harvesting (e.g. Campbell *et al*. 2014). Sustainable intensification can be an attractive option for climate change adaptation in agricultural systems because of its reported capacity to increase resource use efficiencies and reduction of yield variability. Within the setting of Climate-smart agriculture (CSA), which promotes agriculture and food systems that (1) enhance food security, (2) improve resilience to climate variability and change, and (3) mitigate greenhouse gas emissions where appropriate (e.g. Campbell *et al*., 2014; Lamanna *et al*., 2016) adaptation naturally plays a key role, and sustainable intensification options might well deliver double and even triple wins.

However, the success of sustainable intensification is dependent on availability of productive resources (land, livestock), availability of organic resources (crop residues, manure, etc.) and the labor to implement the interventions. All of these are limiting resources for which there are competing demands within the farming system. An example is the discussion on conservation agriculture, and its limited success in sub Saharan Africa up to now, compared to Latin and North America. Despite the sometimes substantial yield increases observed with conservation agriculture (e.g. Rusinamhodze *et al*., 2011) it is likely that competition for the limited amount of crop residues available in many mixed crop – livestock systems and the key role that these crop residues play in feeding cattle is one of the factors limiting uptake of conservation agriculture (see Giller *et al*, 2009) for a detailed discussion of this topic).

One other aspect which has often been overlooked is how much sustainable intensification can actually contribute to improved food security. As has been shown in many studies, sustainable intensification can lead to substantial yield increases, however, whether this leads to similar substantial increases in food security for the poorest farm households has been studied much less. This is an important question, because it critically addresses the targeting and prioritization of intervention options, and the likely efficiency of large scale investment in sustainable intensification as a way to improve food security of the poor agricultural producers. Existing large scale assessments (e.g. Brown *et al*., 2015) often make use of continuous responses between production intensification and country wide food security levels, but it is clear that the regional level these (simulated) (e.g. Fisher *et al*., 2005) relationships do not hold up, possibly leading to policy recommendations that do not target the right part of the population (Van Wijk, 2014).

For different farming systems in sub Saharan Africa we have quantified how much the food security of different farm households can be improved with certain levels of production increases. For this we analyzed existing databases of farm household characterization data (in total roughly 35000 farm households) and quantified a simple indicator of food security (e.g. Frelat *et al*., 2016). Mainly due to limited land availability and productivity levels of the most food insecure farmers, even cereal yield increases of 50% only lead to an improved food security status of only 2-7% of the farmers, the exact value depending on the production system. Production intensification can realistically only target the already more food secure smallholder farmers while intensification strategies must be augmented with transformational strategies to reach the poorest households (Ritzema *et al*., 2017). Many of these transformational changes are likely to be off farm opportunities for the poorest households. One example of transformational change of the farm livelihood that tries to improve the overall agricultural production of the system is the so-called 'girinka' ('One cow per poor family') option that has been promoted in Rwanda. If the farm has enough resources to feed the animal (see critical assessment of that in Klapwijk *et al.*, 2014) such an intervention can indeed transform the farm household and lead to immediate positive effects on food security (Paul *et al.*, 2017).

Effects of climate change on the welfare of farm households are highly dependent on the production system. In cereal based systems dominated by maize, negative yield effects caused by climate change by the year 2050 can be up 30-40% (e.g. Challinor *et al.*, 2014; Lobell *et al.*, 2008) and farmers need to adapt to compensate for these large yield losses. Farmers can do that by making use of intensification options and improved market prices, but in maize-based systems this type of adaptation, on average, can only just compensate for the negative effects of climate change. In sorghum and millet based systems likely climate change effects on productivity are smaller, and farmers can increase their income over time with the predicted increases in market prices. However, it is important to realize that these are average effects, and in each system there is a group of farmers that especially produces for home consumption, and therefore cannot profit from the higher market prices to compensate for the adverse climate change effects. In all cases there are farm households losing out because of climate change, and it is important to take this diversity of responses into account when evaluating adaptation options and quantifying the likely effects of climate change.

The targeting and prioritization of sustainable intensification options not only needs to take into account these differences between farm households and farming systems and their possible responses over time periods of 30-40 years, but also the fact that these livelihoods are changing rapidly over time at this very moment. In new household survey work using the rapid RHoMIS framework (Hammond *et al.*, 2017) we show that even in short time spans as 3-4 years, up 60 to 70% of the farm households can be making significant changes in their farm (e.g. buying/selling land, land use and market orientation) in situations when there is good market access. The prioritization of intensification options has to take into account that we are dealing with a moving target where some farm households are intensifying, while other households are preparing for an exit out of farming. The trajectories of these farm households strongly influence their willingness to adopt agricultural innovation like for example sustainable intensification.

Concluding remarks

Different sustainable intensification interventions are attractive to different groups of farmers. For policy prioritization a key question to answer is 'who do you want to target where?'. Analyses of climate change effects and likely changes in market prices over a time window up to 2050 show that increases in market opportunities and intensification may well outweigh positively the negative effects of climate change, depending on the production system. However, in all cases certain groups of farmers (especially those focusing on subsistence production) will lose out because they cannot compensate for the adverse effects of climate change on production. When doing these analyses it is important to take into account that change in farming systems and livelihoods is occurring at this very moment and that it is occurring rapidly: the farming systems of today might not be the farming systems of tomorrow! Another major trend in several countries in sub Saharan Africa, which we have not dealt with in detail in this executive summary, is the re-investment of urban wealth into agriculture. This might radically change the agricultural sector in these countries (at the moment still highly dependent on smallholder production) on shorter time scales than on which climate change is occurring. These changes need to be taken into account when evaluating the likely success of sustainable intensification, and thereby the efficiency of making investments in the promotion of sustainable intensification.

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PLENARY SESSION 7:
CLIMATE CHANGE ADAPTATION, RESILIENCE, AND LINKAGES TO FOOD SECURITY

Adaptation to water scarcity and drought in the Mediterranean region

ANA IGLESIAS

Drought and water scarcity will intensify in the future

From Syria to Spain, the Mediterranean has sustained his people for millenniums. But rapid changes in population, lifestyle and climate change are turning the region into conflict over water and land. The last ten years were the hottest on the global record and in many Mediterranean areas were also the driest. The resulting crop failures and water imbalances, causing instability in many rural areas, and challenging human development. There is a great collective effort to address the drought problem, from science to policy, but many issues remain unsolved.

A new report by the United Nations highlights the alarming increase in human and economic losses from drought. In the Mediterranean countries drought, aridity, water shortage, water scarcity and desertification are common and overlapping problems.

Climate change projections for the region indicate an increased likelihood of droughts and variability of precipitation – in time, space, and intensity – that would directly influence water resources availability. The combination of long-term change (e.g., warmer average temperatures) and greater extremes (e.g., droughts) can have decisive impacts on water demand, with further impact on the ecosystems. Under all climate change scenarios in the Mediterranean region, available water resources decrease while irrigation demand increases. The human dimension of climate change in the Mediterranean may not stop at the country' boundaries, since there is the potential for more pronounced water conflicts with neighbouring regions (i.e. transboundary issues in the Nile and in many shared aquifers).

Drought management and policy

Water scarcity and drought have multidimensional implications for society and therefore no single management action, legislation or policy can respond to all aspects and demand objectives. However, effective measures to cope with long-term drought and water scarcity are limited and difficult to implement due to the variety of stakeholders involved and the lack of adequate means to negotiate new policies.

In the Mediterranean, national governments and the local authorities have responded to extreme drought vigorously, taking emergency measures, but so far the responses have focused on the effects of drought ex post, rather than on anticipatory measures ex ante (i.e., developing a drought management plan, and coherent resource management). In general, these efforts have neglected to build the capacity needed to deal with similar situations in the future. Information on possible longer-term climate forecasts and/or development of plausible scenarios has not yet been incorporated into any specific action plans.

Drought management plans are actions taken by individuals, industry, organisations or institutions before drought occurs to minimise the risk of damage. The plans may be developed under the Hyogo framework, and therefore provide a comprehensive setting to address disaster risk reduction.

There are strong differences among actions in their nature, expected effectiveness, societal impact or economic costs, so it is necessary to organize their timely activation within the framework of the drought management plan. Not all actions are suitable and applicable in every situation and moment. Drought management plans may be simple or complex depending on the territorial and institutional scope. Nevertheless, a drought management plan may propose some main common elements. First a plan needs to define the institutional and stakeholders roles in the declaration of drought and the evaluation and revision of the plan. Second the plan should provide the tools and methods for the diagnosis of drought risk. This is not easy since drought is characterized by a high level of complexity. The diagnostic rules and criteria have to capture the complexity of drought and at the same time be transparent and easily evaluated by the stakeholders. There is a range of tools and models that can be use in this diagnostic process -- from indices to complex models of hydrological and land use dynamics. Although indicators are simplifications of reality, they play an important role in the definition of thresholds for risk management. Third, an essential component of the plan is the definition of the management objectives in each drought level and selection of the drought management actions. Finally, the plan needs to be reviewed by the stakeholders at different times. The sustainability of drought and desertification policy depends on the ability to respond to social, economic and environmental change.

A framework for risk management of water scarcity

This section describes a framework for risk management of water scarcity based on the analysis of the current adaptation strategies to water scarcity in Mediterranean countries that provides a systematic approach to prevent and/or minimize the impacts of drought on people. The framework is developed in the context of current drought vulnerability, legislation, management, and technologies (see previous section) and intends to be broad enough to incorporate new criteria for establishing priorities as societies change or as scientific and technological aspects of drought management improve. The framework includes the following components:

Data. Evaluate the data and information relevant to characterization (i.e., precipitation) and impacts (i.e., reservoir levels) of water scarcity that conform the monitoring and early warning systems and may be used to produce trigger indicators.

Institutions. Describe the institutional and legal frameworks that have direct or indirect inflows on drought preparedness and management, and the hierarchical relations among them.

Stakeholders. Identify the stakeholders affected by the decisions of each institution and the mechanism of participation in the decision process.

Validation. Validate the interactions among institutions, legislation and stakeholders with concrete historical examples.

Risk. Define thresholds of acceptable risk for a range of water scarcity situations and the indicators used to identify the risk level.

Measures. Describe Elaborate the measures that synthesise the process.

Measures could be grouped according to different severity levels. A commonly used ranking describes three levels of severity (i.e., can be named pre-alarm, alarm, and emergency). It is extremely important to also define the "normal" situation, since the plan is optimally developed at this stage. The management plan is considered a pro-active measure that defines a protocol for implementing reactive measures when the water scarcity situation occurs. The severity levels are determined by established thresholds of indicators that trigger groups of measures in response to the objective of each level (see the Table). There are many examples that validate this framework over the past decades in Mediterranean countries, especially in the pre-alarm and alarm levels. In the emergency level, the main priority is to satisfy drinking water demands and all structural and non-structural measures of high economic, social, or environmental cost are designed and taken in order to minimised water restrictions for urban demand.

Critical points and open questions

Water can lead to political hostilities and many regions with political conflicts are sharing water resources. International Organizations need to address cooperation among nations in order to solve conflicts. Most Mediterranean freshwater and groundwater resources are shared among countries, the Nile River being a key global example. Within the Mediterranean countries, water shared between administrative regions is also common. Disputes exist, especially during drought conditions, which will probably increase as a result of imbalance distribution of water resources among the regions. Policies of central government or single basin management cannot resolve issues over shared water bodies, and local interests are likely to diverge. International Institutions can play a key role as official and independent mechanisms to deal with water related conflicts between the regions.

Planning efforts are not easy and effective plans to combat drought and desertification are faced by some key challenges: Complexity, social change and climate change. First, drought and desertification are complex multi-dimensional issues from the physical and social point of view, involving a variety of stakeholders with different responsibilities and sometimes inadequate legal systems. Second, the evolution of society, technology, and policy may or may not contribute to lowering vulnerability to drought. In Mediterranean countries drought management issues are increasingly complex due to reinforced environmental awareness, rising marginal costs of infrastructure, and public participation in the decision-making process. Climate change is emerging as an additional challenge to effective management. Finally, drafting drought management plans requires the selection of the most appropriate combination of long term and short term actions. Current plans to combat drought and desertification based on changes in mean climate variables should be revised to account for climate change and the potential increase in anomalous events.

Mediterranean countries are making a great effort to reduce the impacts of drought and to avoid desertification. The solution is to plan in advance. The implementation of a preventive and proactive approach implies drafting plans in which the mitigation measures are clearly defined together with the instructions for their implementation. No single management action, legislation or policy can respond to all the aspects and achieve all goals for the effective drought management. Multiple collaborative efforts are needed to integrate the multidimensional effects of drought on society. At this end, a clear assignment of competences among the different involved institutions appears to be a key issue; therefore a legislative act which defines the responsibilities is necessary in each country. Such act could be part of national water resources policy and/or strategy to fight the risks of drought and desertification.

PLENARY SESSION 7:
CLIMATE CHANGE ADAPTATION, RESILIENCE, AND LINKAGES TO FOOD SECURITY

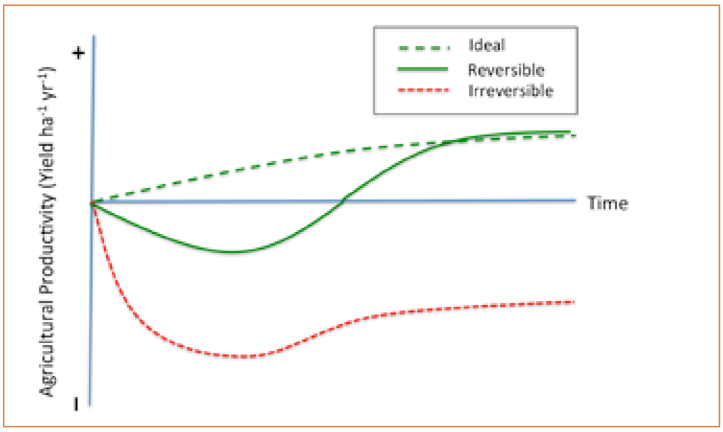
Soil health and soil nutrient management, including soil organic carbon, erosion control and other options to raise agricultural productivity and resilience

DAN PENNOCK

Introduction

Increasing yields of food, fibre, and fodder on current agricultural land in a sustainable manner is a perennial goal of research and extension on sustainable soil management practices. In an ideal scenario (Figure 1), changes to management practices would reinforce positive trajectories in soil functions that support increases in agricultural yields. Unfortunately the regional summaries of trajectories contained in the 2015 Status of the World's Soil Resources (SWSR) report (FAO and ITPS 2015) indicate that significant threats to soil functions persist in most regions of the world, and that the alternatives to the ideal scenario must be explored.

Figure 1: Three trajectories for the effect of human-induced changes in soil functions on agricultural productivity



Reversible versus irreversible soil-induced declines in agricultural productivity

At the conceptual level three distinct trajectories for the effect of human actions on soil functions exist (Figure 1). The first is the ideal trajectory that seems regrettably uncommon at present. In the second, the current trajectory is a gradual decline in many soil functions (e.g. nutrient supply to plants) due to a set of chronic disturbances (e.g. average annual levels of soil erosion due to agricultural practices).

In the third trajectory the decrease in soil functions is essentially irreversible at time scales of relevance to human society (Figure 1). The new equilibrium reached is well below the original starting point and renders the land unusable for agricultural production. This trajectory can occur either due to catastrophic event (e.g. a major wind erosion event or a contaminant spill) or to a chronic disturbance passing a threshold or "tipping point" where the trajectory can no longer be reversed. For threats to soil functions associated with soil chemistry (e.g. salinization/sodification, acidification, contamination) the thresholds where land becomes unusable for crop production are generally well established.

From a management perspective it is critical to discern between the latter two productivity trajectories. The priority for development and implementation of management practices should be first directed at soils that are most likely to experience irreversible loss of soil functions or where the gradual loss of productivity cannot readily be offset by technological measures. It is also critical that the relationship between these processes and climatic drivers be explored through modeling using regionally relevant climate change scenarios.

Examples of irreversible and reversible losses: Soil erosion

Overall the SWSR (FAO and ITPS 2015) found that soil erosion remains as the number one threat to agricultural productivity. Agriculturally induced sheet, wind, and tillage erosion lead to the removal of organically enriched surfaces horizons, which is the main contributor to the gradual productivity decline. If, however, there is a growth-impeding layer within the soil profile (for example, impermeable bedrock or a saline or sodic soil layer) then sheet, wind, and tillage erosion may lead to irreversible loss of productivity when the growth-limiting layer enters into the rooting zone of plants. In this situation the initial period of erosion is marked by a gradual decline in productivity until the growth-limiting layer intersects with the rooting zone, at which time the irreversible productivity decline begins. Major erosion events leading to formation of gullies (where the incision made by water erosion is greater that 0.3 m deep (Castillo *et al*. 2016)) also clearly lead to the irreversible loss of agricultural land.

The SWSR (FAO and ITPS 2015) states that a global median loss of 0.3 percent of annual crop yield occurs due to erosion, leading to gradual productivity decline based on a summary of existing meta-analyses of the erosion- crop productivity relationship. The authors project this loss into the future and state that by 2050 a total reduction of approximately 10% of annual yield could occur. This chronic decrease in soil functions can, however, be decreased or even reversed through the application of sustainable soil management practices. For example, Van Oost and Bakker (2012) found that in Western Europe and North America the effect of erosion on yield is greatly reduced by technological substitutes such as synthetic fertilizers and irrigation; the effects or erosion can be severe, however, in regions where the technological substitutes are unavailable.

No reliable global estimates exist of the area of agricultural land that has been abandoned due to irreversible soil erosion or that is under threat of abandonment. Given this it is impossible to estimate the effect of degradation-induced land abandonment on global agricultural productivity. Many studies in 2016 still rely on the GLASOD study (Oldeman *et al*. 1991) for global estimates of soil degradation. As Boardman (2006, p. 73) notes "At the global scale, an up-date of GLASOD based on a scientific approach is urgent so that we are at least able to identify erosion 'hotspots'".

Complexities in the Management of Soil Erosion: Case Study of No-Till

The most widely practiced (111 M ha in 2009 (Derpsch *et al*. 2010)) measure to reduce soil erosion is a reduction or elimination of the amount of tillage of the soil surface. The practice is variously called no-till, zero till, reduced tillage, or conservation tillage depending on the degree of mechanical disturbance and residue remaining (Reicosky 2015). Reduced tillage results in the retention of residues on the soil's surface and hence is inextricably linked with the benefits of the crop residue retention. Reduced tillage is one of three components of Conservation Agriculture (i.e., reduced tillage, permanent organic soil cover by retaining crop residues, and diverse crop rotations, including cover crops (Palm *et al*. 2014)).

The benefits and costs of no-till have recently been explored in a number of meta-analyses comparing no-till to conventional tillage. Mhazo *et al*. (2016) found that no-till leads to a reduction of soil loss by 60% for regions with temperate climates but that there was no significant difference in soil loss for subtropical and tropical climates. Precipitation runoff was reduced by 33% in temperate climates but was significantly higher in subtropical and tropical climates. Sun *et al*. (2015) found that no-till had no significant effect on runoff for soils with higher clay (>33%) but led to a significant reduction on low-clay soils. Mhazo *et al*. (2016) suggest that the higher clay content of many subtropical and tropical soils limits their improvement by adoption of no-till.

While the benefit of no-till adoption on erosion and runoff is (at least for temperate regions) well established, its effect on soil organic carbon (SOC) levels remains more controversial. While some meta-analyses (e.g. Mangalassery *et al*. 2015) have found that no-till leads to increases in SOC and hence is an effective climate mitigation measure, others such as Powlson *et al*. (2014) state that no-till is a beneficial adaptation measure but is of limited usefulness as a mitigation method. Moreover, erosion and potential SOC sequestration are inextricably related – Chappell *et al*. (2016) found that SOC lost for erosion is commonly attributed to soil respiration in research studies, leading to overestimation of net C flux from plot studies.

Meta-analyses focused on the impact of no-till adoption on yields also show regional differences in response. Overall Pittelkow *et al*. (2015) found that adoption of no-till reduced yields by 5.1%, with the greatest yield reduction in tropical latitudes (-15.1%) and least in the temperate (-3.4%). The benefit of no-till adoption was greatest in dry climates in rain-fed conditions due to the enhancement of water-use efficiency by adoption of no-till. The yield reductions due to no-till can be reduced by additions of sufficient amounts of inorganic N fertilizer – Lundy *et al*. (2015) state that yield reduction due to no-till in tropical and sub-tropical regions can be minimized by adding synthetic N fertilizer at rates greater that 85+/- 12 kg N $ha^{-1}\ yr^{-1}$, but acknowledge that this is far higher that the current rate of fertilizer addition in many areas of these regions.

A final and essential point about no-till adoption relates to its societal context. The forty-three authors of the Nebraska Declaration (CGIAR 2013) state that "Benefits from retention of crop residues in the soil are small at the low average yields typical of many parts of [Sub-Saharan Africa] and [South Asia] …and crop residues are of high value as fodder or fuel and can account for a large portion of total crop value." Hence they suggest that farmers in these regions will be very reluctant to adopt practices such as no-till that reduce farm income while offering only intangible medium- and long-term benefits.

The example of no-till and its effects on soil functions and ultimately crop production offers a number of important points. First, the benefit of no-till to erosion and runoff is regionally specific – there is a significant reduction at the cost of a minor short-term yield in temperate regions but no significant benefit (at the cost of a greater yield reduction) in sub-tropical and tropical regions. Second, to realize the benefits of no-till adoption, a comprehensive nutrient management program must be implemented at the same time. Finally, the degree of societal acceptance (as well as the specific measures to be implemented) must be locally addressed if new measures are to be successful.

Summary: Research gaps and priorities

1. Land that is at risk of being abandoned due to declines in agricultural productivity caused by loss of soil functions should be identified. This includes land currently at risk and land where abandonment is likely under regionally relevant climate change scenarios.
2. Locally appropriate measures need to be identified or developed to address the specific soil threats causing the loss of soil functions in these high-risk landscapes and programs that support adoption of these measures implemented.

Both of these priorities were identified by the Intergovernmental Technical Panel on Soils in the SWSR (FAO and ITPS 2015) as well as many other authors through time. The recent adoption of the Voluntary Guidelines on Sustainable Soil Management (FAO 2016) by FAO Council gives some impetus to the second priority, as do ongoing programs such as the World Overview of Conservation Approaches and Technologies (WOCAT).

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PLENARY SESSION 8:
REGIONAL AND GLOBAL INITIATIVES IN ADAPTATION TO CLIMATE IN FOOD PRODUCTION AND LAND USE

Adaptation through integrated farming practices, landscape approaches, and agroforestry and their economic feasibility/viability for smallholders

ANDY JARVIS, TODD ROSENSTOCK, CHRISTINE LAMANNA, PETER LADERACH

Agriculture and climate function hand in hand; they also dysfunction hand in hand. Today, 32-39% of global crop yield variability is explained by climate, translating into annual production fluctuations of ~2 to ~22 million tonne, for major crops such as maize, rice, wheat and soybean (Ray *et al*. 2015), whilst at the same time agriculture and livestock contribute 19-29% of global greenhouse gas emissions (Vermeulen *et al*. 2012). By 2050, FAO state that we need to deliver 60% more food for a growing global population with shifting consumption patterns (Alexandratos and Bruinsma 2012). And all this in a harsher climate - the IPCC, through a global meta-analysis (Porter *et al*. 2014; Challinor *et al*. 2014), reported that decreases of ~5% in crop productivity are expected for every 1oC warming above historical levels. These global drivers and trends represent a truly grand challenge that requires concerted action.

Numerous studies have shown that climate change can be a significant threat to food availability and stability by reducing agricultural productivity and increasing inter-annual variations in yields (Wheeler and von Braun 2013). A CSA approach is proposed as a solution to transform and reorient agricultural systems to support food security under the new realities of climate change. CSA consists of co-achieving three objectives, or pillars, defined by the FAO (2013) as 1) sustainably increasing agricultural productivity to support equitable increases in incomes, food security and development; 2) adapting and building resilience to climate change from the farm to national levels; and 3) reducing or removing GHG emissions where possible.[1]

Despite the significant global action and investment now being oriented towards CSA, the science is immature. There is scant evidence on the synergies and trade-offs among the distinct pillars of CSA of different practices and technologies across a range of agro-ecologies and social contexts.

Adaptation will be required if food production is to be increased in both quantity and stability in order to meet food security needs during the 21st century (Piontek *et al*. 2014). Research that informs action is needed to address the urgent climate risks to food systems and the global challenge of reducing GHG emissions from all sectors, including agriculture. Yet CSA science is in its infancy. Yield gains from adaptation through crop management and varietal substitution can play an important role, but are likely limited to moderate or low (< +3 °C) levels of warming (Porter *et al*. 2014). Research should therefore address both incremental changes in production as well as transformative changes such as exiting from agricultural livelihoods (Rippke *et al*. 2016), changing diets (Tilman and Clark 2014), new trade regimes (Baldos and Hertel 2015), and the implementation of PES and carbon markets (Newell *et al*. 2014).

Complexity and uncertainty around CSA stand in the way of efficient and effective action. Complexity in CSA stems from the existence of diverse (1) interventions (ranging from field level management practices to national and regional policies), (2) site-specific farming systems and households (from pastoralists to market-oriented smallholders), (3) potential outcomes of success (from soil carbon to maternal dietary diversity) (Bryan *et al*. 2013;Wise *et al*. 2014; Rosenstock *et al*. 2016). Arslan *et al*. (2015) report that the positive impacts of inputs on maize yields in Zambia are conditioned by climatic conditions, whereas Below *et al*. (2012) report a marked dependency of farmer adaptation on socio-economic status. Uncertainty in CSA is the consequence of a lack of information and data about the risks farming families face, and the efficacy of any specific CSA intervention in a given location.

Whilst potential adaptation options may be myriad (e.g. Below *et al*. 2012; Bryan *et al*. 2013), understanding CSA in specific contexts and at scale requires changing the way we assess farming system responses under climate change, including the science outputs we produce. Areas where research can enable action include improving the mismatch

[1] Climate-smart agriculture (CSA) an approach to developing the technical, policy and investment conditions to achieve three main objectives: sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and/or removing greenhouse gases emissions, where possible.

between frequently modeled (Challinor *et al*. 2014), field-tested (Rosenstock *et al*. 2016), and/or perceived (CIAT 2014) potential CSA options; understanding CSA option dependency on climate and socio-economic contexts; the development and validation of decision support tools to aid ex-ante assessment of CSA options; the study of mixed farming systems and minor crops that are prevalent across the tropics (Thornton and Herrero 2015); research on extreme events, nutritional outcomes and pests and diseases (Lesk *et al*. 2016;Wheeler & von Braun 2013); and the understanding of relevant climate impacts predictability limits (Challinor *et al*. in press).

Some specific findings showing the complexity and variability of viability for a range of practices and technologies are presented.

PLENARY SESSION 8:
REGIONAL AND GLOBAL INITIATIVES IN ADAPTATION TO CLIMATE IN FOOD PRODUCTION AND LAND USE

Adaptation of African Agriculture to climate change: from concept to action

PROF. MOHAMED BADRAOUI, INRA-MOROCCO

Summary

The Conference of Parties (COP21) of the UN Framework Convention on Climate Change (UNFCCC) held in Paris in December 2015, resulted in a breakthrough: the promise by developed countries to mobilize "at least US$100 billion a year" for the benefit of developing countries over 2020-2030. These funds will finance, in equal shares, mitigation projects and projects designed to adapt to climate change. The Conference of Parties in Marrakech in November 2016 (COP22) presented an opportunity to launch an initiative for the adaptation of agriculture. Stakeholders had strong expectations for COP22 on the actual implementation of the Paris Agreement's commitments. They took into account the needs and priorities of developing countries, notably in Africa, one of the world's most vulnerable continents and the one worst affected by climate change. The Paris Agreement also acknowledges the importance of food security, a first step toward recognizing agriculture as an integral part of the solution in the fight against climate change.

As the host country of COP22, Morocco has launched an initiative for Adaptation of Agriculture in Africa (AAA). It aims to make African agriculture adaptation one of the priorities on the COP22 agenda, recognizing that adaptation can only benefit mitigation efforts. Improving agricultural productivity and practices, notably in soil and water management, can also contribute to soil carbon sequestration and to reducing deforestation. Agroforestry is a good example of adaptation to climate change, with direct mitigation impacts. It is, therefore, important that a substantial share of climate fund investment is directed towards improving agricultural productivity to help fight against climate change and support food security.

Given the positive effects of good agricultural practices on climate change mitigation, and the significant yield improvement potential in Africa, African agriculture should be considered a global common good to be protected and developed. Available data show that Africa represents about 30 percent of global mitigation potential from forests and 20 percent from soils. Around 60 percent of the world's uncultivated arable land is in Africa, while across the continent potential gains in agricultural productivity could be multiplied by 500 percent on average.

However, Africa receives a tiny share (less than 5 percent) of funds allocated to counter climate change, far short of what it deserves. Adaptation benefits from less than 20 percent of the public funds assigned to climate, while the Paris Agreement aims "to achieve a balance [of financial resources] between adaptation and mitigation". With less than 4 percent of public climate funds, agriculture is one of the sectors that is least prepared to combat climate change and its effects.

The AAA attracts only a small amount of international funds but remains the most vulnerable to climate change. It is now acknowledged that a temperature increase of 2°C in Africa will lead to a decrease in agricultural yields ranging from 15 percent to 20 percent by 2050.

The AAA Initiative will serve as a platform to support the capacity of African countries to develop, formulate and implement adaptation projects backed by climate funds. The initiative supports the principle of monitoring funds effectively disbursed for adaptation and agriculture in Africa, as well as facilitating access to those funds. The AAA Initiative has a facilitation role and can accelerate the development and funding of adaptation projects for those African countries with limited human capacity.

The AAA Initiative also has a solution-oriented component within the Global Climate Action Agenda of the UNFCCC. The objective is to show that African agriculture is part of the solution in halting climate change. The solutions relate to four programmes adapted to the specific situation and priorities of agricultural productivity and food security in Africa.

1. The first programme focuses on the sustainable management of soil resources with a triple objective: (i) improved soil fertility; (ii) increased carbon sequestration capacity of soils, in line with the recommendations of the French "4 for 1000" initiative; and (iii) conversion of annual and itinerant cultivation into fruit trees and agroforestry.
2. The second programme aims to ensure the sustainable management of agricultural water on the continent, from supply to efficient use, through adopting appropriate techniques that have already proved their effectiveness on the African continent. In this, AAA is in line with the FAO global platform on water scarcity launched at COP22 in Marrakech.
3. The third programme seeks to improve management of climate risks, notably through developing farm insurance schemes and implementing early warning systems.
4. The fourth programme sets out to provide smallholder farmers with appropriate innovative funding mechanisms to remove constraints on adopting best agro-ecological practices and enable investment in land management and production.

The specificity of the AAA initiative should be a major focus in agricultural development and climate change circles. It is in line with the UNFCCC framework and aims to develop tools that will enhance Africa's skills on climate issues, facilitate technology transfers, and promote South/South cooperation. This initiative directly follows the Paris Agreement's advances regarding agriculture and food security. It is also in line with the conferences of Maputo (2003) and Malabo (2014), as well as the objectives of the Comprehensive Africa Agriculture Development Programme (CAADP) of the African Union. The AAA initiative is also aligned with the Dakar Conference (BAfD - 2015), and with the Abidjan Declaration (FAO - 2016) for the transition towards more productive and resilient African agriculture.

The AAA initiative concerns all stakeholders: governments, international institutions, the private sector, civil society, the scientific community and contributes to the achievement of the UN's Sustainable Development Goals.

A global, multi-stakeholder coalition supports the AAA initiative. On 29-30 September a high level meeting bringing together the key stakeholders supporting it took place in Marrakech. The coalition has adopted the Marrakech Declaration on the Initiative for the Adaptation of Agriculture in Africa. At present, 28 African countries, most of the development partners and financial institutions, major agribusiness players and many NGOs are supporting AAA. A Scientific Committee comprising 40 eminent scientists also backs the initiative.

The AAA is in line with the Initiative for Adaptation in Africa (IAA), announced by the Egyptian President at the COP21 on behalf of the African Ministerial Conference on Environment (AMCEN), promoted by the African Group of Negotiators at the UNFCCC. The AAA initiative could be considered as the agricultural component of the IAA initiative.

The AAA portfolio contains 42 projects originating from African countries, NGOs and private sectors partners, covering all the adaptation solutions proposed. Some of these are being implemented while others are under construction.

PLENARY SESSION 8:
REGIONAL AND GLOBAL INITIATIVES IN ADAPTATION TO CLIMATE IN FOOD PRODUCTION AND LAND USE

The Scientific Conceptual Framework for Land Degradation Neutrality

ANNETTE COWIE

Land resources provide food, feed and fibre, and support the often-overlooked regulating and supporting services on which the provisioning services depend, as well as to cultural services delivered by healthy ecosystems. Pressure on the finite land resources will grow as the world's population grows and increases in affluence. Increased competition for land resources is likely to increase social and political instability, exacerbating food insecurity, poverty, conflict and migration. Maintenance of the capacity to deliver these ecosystem services will depend on resilience in the face of global environmental change.

However, while demands on the global land resources are increasing, the overall health and productivity of land is declining. Thus, it is critical to find effective measures to address land degradation. Avoiding and reversing land degradation will have co-benefits for climate change mitigation and adaptation, and also for biodiversity conservation, in addition to enhancing food security and sustainable livelihoods.

Land Degradation Neutrality (LDN) is a new initiative intended to halt the ongoing loss of healthy land through land degradation, based on a "no net loss" approach. The United Nations Convention to Combat Desertification (UNCCD) defines LDN as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems".[1] The "Scientific Conceptual Framework for Land Degradation Neutrality" is intended to provide a scientifically-sound basis for understanding, implementing and evaluating LDN, and to inform the development of practical guidance for pursuing LDN and monitoring progress towards the LDN target. The LDN conceptual framework focuses on the neutrality aspect of LDN, highlighting those features that differ from historical approaches to land degradation assessment and management.

The aspirational goal of LDN is to maintain or enhance the natural capital of the land and associated land-based ecosystem services. Pursuit of LDN therefore requires effort to avoid further net loss of the land-based natural capital relative to a reference state, or baseline. Therefore, unlike past approaches, LDN creates a target for both land use planning and land degradation management, promoting a dual-pronged approach of measures to avoid or reduce degradation of land, combined with measures to reverse past degradation. The intention is that losses are balanced by gains, in order to achieve a position of no net loss of healthy and productive land. The definition emphasises the importance of ecosystem services in achieving food security. The objectives of LDN can be summarised as:

- Maintain or improve the sustainable delivery of ecosystem services.
- Maintain or improve productivity, in order to enhance food security.
- Increase resilience of the land and populations dependent on the land.
- Seek synergies with other social, economic and environmental objectives; and
- Reinforce responsible and inclusive governance of land.

The goal of LDN – to maintain or enhance the land-based natural capital, and the ecosystem services that flow from it, including the supporting processes required to deliver this goal - is the foundation for the conceptual framework. The framework is presented as five modules: Vision of LDN, which captures the goal that LDN is intended to achieve; Frame of Reference, that explains the LDN baseline; Mechanism for Neutrality, that describes the counterbalancing mechanism; Achieving Neutrality, that presents the theory of change (logic model) articulating the pathway for implementing LDN, including preparatory analysis and enabling policies; and Monitoring Neutrality, which presents the

[1] UNCCD. 2016. Report of the Conference of the Parties on its twelfth session, held in Ankara from 12 to 23 October 2015. Part two: Actions. ICCD/COP(12)/20/Add.1. United Nations Convention to Combat Desertification (UNCCD), Bonn. See Decision3/COP.12, page 8. Parties of the UNCCD recognize that for the purpose of this Convention, this definition is intended to apply to affected areas as defined in the text of the Convention.

LDN indicators. Principles are provided for each module, to govern application of the framework and to help prevent unintended outcomes during implementation and monitoring of LDN.

Achieving LDN will require tracking land use changes where degradation is anticipated so that cumulative negative impacts can be estimated, and implementing an optimal mix of interventions designed to avoid, reduce or reverse land degradation, with the intent of achieving neutrality at national scale. Therefore, the conceptual framework introduces a new approach in which land degradation management is coupled with land use planning. Decision-makers are encouraged and guided to consider the cumulative effects on the health and productivity of a nation's land resources caused by the collective impact of their individual decisions that influence management of particular parcels of land. LDN thus promotes integrated land use planning, with a long-term planning horizon including consideration of the likely impacts of climate change. The counterbalancing mechanism requires implementation of interventions that will deliver gains in land-based natural capital equal to or greater than anticipated losses elsewhere.

Actions to achieve LDN include sustainable land management approaches that avoid or reduce degradation, coupled with efforts to reverse degradation through restoration or rehabilitation of land that has lost productivity. The response hierarchy of Avoid > Reduce > Reverse land degradation articulates the priorities in planning LDN interventions. The implementation of LDN is managed at the landscape scale, considering all land units of each land type and their interactions and ecological trajectories, so that LDN interventions can be optimized among those land units, in order to maintain or exceed no net loss, per land type. Counterbalancing anticipated losses with measures to achieve equivalent gains is undertaken within each land type, where land types are defined by land potential. Monitoring achievement of neutrality will quantify the balance between the area of gains (significant positive changes in LDN indicators=improvements) and area of losses (significant negative changes in LDN indicators=degradation), within each land type across the landscape. The LDN indicators (and associated metrics) are land cover (land cover change), land productivity (net primary production) and carbon stocks (soil organic carbon stocks).

The LDN conceptual framework is designed to be applicable to all land uses (i.e. land managed for production – e.g. agriculture, forestry; for conservation – e.g. protected areas; and also land occupied by human settlements and infrastructure); and all types of land degradation, across the wide variety of countries' circumstances, so that it can be implemented in a harmonized fashion by all countries that choose to pursue LDN. To achieve the broader development objectives of the UNCCD and the Sustainable Development Goals, LDN interventions should seek to deliver 'win-win' outcomes whereby gains in natural capital contribute to improved and more sustainable livelihoods. It is critical that safeguards are introduced to ensure that vulnerable communities are not displaced when lands are targeted for restoration activities. The implementation of LDN requires multi-stakeholder engagement and planning across scales and sectors, supported by national-scale coordination that should work with and incorporate existing local and regional governance structures. Learning is a key cross-cutting element, linked to adaptive management. Knowledge from monitoring is verified through stakeholder consultation, and applied to adapt LDN implementation and future management of land degradation.

Further information:

UNCCD/Science-Policy Interface (2016). Scientific Conceptual Framework for Land Degradation Neutrality. A Report of the Science-Policy Interface. Barron J. Orr, Annette L. Cowie, Victor M. Castillo Sanchez, Pamela Chasek, Neville D. Crossman, Alexander Erlewein, Geertrui Louwagie, Martine Maron, Graciela I. Metternicht, Sara Minelli, Anna E. Tengberg, Sven Walter, and Shelly Welton. (Forthcoming). United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany, ISBN 978-92-95110-42-7 (hard copy), 978-92-95110-41-0 (electronic copy).

UNCCD/Science-Policy Interface (2016). Land in Balance: Scientific Conceptual Framework for Land Degradation Neutrality. Science-Policy Brief 02- September 2016. http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/10_2016_spi_pb_multipage_eng.pdf

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Theme 5. Policies for land use, sustainable food production, consumption and climate action

PLENARY SESSION 9:
THE FUTURE OF FOOD SYSTEMS UNDER CHANGING CLIMATE AND SUSTAINABILITY CONSTRAINTS: RETHINKING OUR ECOLOGICAL AND ECONOMIC "TOOLBOX" FOR THE FUTURE OF FOOD AND LAND USE

Building the Sustainability Bridge: Policy Considerations

ROBERT WALKER

Introduction

Food systems, and especially their agricultural components, represent a critical nexus between human welfare and our ecological support system. That said, there is growing concern that the heavy ecological footprint of contemporary agriculture may not be sustainable over the long-run. This concern is pronounced in an age of climate change, given future uncertainties in production and the increased stress that ecosystems are likely to suffer. If we are to sustain both ecosystems and food security through the 21st century, we face two challenges, namely to (1) adapt agriculture to a changing climate, and to (2) practice it in an environmentally conscientious manner. In this document, I address the second challenge involving agricultural land use and ecosystems. Specifically, I consider how to shape policy for building a "sustainability" bridge, capable of providing an ecological transition to environmentally-sound production systems that can provide food security in the face of climate change. In the discussion that follows, I take agriculture as a broad category comprising crop production, livestock operations, and forestry.

Many have risen to the agriculture-ecosystem challenge, and one oft cited approach involves finding the "right type" of agriculture, an ecologically-based "magic bullet" that achieves both human welfare and environmental objectives simultaneously. In this regard, we often hear reference to the potentials of agroforestry, landscape-based agriculture, polyculture, and organic farming, to name just a few. It is also critical to consider forestry management in this context, given the magnitude of ecological impacts associated with timber extraction. It should come as no surprise that the exploitation of non-timber forest products, in place of wood, is regarded as key to sustainability, and recently attention has turned to the ecosystem services that forests provide, such as carbon sequestration, biodiversity maintenance, and climate and hydrological regulation. Note that ecologically-based systems are nothing new, and we need not look far to find examples in the form of shade coffee (and cocoa), diversified smallholder farming, and the extraction of natural rubber and Brazil Nut. Unfortunately, over the long run, input-intensive agriculture -- with a much heavier ecological footprint -- has gained the upper hand, which indicates sharp institutional and technological barriers to the "magic bullet" of low impact crop production, livestock operations, and forestry.

Agriculture and Ecosystems: Competitors for Land

Discussions of the ecological impact of agriculture often overlook the fact that "natural" systems are land demanding, which puts them into competition with agriculture for the use of land. Formulating the ecological problem in terms of land reveals policy types capable of encouraging the identification and practice of sustainable agriculture. Specifically, policy can limit the supply of land, reduce its demand (i.e., land "sparing"), or integrate agriculture and ecosystems in a mutually beneficial manner (i.e., land "sharing"). I now consider each of these briefly, pointing out both limitations and potentials.

Limiting the Supply. Limiting the supply of land available for agricultural use comprises both the setting aside of land and the designation of use restrictions on private holders. Set-asides include the designation of protected areas such as parks, forests, and wildlife refuges, while use restrictions typically involve zoning. Depending on the jurisdiction, supply limitations may apply at local scale (e.g., municipal) as well as national. Limiting land supply represents an age-old approach to protecting ecological features deemed of societal value, and to reducing environmental hazards. Supply limitations can be difficult to maintain with poor, high-density, rural populations.

Reducing demand for land. Over the long run, technological change has vastly increased agricultural productivity, and reduced the demand for land via intensification, thereby paving the way to forest transition in many parts of the world. A land sparing outcome consistent with the Borlaug hypothesis is dependent on market conditions, however, in which case intensification can augment the demand for land, at least in the short run. This appears to have occurred in Brazil, with the advance of soybean farming into the savanna regions of the Amazon Basin, in the State of Mato Grosso.

Integrating agriculture and ecology. A form of agro-ecological system producing abundant food while maintaining ecological function represents the ideal of a land sharing approach to downsizing the ecological footprint to sustainable dimensions. However, as already suggested, economies have tended to incentivize shifts away from ecologically-based production, toward cost-minimizing, revenue maximizing monocultures. This shift is observable in forest-based extractive systems as well, most notably the recent move away from natural rubber production to small-scale livestock operations in the Amazon Basin.

Despite these unwelcome trends vis-à-vis ecosystem impact, there does exist the potential for managing the spatial occupation of new frontiers in a manner that minimizes biodiversity impacts. In particular, modelling studies have shown that the pattern of forest fragmentation stemming from specific road designs enables species mobility through landscape corridors, thereby mitigating the impact of climate changes on biodiversity. Further, the spatial configuration of protected areas at regional scale regulates continental rainfall regimes in the face of deforestation. Here, modelling studies have identified a configuration capable of sustaining rainfall across the Amazon basin, even with extreme encroachments of agriculture into the closed moist forest.

Ecosystem services and natural capital

A great deal of interest has emerged recently in protecting natural areas and resident ecosystems by invoking the concept of natural capital, and the ecosystem services thus provided. In fact, this represents a form of reducing the demand for land, but I treat it separately from intensification given it valorizes natural land cover and operates independently from technological change in agriculture. The ecosystem service concept was developed and first applied by the ecologist, Howard Odum, who recycled sewage effluent in cypress domes rather than municipal treatment plants. Although the cypress ecosystem functioned as predicted, the wastewater treatment values failed to compensate alternative use by the mulch industry, and hardly any old growth cypress remains in the experimental region. The same problem is observed in the Amazon Basin, where land values in agriculture are significantly greater than what the market pays for carbon sequestration. For the ground-level land manager, the opportunity cost of providing the ecosystem service is simply too high, in which case incentives give way to agricultural land use, typically for livestock operations.

The sustainability bridge to peaceful coexistence

The long-run suppression of ecosystems by agricultural activity is attributable to the efficiency of modern technologies, and the demand for product standards and supply regularity. Reversing the historical trend, and crossing the sustainability bridge to a form of integrated eco-agriculture, or to a level of productivity sufficient to precipitate global land sparing, will not be easy. That climate change has begun to manifest adds urgency and complexity to the task ahead. It is in this context that I call attention to the issue of time-scale, given much of the policy discussion remains insensitive to the pace of the processes now unfolding. I first note the cogent view expressed by the Food and Agricultural Organization (FAO) regarding the efficiency of risk reduction relative to disaster relief, which counsels us to be proactive rather than reactive in dealing with the challenges confronting us with respect to agriculture and human welfare. In this regard, it is important to consider recent admonitions by the US National Research Council to prepare for a more rapid onset of climate change effects than originally expected. In particular, such effects could begin being felt within decades, perhaps even years. Although the rapid onset discussion refers to climate change, I wish to extend it to the competition between agriculture and ecosystems for land, a competition that nature is losing ever more quickly. The literature on the Anthropocene points not only to the disaster of a looming uptick in average global temperature, but also to a mass extinction of species, spearheaded by the agricultural advance on natural habitats and by extractive activities. Many of us have lived through or experienced the loss of entire ecosystems in our own lifetimes, which is to say we all have personal proof of a decadal pace of ecological degradation. The gathering force of climate change will accelerate this, in which case we need to confront the possibility that the technological and institutional changes we need to reduce the ecological footprint once-and-for-all will take too long.
It is in light of these considerations that I propose a two-pronged approach to building the sustainability bridge, one

that partitions policy formulation into short- and long-run perspectives. If the "magic bullet" cannot be found in the short-run, which we should assume, then we must focus on the age-old approach of restricting the supply of land to agriculture through protected areas. This is to say, we must let nature "constrain" the use of land while we continue the hard work of innovation, which requires time. Then, once successful, the constraint of nature relaxes naturally, as eco-agriculture spares and shares land, thereby achieving the difficult task of providing for human welfare at minimal to no ecological cost.

Appendix 02
Post-AR5 annotated bibliography

POST-AR5 ANNOTATED BIBLIOGRAPHY ON CLIMATE AND HUMAN-DERIVED IMPACTS ON AGRICULTURE AND LAND-BASED ECOSYSTEMS AND POLICIES FOR ADAPTATION, MITIGATION, AND FOOD SECURITY

Compiled and annotated by Aziz Elbehri (FAO)

Web search and archival assistance by Evelyne van Heck (FAO)

SYNOPSIS

This annotated bibliography offers a selective but comprehensive supplement to the EM report covering a large number of themes related to the FAO-IPCC Expert Meeting on climate change, land use, and food security. The bibliography structure roughly follows the order of themes in the EM agenda. In selecting the references to cite, several factors were considered: the five thematic areas covered in the EM; only post-AR citations published since 2013; and citations with direct or indirect links to food security. The vast majority of the citations are academic, peer-reviewed papers, but not all. The bibliography also includes sections that expand beyond the topics covered at the EM, thus offering more balance that what was covered in the EM owing to the participants' disciplinary knowledge. For example, while the EM discussions on mitigation options for crops focused exclusively on rice, the bibliography includes a section on non-rice crops. In addition, trade, which was barely discussed at the EM, receives a full section in the bibliography given its important role in climate change policy and food security. Few topics directly linked to food security, such as sea fisheries, were not included given the EM focus on land issues; but aquaculture and inland fisheries are covered. Finally, the bibliography includes an extensive coverage of policies addressing a wide range of topics, even though some readers may still underrepresented areas. The hope is to provide readers an entry point into their area of interest and take this as a starting point for further exploration and analysis.

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4. ADAPTATION AND RESILIENCE IN FOOD AND LAND BASED ECOSYSTEMS

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5. POLICIES FOR LAND-USE, FOOD SECURITY AND CLIMATE ACTION

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Appendix 03
Meeting agenda

MONDAY 23 JANUARY 2017

08.00-09.00 Registration

WELCOME AND OPENING SESSION

Welcome address
- Chair: René Castro Salazar, Assistant Director-General, Climate, Biodiversity, Land and Water Department, FAO

09.00-09.30
- Martin Frick, Director, Climate and Environment Division, FAO
- Abdalah Mokssit, Secretary-General, IPCC

THEME 1: CLIMATE IMPACTS ON LAND USE, AGRICULTURE AND RELATED ECOSYSTEMS

Plenary Session 1: Climate impacts on land use, food production and productivity (direct impacts)
- Session chair: Petr Havlik, IIASA
- Rapporteur: Alexandre Meybeck, FAO

09.30-09.50	Climate impacts on crop yields, including extreme events, regional hot spots, crop suitability Andy Challinor, University of Leeds
09.50-10.10	Climate change impacts on livestock both direct (animals) and indirect (feed) and implications for adaptation and food security An Notenbaert, CIAT
10.10-10.45	Plenary discussion
10.45-11.15	Coffee break

Plenary Session 2: Climate impacts on land use, food production and productivity (indirect impacts)
- Session chair: René Castro Salazar, FAO
- Rapporteur: Douglas Muchoney, FAO

11.15-11.35	Climate impacts on land-based fisheries and aquaculture and links to food supply Sena De Silva*, Deakin University and Doris Soto, INCAR-Chile
11.35-11.55	Climate impacts on forest ecosystems (e.g. pollinators) and their roles for food supply David Inouye*, University of Maryland, Stein Joar Hegland*, Western Norway University of Applied Sciences and Simon Potts, University of Reading
11.55-12.15	Climate impacts on soil health (including soil carbon, microbial life, nutrients): implications for ecosystem services and food production Jean-Francois Soussana*, INRA-France and Pete Smith, University of Aberdeen
12.15-13.00	Plenary discussion
13.00-14.00	Lunch break

* Speakers

MONDAY 23 JANUARY 2017 (CONT'D)

THEME 2: HUMAN-DIRECTED DRIVERS FOR LAND USE, LAND USE CHANGE, LAND DEGRADATION, AND DESERTIFICATION, AND IMPLICATIONS FOR FOOD SECURITY

Plenary Session 3: Human-directed drivers of land use and land use change, land degradation and implications for food security

- Session chair: Riccardo Valentini, University of Tuscia
- Rapporteur: S. Niggol Seo, Muaebak Institute of Global Warming Studies

14.00-14.20	Human-directed drivers of land use change: implications for food security, economic and resource costs Alisher Mirzabaev* and Joachim Von Braun, University of Bonn
14.20-14.40	Human-directed causes of land degradation and desertification, and restoration options implications for food production and GHG fluxes Luca Montanarella, European Commission/Chair of ITPS
14.40-15.00	Synergies and trade-offs between forestland management and food production and productivity Arild Angelsen, Norwegian University of Life Sciences
15.00-15.45	Plenary discussion
15.45-16.15	Coffee break

Plenary Session 4: Human-directed impacts on water scarcity, biodiversity and implications for food security

- Session chair: Annette Cowie, UNCCD-SPI
- Rapporteur: Manuel Barange, FAO

16.15-16.35	Freshwater availability and water scarcity: trends and projected effects on water scarcity and implications for land use patterns Tim Hess, Cranfield University
16.35-16.55	Global framework on water scarcity: a multi-partner initiative Eduardo Mansur, FAO
16.55-17.15	Biodiversity and ecosystem management (including wetlands, mangroves) and implications for land use and food production Daniel Murdiyarso, CIFOR
17.15-18.00	Plenary discussion

18.30-20.00	**Cocktail reception (Atrium)**

* Speakers

TUESDAY 24 JANUARY 2017

THEME 3: CLIMATE MITIGATION IN AGRICULTURE AND OTHER LAND USES AND LINKAGES TO FOOD SECURITY

Plenary Session 5: Emissions from agriculture and land using systems and from food consumption

- Session chair: Christopher Martius, CIFOR
- Rapporteur: Margaret Gill, University of Aberdeen

09.00-09.20	Trends of GHG emissions resulting from food systems (crops, livestock, land-based aquaculture, processed food) Louis Verchot, CIAT
09.20-09.40	Grassland/rangelands based livestock production systems: Options and trade-offs between productivity and GHG emissions reductions Azaiez Ouled Belgacem, ICARDA
09.40-10.00	Mitigation options in agriculture with win-win outcomes for food security, livelihoods, and ecosystem conservation and management Reiner Wassmann* and Bjoern Sander, IRRI
10.00-10.45	Plenary discussion
10.45-11.15	Coffee break

Plenary Session 6: Mitigation options in agriculture and other land uses: Synergies and trade-offs to food security

- Session chair: David Reay, University of Edinburgh
- Rapporteur: Martial Bernoux, FAO

11.15-11.35	Mitigation options through afforestation and sustainable forest management, and economic implications Michael Obersteiner, IIASA
11.35-11.55	Rebuilding soil organic carbon (SOC): scientific basis and feasibility issues for SOC sequestration Keith Paustian, Colorado State University
11.55-12.15	Soil carbon mapping initiative: Global Soil Partnership Ronald Vargas, FAO
12.15-12.35	Novel ways and prospects of addressing emissions that are currently difficult to mitigate (enteric fermentation) Harry Clark, NZ Agricultural GHG Research Center
12.35-13.00	Plenary discussion
13.00-14.00	Lunch break

* Speakers

TUESDAY 24 JANUARY 2017 (CONT'D)

THEME 4: CLIMATE CHANGE ADAPTATION, RESILIENCE, AND LINKAGES TO FOOD SECURITY

Plenary Session 7: Climate change adaptation, resilience, and linkages to food security

- Session chair: Eduardo Mansur, FAO
- Rapporteur: Henning Steinfeld, FAO

14.00-14.20	Sustainable intensification as adaptation: Potential and limits Mark Van Wijk, CGIAR-ILRI
14.20-14.40	Adaptation to water scarcity and its variants including physical, economic and institutional Ana Iglesias, Universidad Politécnica de Madrid
14.40-15.00	Soil health and soil nutrient management, including soil organic carbon, erosion control and other options to raise agricultural productivity and resilience Daniel Pennock, University of Saskatchewan
15.00-15.45	Plenary discussion
15.45-16.15	Coffee break

Plenary Session 8: Regional and global initiatives in adaptation to climate in food production and land use

- Session chair: Richard Thomas, ICARDA
- Rapporteur: Olcay Unver, FAO

16.15-16.35	Adaptation through integrated farming practices, landscape approaches, and agroforestry and their economic feasibility/viability for smallholders Andrew Jarvis, CGIAR-CIAT
16.35-16.55	Adaptation for African Agriculture: From concept to action Mohamed Badraoui, INRA-Morocco
16.55-17.15	Land Degradation Neutrality Initiative Annette Cowie, UNCCD-SPI
17.15-18.00	Plenary discussion

WEDNESDAY 25 JANUARY 2017

THEME 5: POLICIES FOR LAND USE, SUSTAINABLE FOOD PRODUCTION, CONSUMPTION AND CLIMATE ACTION

Plenary Panel Session 9: The Future of food systems under changing climate and sustainability constraints: Rethinking our ecological and economic "toolbox" for the future of food and land use

- Session chair: Robert Vos, FAO
- Rapporteur: Aziz Elbehri, FAO

	Panelists:
09.00-09.20	Jon Erickson, Gund Institute/University of Vermont
09.20-09.40	Robert Walker, University of Florida
09.40-10.30	Plenary discussion
10.30-11.00	Coffee break

* Speakers

WEDNESDAY 25 JANUARY 2017 (CONT'D)

Plenary Session 10: (BREAK OUT GROUPS): Policies for land use, sustainable food production and consumption, and climate action

11.00-13.00 (German Room)

Break out Group 1: Resource management policies and food security
- Session chair: Giovanna Valverde, Minister Counselor, Costa Rica
- Rapporteur: Hayden Montgomery, Global Research Alliance

- Climate-supportive sustainable land and forest management policies, including tenure, payment for services and other instruments (REDD+).
- Water and land-use policies, market and institutional reforms to improve efficiency of water management under scarcity.
- Approaches in cross-sectoral sustainable management of ecosystems, biodiversity protection, and conservation with direct and indirect implications for sustainable agriculture and food security.
- Policy options that exploit synergies between adaptation, mitigation, enhance economic diversification and food security, including non-market approaches.

11.00-13.00 (Lebanon Room)

Break out Group 2: Food demand/Sustainable consumption-policy options
- Session chair: Craig Hanson, World Resources Institute
- Rapporteur: Adriana Ignaciuk, FAO

- Food consumption, dietary patterns and derived GHG emissions.
- Tackling food waste and loss as climate adaptation and mitigation necessity: economics and technology.
- Adaptation technologies and market instruments to manage risks and build sustainable food supply chains.
- Access to sustainable wood energy for cooking and safe drinking water: policies, economic incentives.
- Mitigation potential for bioenergy in food and water systems: policies and investments.

11.00-13.00 (Mexico Room)

Break out Group 3: Socio-economic and pro-poor policies to build climate resilience
- Session chair: Eric Patrick, IFAD
- Rapporteur: Lorenzo Bellu, FAO

- Policies to strengthen small-scale farmer's ability to cope with climate-induced food production variability.
- Socio-economic policies (social safety nets and pro-poor measures) targeting rural farms and households, including those with GHG mitigation and adaptation benefits
- Policies and programs to scale up investments in R&D, including crop/livestock genetics, and technology transfer for accelerating the uptake of adaptation and mitigation solutions
- Policies and agreements to harness trade as a climate adaptation and mitigation mechanism.

13.00-14.00 Lunch break

Plenary Session 11: Reporting and discussion of the Breakout Groups 1, 2 and 3 outcomes
- Session chair: Youba Sokona, South Centre/Cote d'Ivoire and IPCC Vice-Chair

14.00-15.00	Report BOG1, BOG2, BOG3
15.00-15.45	Plenary discussion
15.45-16.15	Coffee break

Plenary Session 12: Conclusions and recommendations for research, policy and concerted action; Critical issues for IPCC further consideration
- Session chair: René Castro Salazar, FAO
- Rapporteur: Aziz Elbehri, FAO and Andy Reisinger, IPCC

16.15-17.30	Wrap-up and putting it all together
17.30	Meeting adjourns

Appendix 04
List of participants

Arild ANGELSEN
Norwegian University of Life Sciences
Norway
arild.angelsen@nmbu.no

Mohamed BADRAOUI
INRA/Ministère de l'Agriculture et la Pêche Maritime
Morocco
mohamedbadraoui@gmail.com

Bojana BAJZELJ
WRAP/UK
Slovenia
bojana.bajzelj@wrap.org.uk

Jeff BALDOCK
CSIRO/Australia
Australia
jeff.baldock@csiro.au

Manuel BARANGE
FAO, Fisheries and Aquaculture Policy and Resources Division
Spain
manuel.barange@fao.org

Lorenzo BELLU
FAO, Economic and Social Development Department
Italy
lorenzo.bellu@fao.org

Martial BERNOUX
FAO, Climate and Environment Division
France
martial.bernoux@fao.org

Ian CAMPBELL
Agriculture and Agri-Food Canada
Canada
iand.campbell@agr.gc.ca

Victor CASTILLO SANCHEZ
UNCCD/Germany
Spain
vcastillo@unccd.int

René CASTRO SALAZAR
FAO, Climate, Biodiversity, Land and Water Department
Costa Rica
rene.castro@fao.org

Maria Vincenza CHIRIACÒ
Fondazione CMCC
Italy
mariavincenza.chiriaco@cmcc.it

Andrew CHALLINOR
University of Leeds
United Kingdom
a.j.challinor@leeds.ac.uk

Jean-Luc CHOTTE
IRD/UNCCD-PSI
France
jean-luc.chotte@ird.fr

Florian CLAEYS
Ministry of Agriculture, Agrifood and Forestry
France
florian.claeys@agriculture.gouv.fr

Harry CLARK
Agricultural GHG Research Center (NZAGRC)
New Zealand
harry.clark@nzagrc.org.nz

Sarah CONNORS
Science Officer, IPCC WGI
France
sarah.connors@universite-paris-saclay.fr

Sarah CORDERO
MPA Harvard University
Costa Rica
Sarah.cordero.cr@gmail.com

Annette COWIE
UNCCD Science Policy Interface
Australia
annette.cowie@dpi.nsw.gov.au

Edouard DAVIN
ETH Zurich/Switzerland
France
edouard.davin@env.ethz.ch

Susanna DE BEAUVILLE-SCOTT
Ministry of Education, Innovation, Gender Relations and Sustainable Development
Saint Lucia
susannascottpmp@gmail.com

Sena Susantha DE SILVA
Deakin University
Australia
sena.desilva@deakin.edu.au

Robert DELVE
IFAD/Policy and Technical Advisory Division
United Kingdom
r.delve@ifad.org

Delphine DERYNG
Climate Analytics
France
delphine.deryng@climateanalytics.org

Marlos DESOUZA
FAO, Land and Water Division
Australia
marlos.desouza@fao.org

Houria DJOUDI
CIFOR/Indonesia
Ethiopia
H.Djoudi@cgiar.org

Aziz ELBEHRI
FAO, Economic and Social Development Department
United States of America/Morocco
aziz.elbehri@fao.org

Wafaa ELKHOURY
IFAD/Policy and Technical Advisory Division
Lebanon
w.elkhoury@ifad.org

Jon ERICKSON
University of Vermont
United States of America
Jon.Erickson@uvm.edu

Agus FAHMUDDIN
Indonesian Soil Research Institute
Indonesia
f_agus@litbang.pertanian.go.id

Julian FOX
FAO, Forestry Policy and Resources Division
Australia
julian.fox@fao.org

Martin FRICK
FAO, Climate and Environment Division
Germany
martin.frick@fao.org

Manuel FULCHIRON
Global Water Partnership Organization/Sweden
France
manuel.fulchiron@gwp.org

Margaret GILL
University of Aberdeen
United Kingdom
m.gill@abdn.ac.uk

Maria Beatriz GIRAUDO
Ministry of Agroindustry
Argentina
nlucas@magyp.gob.ar

Craig HANSON
World Resources Institute
United States of America
CHanson@wri.org

Petr HAVLIK
IIASA (International Institute for Applied Systems Analysis)
Austria
havlik.petr@gmail.com

Bayan HEFZI
Ministry of Energy, Industry and Mineral Resources
Saudi Arabia
Bayan.Hefzi@meim.gov.sa

Stein Joar HEGLAND
Western Norway University of Applied Sciences
Norway
stein.joar.hegland@hvl.no

Gholamali HESHMATI
Gorgan University of Agricultural Sciences and Natural Resources
Islamic Republic of Iran
heshmati.a@gmail.com

Tim HESS
Cranfield University
United Kingdom
t.hess@cranfield.ac.uk

William HOHENSTEIN
US Department of Agriculture
United States of America
whohenst@oce.usda.gov

Matthew HOOPER
New Zealand Government
New Zealand
matthew.hooper@mfat.govt.nz

Ana IGLESIAS
Universidad Politécnica de Madrid
Spain
ana.iglesias@upm.es

Adriana IGNACIUK
FAO, Agricultural Development Economics Division
Poland
adriana.ignaciuk@fao.org

David INOUYE
University of Maryland
United States of America
inouye@umd.edu

Andrew JARVIS
CGIAR/Columbia
United Kingdom
a.jarvis@cgiar.org

Poolad KARIMI
UNESCO-IHE
Islamic Republic of Iran
p.karimi@unesco-ihe.org

Roberta LIMA FERREIRA
Brazilian Alternate Permanent Representative to FAO
Brazil
pararobertabrasil@gmail.com

Eduardo MANSUR
FAO, Land and Water Division
Brazil
eduardo.mansur@fao.org

Christopher MARTIUS
Center for International Forestry Research (CIFOR)
Germany
c.martius@cgiar.org

Nancy MCCARTHY
Lead Analytics Inc.
United States of America
nmccarthy@leadanalyticsinc.com

Alexandre MEYBECK
FAO, Agriculture and Consumer Protection Department
France
alexandre.maebeck@fao.org

Alisher MIRZABAEV
Center for Development Research (ZEF)/University of Bonn
Uzbekistan
almir@uni-bonn.de

Luca MONTANARELLA
European Commission
Italy
luca.montanarella@ec.europa.eu

Hayden MONTGOMERY
Global Research Alliance on Agricultural Greenhouse Gases (GRA)
New Zealand
hayden.montgomery@globalresearchalliance.org

Anne MOTTET
FAO, Livestock Information, Sector Analysis and Policy Branch
France
anne.mottet@fao.org

John MULDOWNEY
Department of Agriculture, Food & the Marine/Ireland
Ireland
john.muldowney@agriculture.gov.ie

Daniel MURDIYARSO
Center for International Forestry Research (CIFOR/Indonesia)
Indonesia
d.murdiyarso@cgiar.org

Sawsan MUSTAFA
Ministry of Animal Resources and Fisheries
Sudan
sawsanatkh@yahoo.com

Ali NAJAFINEJAD
Gorgan University of Agricultural Sciences and Natural Resources
Islamic Republic of Iran
najafinejad@gmail.com

Mi NGUYEN
Deputy Permanent Representative for Canada to FAO
Canada
ec.giec-ipcc.ec@canada.ca

An NOTENBAERT
CIAT-CGAIR
United Kingdom
a.notenbaert@cgiar.org

Michael OBERSTEINER
IIASA (International Institute for Applied Systems Analysis)
Austria
oberstei@iiasa.ac.at

Phillip O'BRIEN
IPCC Working Group III
Ireland
phillip.obrien@nuigalway.ie

Jørgen Eivind OLESEN
Aarhus University/Dept. of Agroecology
Denmark
jeo@agro.au.dk

Pedro Luiz OLIVEIRA de ALMEICA MACHADO
Embrapa/Brazil
Brazil
pedro.machado@embrapa.br

Ryudai OSHIMA
Ministry of Agriculture, Forestry and Fisheries
Japan
ryudai_oshima900@maff.go.jp

Erik PATRICK
IFAD, Environment and Climate Division
Italy
e.patrick@ifad.org

Keith PAUSTIAN
Colorado State University
United States of America
Keith.Paustian@colostate.edu

Anssi PEKKARINEN
FAO, Forestry Policy and Resources Division
Australia
anssi.pekkarinen@fao.org

Daniel PENNOCK
University of Saskatchewan
Canada
Daniel.pennock@usask.ca

Jan PETZOLD
IPCC Working Group II Technical Support Unit
Germany
jan.petzold@ipcc-wg2.awi.de

Prajal PRADHAN
Potsdam Institute for Climate Impact Research (PIK)/Germany
Nepal
pradhan@pik-potsdam.de

Golam RASUL
International Centre for Integrated Mountain Development (ICIMOD)
Bangladesh
golam.rasul@icimod.org

Dave REAY
University of Edinburgh
United Kingdom
david.reay@ed.ac.uk

Andy REISINGER
Agricultural GHG Research Centre/New Zealand
Germany
andy.reisinger@nzagrc.org.nz

S. Niggol SEO
Muaebak Institute of Global Warming Studies/South Korea
South Korea
niggol.seo@aya.yale.edu

Youba SOKONA
South Centre/Côte d'Ivoire; IPCC Vice-Chair
Mali
ysokona@gmail.com

Doris SOTO
Interdisciplinary Center for Aquaculture Research (INCAR)
Chile
dorisst07@gmail.com

Jean-Francois SOUSSANA
INRA
France
jean-francois.soussana@inra.fr

Henning STEINFELD
FAO, Livestock Information, Sector Analysis and Policy Branch
Germany
henning.steinfeld@fao.org

Miguel Angel TABOADA
INTA Institute of Soils
Argentina
taboada.miguel@inta.gob.ar

Christiane TEXTOR
DLR Project Management Agency
Germany
christiane.textor@dlr.de

Richard THOMAS
International Center for Agricultural Research in the Dry Areas/Jordan
United Kingdom
r.thomas@cgiar.org

Murielle TROUILLET
Ministry of Agriculture, Agrifood and Forestry
France
murielle.trouillet@agriculture.gouv.fr

Steve TWOMLOW
IFAD/Policy and Technical Advisory Division
United Kingdom
s.twomlow@ifad.org

Olcay UNVER
FAO, Land and Water Division
Turkey
olcay.unver@fao.org

Riccardo VALENTINI
University of Tuscia/CMCC
Italy
riccardo.valentini@cmcc.it; rik@unitus.it

Giovanna VALVERDE
Embajada de Costa Rica en Italia
Costa Rica
gvalverde@rree.go.cr

Mark VAN WIJK
International Livestock Research Institute (ILRI)
Netherlands
M.VanWijk@cgiar.org

Ronald VARGAS
FAO, Land and Water Division
Bolivia
ronald.vargas@fao.org

Louis VERCHOT
International Center for Tropical Agriculture (CIAT)
Columbia
l.verchot@cgiar.org

Sonja VERMEULEN
CCAFS/UK
South Africa
s.vermeulen@cgiar.org

Raffaele VIGNOLA
Tropical Agriculture Research and Higher Education Centre (CATIE)
Costa Rica
rvignola@catie.ac.cr

Robert VOS
FAO, Agricultural Development Economics Division
Netherlands
robert.vos@fao.org

Robert WALKER
University of Florida
United States of America
roberttwalker@ufl.edu

Reiner WASSMANN
International Rice Research Institute/Philippines (IRRI)
Germany
R.Wassmann@irri.org

Lini WOLLENBERG
CGIAR-CCAFS
United States of America
Lini.Wollenberg@uvm.edu

Miguel Ángel OBREZON LOPEZ
FAO Mission/Rome
Costa Rica
maobregon@rree.go.cr

I7068EN