MITIGATING GREENHOUSE GAS EMISSIONS FROM TROPICAL AGRICULTURE: SCOPE AND RESEARCH PRIORITIES

REINER WASSMANN[1]* and PAUL L.G. VLEK[2]
[1]*Institute for Meteorology and Climate Research (IMK-IFU), Forschungszentrum Karlsruhe, Garmisch-Partenkirchen, Germany;* [2]*Center for Development Research (ZEF), University of Bonn, Germany*
*(*author for correspondence, e-mail: reiner.wassmann@imk.fzk.de; fax: -49-8821-183296; tel.: -49-8821-183139)*

Abstract. The scope of mitigation options in tropical agriculture is discussed for three different activities (a) agroforestry, (b) rice-based production systems and (c) pasture/animal husbandry. The prevention of deforestation – and the re-forestation of degraded land – could become a key elements to national climate protection programs of some developing countries. Agroforestry may offer economically viable windows of opportunity for sustainable use of tropical forests whereas additional funds (e.g. through "Clean Development Mechanism") will be required to make re-forestation programs profitable. Alternative management practices in rice-based systems may offer win–win options to reduce emissions and – at the same time – to obtain another improvement in the production system, namely through optimized timing of nitrogen fertilizer, temporary drainage in irrigated rice fields and integrated residue management. Introducing pasture in degraded land can sequester substantial amounts of carbon (similar to re-forestation).

Future research has to include participation of stakeholders from all conceivable levels, i.e. farmers' cooperatives, non-governmental organizations, national agricultural research centers and extension services, to devise simple and financially interesting incentives for reducing emissions. The feasibility of environmentally friendly production techniques has to be disseminated to the public through 'success stories' (documented in public media) and demonstration farms.

Key words: agroforestry, biomass burning, efficiency, participatory research, pasture, policy, residue, rice.

1. Introduction

The workshop entitled "Tropical Agriculture in Transition – Opportunities for Mitigating Greenhouse Gas Emissions?" was jointly organized by Center for Development Research, Bonn, and the Fraunhofer Institute for Atmospheric Environmental Research, Garmisch-Partenkirchen (recently integrated as IMK-IFU within Research Center Karlsruhe). The workshop was held in Bonn from November 9 to 11 2001 and was attended by fifty scientists from national and international research institutes.

The topic of the workshop has gained special attention through the Kyoto Protocol that introduces new mechanisms to finance the mitigation of greenhouse gas (GHG) emissions in developing countries. Production from tropical agricultural systems will need to increase drastically, because of rising demands in quantity and

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quality of food. Meeting this demand with current technologies of intensification (i.e. increasing inputs on given land) and/or extensification (i.e. increasing land area used for agriculture) may lead to enhanced GHG production. The workshop aimed at assessing the pros and cons of strategies to meet future demands for food, fiber and renewable energy.

The workshop was concluded by a wrap-up session providing a forum for an intensive information exchange in which the workshop participants reached broad consensus on the scope of mitigation options and research priorities for tropical agriculture. The purpose of this paper is to summarize the basic findings reached during these discussions at the workshop.

2. Rationale for mitigation options

Researcher are often confronted with the fundamental question – posed by politicians and farmers alike – to what extent emissions from agriculture are tolerable and in what quantity they have to be regarded as harmful. Obviously, the nature of the greenhouse effect defies the definition of a clear threshold between acceptable and unacceptable emission levels for agriculture. Being a gradual process caused by composite sources, the overarching question about harmful emissions has to be split into two sub-questions: (a) the acceptable level of global warming and (b) the individual share allotted to agriculture within the entire suite of sources. Whatever answers are given, they will in both cases reflect more social considerations than scientific arguments.

The point of departure for justifying mitigation options in tropical/subtropical agriculture should be the statements in the United Nations Framework Convention on Climate Change (UNFCCC, 1992). All signatories acknowledge "that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions ...". The cooperation by all countries is called for irrespective of the recognition that "per capita emissions in developing countries are still relatively low" (UNFCCC, 1992). Since almost all developing countries have signed and ratified the UNFCCC, mitigation options should be implemented within the "the sovereign right of states to own environmental and developmental policies" (UNFCCC, 1992). Thus, mitigation of GHG emissions from tropical agriculture may not need additional justification as long as production systems offer win–win options for increased productivity and reduced GHG emissions.

3. The scientific base

3.1. Individual source strengths of agricultural activities

Tropical agriculture comprises an enormous variety of activities that directly or indirectly affect GHG emissions. Globally, the most significant activities were identified as (a) deforestation for reclaiming new agricultural land as a source of carbon dioxide, (b) rice-based production systems (incl. rice–wheat rotation) as sources of methane and nitrous oxide (as well as carbon dioxide when repeated straw burning leads to depletion of the soil carbon pool) and (c) animal husbandry as a source of methane. Among these activities, deforestation has the largest emission potential for GHGs. The prevention of deforestation – and the re-forestation of degraded land – could become one of the key elements to national climate protection programs of some developing countries. Agroforestry may offer economically viable windows of opportunity for sustainable use of tropical forests whereas additional funds (e.g. through the "Clean Development Mechanism" (CDM) introduced in the Kyoto Protocol) will be required to make re-forestation programs profitable.

The scope for mitigating emissions from rice-based systems and animal husbandry is rather small as compared to emissions deriving from fossil fuel consumption. However, alternative management practices offer win–win options to reduce emissions and – at the same time – to obtain another improvement in the production system (see below).

3.2. National inventories

One of the stipulations of UNFCCC (1992) is that each signatory compiles a "national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases". Although national estimates have been submitted by most countries, these estimates of sources and sinks were largely based on IPCC methodology; i.e. multiplying country-specific "activity data" with default emission factors and algorithms. Such a generic approach can only achieve a very limited accuracy, because region-specific features of agricultural production are ignored. In fact, measurement programs aimed at upscaling of measured emissions revealed pronounced heterogeneity of basically all production systems investigated so far. In the case of rice paddies, for example, it was shown that permanent water logging (as practiced in some areas of Central China) can trigger excessively high methane emissions and should not be pooled with other rice systems (see Wassmann et al., this issue). Likewise, spatial and temporal variability of carbon stocks yields pronounced differences in net C emissions through deforestation as documented in several field studies (see Palm et al., this issue). Default-based inventories will inevitably omit such hot-spots of GHG emissions.

Another source of errors attached to national inventories is the incomplete statistics on agricultural activities. Only those activities associated with pecuniary

transactions, e.g. fertilizer consumption, are recorded reasonably well in statistics. However, GHG emissions are largely determined by residue management, an activity not shown in agricultural statistics. Moreover, assessment of net Global Warming Potential (GWP) should include off-site emissions (e.g. CO_2 emissions through fertilizer production and transport) and life cycle assessment (e.g. the fate of timber products).

3.3. Mechanisms of emission/sequestration

The level of understanding CH_4, N_2O and CO_2 fluxes from tropical agriculture has substantially increased due to recent field, greenhouse and laboratory studies (see Mosier et al., this issue). However, some fundamental questions still remain unanswered:

- As for methane emissions, the major problem of synthesizing emission records into a 'bottom line' is the enormous spatial variability. At this point, the priority should be on integrating GIS data bases and models to capture the heterogeneity (in natural factors and crop management) rather than providing more field data.
- As for nitrous oxide emissions, the field data base is not as exhaustive as for methane. Apart from spatial variation, the nature of N_2O emissions also causes methodological problems in capturing temporal variations. The temporal patterns of N_2O emission typically show distinct intervals with very high emissions that may be missed out by discontinuous measurements. Continuous emission records by automated systems showed that such individual episodes, e.g. after heavy rainfall, can account for the bulk annual N_2O emissions.
- As for carbon sequestration, the mechanisms and limits of this process in tropical systems are only poorly understood. While the sequestration potential of an ecosystem is often perceived as carbon fixation in the vegetation, carbon sequestration in the soils may in fact become the more effective component in the long-term CO_2 balance (see Batjes, this issue). Temperate forests have been identified as a net-sink for carbon, but the role of tropical forests and agroforestry in the global carbon budget is still unclear (see Palm et al., this issue). Likewise, carbon sequestration in crop land has been studied in many temperate systems whereas the data base on tropical land use affecting carbon fluxes is still very scarce (see Mosier et al., this issue; Wassmann et al., this issue).

For future studies, more emphasis should be given to the interaction of CH_4, N_2O and CO_2 emissions. Controlling factors for GHG source and sink functions have to be identified based on the GWP balance (see Robertson and Grace, this issue), and not only on one GHG.

4. Systems design and optimization

4.1. Improving efficiencies

In a broader context of sustainability, mitigation options should aim at improving input/output use efficiency of energy, carbon, nutrients and water (see Vlek et al., this issue). Optimizing the use of these valuable resources offers various synergies with mitigation GHG emissions, e.g.:

- Timing of nitrogen fertilizer according to actual needs reduces nitrous oxide emissions.
- Temporary drainage in irrigated rice fields can reduce both, water consumption and GHG emissions (see Wassmann et al., this issue).
- The common practice of biomass burning causes in many cases a depletion of soil organic carbon.
- Introducing pasture in degraded land can sequester substantial amounts of carbon (see Fisher and Thomas, this issue).

Efficiency increases can be targeted in both, intensive (high input) and extensive (low input) agricultural systems. Coordination with the energy sector will integrate mitigation efforts in "high input" agriculture into a broader scheme of energy policies. Rapid technological development in these highly productive systems demands an "early warning" framework for detrimental impact of new technologies, including excessive emissions of GHG. For low-input agriculture, the major thrusts should be (a) investigating agroforestry systems and (b) reversing the trend of declining soil fertility as observed in many marginal areas.

4.2. Residue management/burning

The fate of residues is a crucial component to determine the sustainability of agroforestry and cereal production systems. In large parts of the tropics, plant residues are burnt to clear the field for the next cropping cycle. This concerns wood and litter in slash-and-burn systems as well as straw in cereal production. The common practice of residue burning not only is a waste of a valuable carbon source, but also depletes the native carbon pool and has adverse impacts on local air quality. Moreover, substantial amounts of organic material are often wasted during processing of agricultural produce, e.g. milling.

The total biomass that is annually burnt corresponds to app. 4000 Tg C including app. 900 Tg C deriving from the burning of agricultural residues (Levine, 1994). Asia is the continent with the highest intensity of residue burning and accounts for app. 68% of residue-borne emissions (Koopmans and Koppejan, 1998). Composition and availability of agricultural wastes show pronounced variation within different production systems. Table I compiles "residue to product ratios" (RPR) and estimated annual biomass for some important crops in Asia. Farming

TABLE I. "Residue to product ratios" (RPR) and estimated annual amounts for some important crops in Asia (Koopmans and Koppejan, 1998).

Crop residue	RPR	Σ_{Asia} (Tg)	Crop residue	RPR	Σ_{Asia} (Tg)
Rice straw	1.76	885	Cassava stalks[1]	0.062	3
Rice husks	0.27	135	Sugar cane tops	0.30	159
Wheat straw	1.75	371	Sugar cane bagasse	0.29	154
Maize stalks	2.00	274	Oil palm fiber[2]	0.15	10
Maize cob	0.27	37	Oil palm shells[2]	0.065	5
Maize husks	0.2	27	Oil palm bunches[2]	0.23	17

[1]Excluding fuel consumption of wood and leaves.
[2]Excluding biomass at clearing of mature trees.

residues are usually burnt in smoldering fires and emit relatively less CO_2 than other fires, e.g. 40% less CO_2 emissions as compared to the burning of charcoal (Andreae and Merlet, 2001). In turn, however, smoldering fires emit more CO (app. 500%) and CH_4 (app. 270%) than flames. CO has adverse effects on local air chemistry and CH_4 has a strong GWP. Fire-borne organic compounds and nitrogen oxides lead to tropospheric ozone formation; high ozone concentrations coincide with the peak of the residue burning season in Asia.

The immediate alternative to residue burning is plowing of organic material into the soil. Soil incorporation of fresh residues with high C/N ratios results in temporary nitrogen immobilization. Therefore, these materials should either be blended with other fertilizers or should be composted before incorporation. While the principles and technical aspects for composting agricultural residues are well known, this technique has only scarcely been adopted in Asia. A further alternative is to leave the straw as mulch, an option that is largely restricted to no-till systems, which have spread to around 300.000 ha in the Indo-Gangetic plains.

For oil palm plantations, mechanical clearing followed by mulching of the organic material may allow substantial recycling of plant material. This technique developed for an environmentally sound practice of shifting cultivation (Kato et al., 1999) could be exploited to reduce the rampant haze development in regions dominated by oil palm plantations.

Apart from recycling, the use of plant residues for energy consumption has a great potential that is insufficiently tapped at present. For example, bagasse is commonly used as biofuel in USA, whereas its use in Asia is rather inefficient. Innovative biofuel technologies may yield new prospects for tropical agriculture in the future. Initial demonstration projects show that straw could successfully be used for ethanol production or directly be fed into electricity generators.

The practice of residue management is closely intertwined with other management practices such as tillage, fertilization etc. Thus, alternative approaches of plant residue management have to be incorporated in a system approach providing economic benefits to the farmers. The objective of residue management (in all systems) should be to strike a sound balance between effective use of energy and sufficient retention of organic matter and nutrients in the soil.

5. Comprehensive research approaches

5.1. Farmers' participatory research

There was broad consensus among all workshop participants that participatory research has been largely neglected so far in the context of mitigation efforts. Farmer's participation appears indispensable for technology transfer of any kind, including management changes aimed at sustainable production systems (see Carvalho et al., this issue). Scientist should start the dialogue with farmer groups about GHG concerns through various pathways:

- Improving the understanding of farmers' perceptions and decision making to classify different target groups for specific mitigation strategies.
- Conducting research on farmer's fields or community forest (instead of research stations) as a "reality check" for suggested improvements.
- Developing alternative management options (e.g. to residue burning) in close collaboration with farmers, preferably derived from indigenous knowledge on sustainable management practices.
- Focussing on farm households rather than individual production systems and evaluating the economic benefit to the farmer, e.g. affordability *versus* profitability.
- Packaging scientific knowledge in practical and user-friendly forms (e.g. easy decision-support tools).
- Establishing continuous feed-back on mitigation strategies over longer time spans, e.g. farmers perception on water pricing may vary according to recent weather events.
- Educating farmers and rural communities by through schools, farmer cooperatives and local newspaper/radio stations.

5.2. Policy research

In most developing countries, the public awareness of GHG emissions as an environmental problem is still rudimentary. Research findings have to be communicated not only to farmers, but also to decision-makers at all conceivable levels. Researchers have to identify information needs of the policy making process and stress the mitigation potential of tropical agriculture. The costs of mitigation options in agriculture have to be set against mitigation costs in other sectors. Technical education on mitigation options should target national agricultural research agencies and extension services.

Mitigation efforts have to become an integral component of environmental policy and capitalize on synergies with other environmental targets. Improving air quality is a fundamental argument against biomass burning. Water saving will become top priority in many rice growing areas and will thus work indirectly in favor of low

methane emissions. In turn, national policies should aim at providing (simple and financially interesting) incentives to farmers to apply 'best management practices'.

Ecological research has to team up with agronomic, economic and social research to define commonly accepted methodologies for comprehensive cost/benefit analyses of mitigation options. Exploring profitable uses of straw/ agricultural debris and timber/non-timber forest products will rely on profound knowledge of local markets and industries. Only interdisciplinary research can advise policy makers on

- institutional reforms,
- clear legal regulations and
- economic incentives e.g. prize stabilization and taxation.

National and international institutes have to be linked to research networks on mitigation to avoid redundancies and to ensure best possible outputs.

Public awareness programs and multimedia campaigns on recycling should promote community action to eliminate unnecessary emissions. Many Non-Governmental Organization (NGOs) in rural areas aim at improving the livelihood of farmers through sustainable agriculture. These NGOs could become genuine partners for establishing 'success stories' on sustainable (and low-emitting) production systems. In the next step, these show-cases can be used to demonstrate how the CDM and/or private sponsorship may fund mitigation efforts.

References

Andreae, M.O. and Merlet, P.: 2001, 'Emission of trace gases and aerosols from biomass burning', *Global Biogeochemical Cycles* **15**, 955–966.

Batjes, N.H.: (this issue), 'Estimation of soil carbon gains upon improved management within croplands and grasslands of Africa', *Environment, Development and Sustainability*.

Carvalho, G., Moutinho, P., Nepstad, D. Mattos, L. and Santilli, M.: (this issue), 'An Amazon perspective on the forest–climate connection: opportunity for climate mitigation, conservation and development?', *Environment, Development and Sustainability.*

Fisher, M.J. and Thomas, R.J.: (this issue), 'Implications of land use changes in the central lowlands of tropical South America for carbon stocks', *Environment, Development and Sustainability.*

Kato, M.S.A., Kato, O.R., Denich, M. and Vlek, P.L.G.: 1999, 'Fire-free alternatives to slash-and burn for shifting cultivation in the Eastern Amazon region: the role of fertilizers', *Field Crops Research* **62**, 225–237.

Koopmans, A. and Koppejan, J.: 1998, 'Agricultural and forest residues – generation, utilization and availability', in *Proceedings of the Regional Expert Consultation on Modern Applications of Biomass Energy*, FAO Regional Wood Energy Development Programme in Asia, Report No. 36, Bangkok. pp. 23.

Levine, J.S.: 1994, 'Biomass burning and the production of greenhouse gases', in R.G. Zepp (ed.), *Climate Biosphere Interaction: Biogenic Emissions and Environmental Effects of Climate Change*, New York, John Wiley and Sons, pp. 139–159.

Mosier A, Wassmann R, Verchot L. and Palm C.: (this issue) 'Greenhouse gas emissions from tropical agriculture: sources, sinks and mechanisms', *Environment, Development and Sustainability.*

Palm, C. Tomich, T., van Noordwijk, M., Vosti, S., Gockowski, J., Alegre, J. and Verchot, L.: (this issue), 'Mitigating GHG emissions in the humid tropics: case studies from the alternatives to slash and burn program (ASB)', *Environment, Development and Sustainability*.

Robertson, G.P. and Grace, P.R.: (this issue) 'Greenhouse gas fluxes in tropical agriculture: the need for a full-cost accounting of Global Warming Potentials', *Environment, Development and Sustainability.*

Vlek, P.L.G., Rodríguez-Kuhl, G. and Sommer, R.: (this issue), 'Energy use and CO_2 production in tropical agriculture and means and strategies for reduction or mitigation', *Environment, Development and Sustainability.*

UNFCCC (United Nations Framework Convention on Climate Change): 1992, *Full text of the Convention,* Climate Change Secretariat, Bonn, http://unfccc.int/resource/docs/convkp/conveng.pdf.

Wassmann, R., Neue, H.U., Ladha, J.K. and Aulakh, M.S.: (this issue), 'Mitigating greenhouse gas emissions from rice–wheat cropping systems in Asia', *Environment, Development and Sustainability*.