Plenary Lecture

Land use intensification and associated sediment transport and nutrient flows in watersheds in tropical mountainous regions

G. Cadisch[1], P. Schmitter[1,2], J. Slaets[1], C. Brand[1], R. Schauffelberger[1], T. Hilger[1], M. Lippe[1], V.D. Tuan[1], R. Rasche[1], T. Duc Vien[3], and C. Marohn[1]

[1]Institute of Plant Production and Agroecology in the Tropics and Subtropics, University Hohenheim, Germany; [2]National University of Singapore, Singapore; [3] Hanoi Agricultural University, Vietnam

Deforestation in combination with land use intensification has led to severe degradation of upland soils in many tropical mountainous regions. In South East Asia, this process has been driven in part by the increasing demand for feed stock, in particular maize, to supply the rapidly expanding livestock sector that caters for the demand of a more affluent and growing urban population. While considerable research has been done regarding the local effects of land use intensification on soil degradation and erosion, much less is known about its impact on water reservoirs and lowland production systems through sediment transport. Knowledge is also limited about the potential of soil conservation measures implemented in the uplands to abate these problems.

A combination of erosion and discharge measurements, flow proportional water sampling and turbidity sensors was used in order to understand rainfall induced carbon fluxes at basin scale. High quality sediment delivery (0.8 Mg C and 0.7 Mg N/ha) from the intensified uplands (monocropped maize and cassava) through the irrigation system resulted in a significant increase in SOC ($p<0.001$) in paddies following an increasing trend of SOC along the lower laying rice cascades. Such continued sediment delivery resulted in substantial yields even in non-fertilized rice fields, e.g. 4.0 ± 1.4 Mg and 6.6 ± 2.5 Mg/ha in the spring and summer crop, respectively, being one of the reasons of sustainable rice production in the area. However, direct sediment depositions during high rainfall events and increasingly originating from the highly eroded and unfertile uplands strongly decreased soil fertility in the rice fields due to their low nutrient and high sand content. Furthermore, flooding associated with typhoons resulted in less fertile deposits on the lower situated fields with a significant decrease (24%, $p<0.001$) in SOC making the intensified systems susceptible to climate change impact.

A compound-specific (fatty acid ^{13}C (FAME)) stable isotope approach was developed to identify the source-sink mechanisms of C within the watershed to the irrigation reservoir. The approach showed that there were significant differences in the isotopic signatures of different land cover types. Using a Bayesian model with a Markov chain Monte Carlo model fitting allowed the source identification with maize and cassava as main contributors to sediment delivery to the reservoir. However, the approach was limited as only a few FAMEs could be found in the respective sediment and all contributing soils to allow a wide use across all land uses.

To identify the processes behind soil fertility changes and nutrient redistributions across the landscape a spatially explicit landscape model LUCIA (Land Use Change Impact Assessment) was developed (Marohn and Cadisch, 2011). LUCIA allowed assessing the impact of land use change on ecosystem services (C sequestration, peak water discharge), soil redestributions and decreasing crop productivity over time. LUCIA contains detailed routines on soil water and horizontal material flows in small catchments using a variable grid cell representation of landscapes. LUCIA has been developed especially for mountain areas by our research group, and allows a spatially explicit evaluation of daily weather observations and variability in soil fertility (CENTURY, Parton et al. (1987)), hydrology (adapted KINEROS 2 (Semmens et al., 2008)), soil physics (SPAW (Saxton and Rawls, 2006)), erosion (Rose et al., 2007), vegetation cover and management. Its plant module builds on the routines of the WOFOST-CGMS model (Supit, 2003).

Field evaluations revealed that under current farmers' upland practice annual soil loss reached up to 180 Mg/ha on steep sloping maize fields under high rainfall intensity during crop establishment. Observations and simulations suggest a resulting considerable siltation of the rice irrigation reservoir under increasing extension of maize in the uplands under these conditions. Paddy terraces are not accounted for in the current model topography, and eroded material is assumed to reach the outlet of the watershed within one day. Currently, a module to simulate water flow and sediment transport along paddy cascades is being developed within the LUCIA framework to better assess upland-lowland interactions.

Soil conservation measures with grass barriers or simultaneous legume cover crops (*Arachis pintoi*) reduced erosion significantly but decreased yields. Minimum tillage and *Phaseolus calcaratus* relay cropping reduced soil loss by 94% and gave maize yields similar to the control, and additionally produced substantial amounts of beans to enhance food security. To capture these feedback effects and the resulting human-environment interactions, we used an agent-based modeling approach which coupled LUCIA with a farm decision-making model (MP-MAS). Scenario analysis covering the introduction of low-cost soil conservation techniques confirmed that some of these techniques had a substantial impact on soil erosion, sediment delivery and crop productivity as well as household income in the study catchment area. The simulation results showed that under current economic conditions and assuming no knowledge constraints, farm households would gradually adopt low-cost soil conservation methods over a substantial proportion of their maize area (37% over 25 years). However, adoption was predicted to be slow and delayed over several years. Scenario analyses suggested that lowering labor requirements of soil conservation techniques did not affect their adoption, but that the currently low fertilizer prices do have a substantial, though indirect, effect on delaying the adoption of soil conservation (a 20% reduction in fertilizer price reduced adoption by 42%). Under the current high maize prices external incentives (e.g. PES) are needed and a better *in situ* integration of livestock systems is required to effectively develop highly productive and sustainable integrated land use systems in these mountainous areas.

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Mitigation measures to improve water quality in agrosystems.

J.M. Sanchez-Perez[1,2]
[1] *University of Toulouse; INPT, UPS; Laboratoire Ecologie Fonctionnelle et Environnement (EcoLab), France*
[2] *CNRS, EcoLab, France*

Agriculture is known to have a great impact of nutrients enrichment on continental water resources. Water resources are essentially surface water and shallow aquifer. Nitrogen dynamic in river is complex and highly variable throughout season and year, depending on hydrology, land-use, and removal in stream. In this context, agricultural impacts on nitrogen concentration are a matter of concern for agricultural decision-maker.

In order to introduce sustainable land use concepts hydro-agro-environmental modelling has been tested as a valuable tool to evaluate the consequences of such land use changes on water and nutrient balance components. The aim of this modelling exercise is to simulate nitrogen load in surface water or/and groundwater depending on plant growth, culture rotation and management practices in different conditions (at the catchment scale, at the alluvial plain scale). The different simulations based on different scenarios should help water managers to choose the best mitigation measures in accordance with the environmental, economic and sociologic context. The role of the buffers zones to improve nitrate concentrations in the riparian zones was evaluated.

*jose.sanchez@univ-tlse3.fr

Climate change and New Zealand agriculture: emissions, impacts and adaptations: case studies using extensive pastoral systems.

Mark Lieffering, Paul Newton, Ronaldo Vibart, Frank Li
AgResearch NZ, Grasslands Campus, Palmerston North, New Zealand

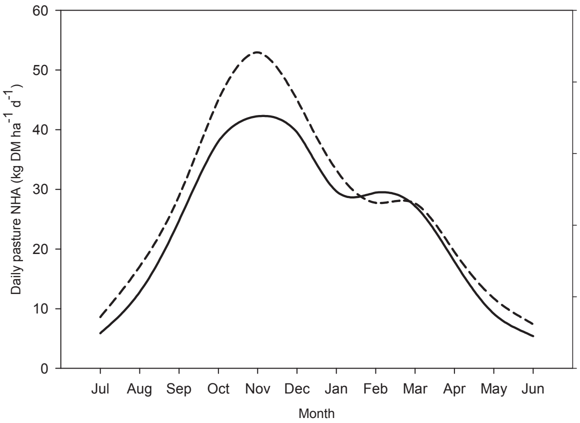
New Zealand (NZ) is an island nation of approximately 4 million people located in the South Pacific Ocean. Globally increasing concentrations of anthropogenic greenhouse gases (GHG) are expected to affect the Earth's energy balance and hence the climate. For NZ, climate change projections vary with location, though it is anticipated that average temperatures by 2040 will be around 1-1.5 °C warmer while annual rainfall will increase in the south and west of the country but decrease or change little in the north and east.

New Zealand's economy is heavily dependent on pastoral agriculture, with about 40% of total merchandise exports consisting of dairy products, red meat (predominantly lamb and beef) and wool. Because this agricultural output is dependent on pasture harvested by ruminant animals, NZ is unique amongst developed nations in that nearly 50% of total GHG emissions are derived from agriculture with enteric methane (CH_4) and nitrous oxide (N_2O) from grazed systems being the dominant contributors. It must be noted that the large GHG contribution from agriculture is to some extent an artefact of the very high (70%) level of renewable electricity generated in NZ; notwithstanding this, NZ's per capita GHG emissions are double those of other developed nations such as Japan.

Although NZ only contributes about 0.2% of global GHG emissions, as a signatory to various international agreements, until very recently research efforts have focussed on developing agricultural GHG mitigation options. However, the development of effective mitigation strategies has proven elusive: reducing CH_4 emissions while maintaining productivity is difficult while potential food safety concerns have thwarted the only N_2O mitigation option currently available and used. Hence more recently there have been increasing research efforts exploring adaptation options for pastoral agriculture. Here we highlight some of these efforts using case studies on the impacts and adaptations of NZ extensive pastoral systems to climate change. Given the importance of pastoral agriculture to the NZ economy, it is important to explore the potential impacts of future climate change on its production base and the capacity of the farming systems to adapt.

About 50% of NZ's pastoral lands are regarded as "hill country" with slopes >15%. A typical farm is family owned and operated, 500 ha in size and grows 7,000 kg DM ha^{-1} yr^{-1} of pasture; this supports 5000 "stock units" consisting of a 60:40 sheep:cattle ratio. The farm is subdivided into 30 "paddocks" which are rotationally grazed by mobs consisting of different types and ages of animal; all supplementary feed is usually made on-farm. A defining feature of NZ hill country farming is the variability within farms in terms of topography and hence seasonal pasture production as well as between farms, catchments and regions; this results in a myriad of management systems which can also vary year-to-year depending on the weather. A further feature of hill country is that currently there are few technological options available when considering adaptation to climate change: for example the land is generally too steep for machinery and interventions such as irrigation are impossible, impractical or uneconomic. Hence not only are there a lack of adaptation options, but because of the variability, a "one size fits all" approach is difficult.

The case studies we will consider in this paper were located in two regions of NZ with contrasting climates and climate change projections: one (Southland) getting warmer and wetter and the other (Hawke's Bay) becoming warmer and drier in summer/autumn. We first using downscaled climate projections (including elevated CO_2) and a pasture simulation model to generate average monthly pasture net herbage accumulation (NHA) curves for 20-year periods centred on 1990 (current) and 2040 (future) (Fig.1).



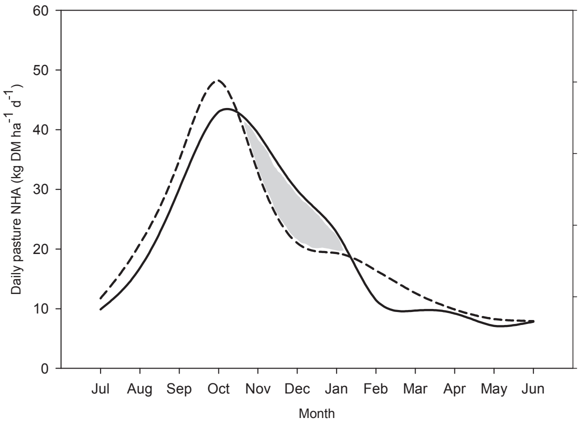


Fig. 1 Average monthly pasture net herbage accumulation rates (NHA) for Southland (A) and Hawke's Bay (B) under current (1990; solid lines) and future (2040; dashed lines) climate conditions. The late summer feed deficit is shown as shaded for Hawke's Bay (B); see text.

For Southland annual pasture NHA was projected to increase from about 8,500 kg DM ha^{-1} y^{-1} in 1990 to just under 10,000 kg DM ha^{-1} y^{-1} in 2040 while for Hawke's Bay it decreased from 6,500 to about 6,2000 kg DM ha^{-1} y^{-1}. More notably, projected seasonal pasture NHA changed markedly with earlier growth and a higher peak in spring for both regions but a noticeable decrease in the late summer pasture NHA for Hawke's Bay (Fig. 1). We used the 1990 pasture growth rates to set up farm systems for the two regions and determined gross margins for the 20 years in the 1990 period. The 1990 farming systems were then applied to the pasture growth curves for the 2040 period and gross margins determined. These were 30% higher for Southland (to \$1000 ha^{-1}) while for Hawke's Bay they decreased from just under \$500 ha^{-1} to about \$230 ha^{-1}; more importantly for Hawke's Bay the variability in gross margins increased substantially. We then adapted the 1990 management systems to take advantage (for Southland) or ameliorate the impacts (Hawke's Bay) of climate change. In both cases this involved applying a combination of currently available tactical and strategic adaptations such as changing the timing of stock management (e.g. lambing and weaning dates) and increasing reproductive efficiencies. These led to further projected increases in the gross margin for Southland and managed to restore Hawke's Bay's to 1990 levels.

Although we demonstrated that economically NZ pastoral agriculture may benefit or at least be able to remain viable under climate change, there are caveats to our results: a) although our pasture modelling did consider the first order effects of elevated CO_2 on pasture NHA, it did not incorporate higher order effects such as the potential reduction in N fixation (the only *de novo* source of N in these systems), potential reduced intake by animals or changing incidence of pests and diseases; b) for the 1990 farms we modelled average current farming systems and while the adaptations used for the 2040 management systems were not outside the biologically feasible options achievable today, they did involve changes in reproductive efficiency and animal growth rates that are only currently achieved on the highest performing farms; c) the adaptations assumed and depended on stock and feed movement between farms and regions, however we were not able to assess the possibility of synchronous, widespread droughts in multiple regions. Should the incidence of these increase then our adaptations would be challenging and could also put pressure on current agricultural infrastructure.

Greenhouse gas emission from China's croplands increased over the last three decades, but effective mitigation is possible

Yao Huang[1], Wen Zhang[2], Yongqiang Yu[2], Tingting Li[2], Wenjuan Sun[1]

[1] *LVEC, Institute of Botany, Chinese Academy of Sciences, China;*
[2] *LAPC, Institute of Atmospheric Physics, Chinese Academy of Sciences, China*

Along with carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the atmosphere are two critical greenhouse gases (GHG) because of their potent impact on global warming. Since the pre-industrial era, the atmospheric CH_4 and N_2O concentrations have increased. In 2011, the atmospheric CH_4 and N_2O concentrations were 259% and 120% greater, respectively, than their pre-industrial levels. Globally, 47–84% of the anthropogenic CH_4 and N_2O emissions are due to agricultural activities.

China, the largest consumer of synthetic nitrogen (N) in the world, accounts for approximately one-third of the global N consumption. The overuse of synthetic N fertilizers has become widespread across China, resulting in a rapid increase in N_2O emissions. The harvest area of rice in China is 18% of the world's total, being responsible for national CH_4 emissions. Soils in China's croplands have been shown to sequester carbon over the last decades. Yet the spatiotemporal changes in the N_2O and CH_4 emissions and the soil organic carbon (SOC) are unclear with regard to an integrated global warming potential (GWP) in China's croplands. This shortcoming limits our overall evaluation of anthropogenic GHG emissions and impairs effective decision making.

Based primarily on model simulations, we estimated GHG emissions and the change in soil organic carbon across China's croplands from 1980 to 2009. Our estimations indicate a 69% increase in the gross GWP of CH_4 and N_2O emissions, from 244 Tg CO_2-eq. yr^{-1} in the early 1980s to 413 Tg CO_2-eq. yr^{-1} in the late 2000s. The incremental increase in N_2O emissions is responsible for ~86% of the increase in gross GWP. Although the rice-based cropping system accounts for only ~20% of the total cropland, it contributes more than half of the gross GWP. This disproportionate contribution is due not only to the CH_4 emitted during the rice growing season but also to the N_2O emitted during both the rice and off-rice upland crop seasons. The carbon sequestered in the cropland soils amounts to 54–117 Tg CO_2-eq. yr^{-1}, thus offsetting 22–28% of the gross GWP. A reduction in the carbon input during the rice season with an increase in the input during upland crop seasons, along with an improvement of synthetic N use efficiency to 40%, would mitigate GHG emissions by 111 Tg CO_2-eq. yr^{-1} and keep SOC sequestration at 82 Tg CO_2 yr^{-1}. Together, this would amount to a reduction of 193 Tg CO_2-eq. yr^{-1}, representing ~47% of the gross GWP in the late 2000s. This amount is the equivalent of ~3% of China's total GHG emissions in 2005 and is thus of national significance.

The ten provinces with the highest gross GWP of N_2O and CH_4 emissions in the late 2000s were Henan, Shandong, Hunan, Jiangsu, Hubei, Sichuan, Anhui, Jiangxi, Guangdong and Hebei. These areas were responsible for ~63% of the national gross GWP from cropland. A reduction of GHG emissions in these provinces could mitigate ~66% of the national cropland GHG emissions, and thus the mitigation in these provinces should be given priority.