International Max Planck Research School on
EARTH SYSTEM MODELLING

Modelling the Global Dynamics of Rain-fed and Irrigated Croplands

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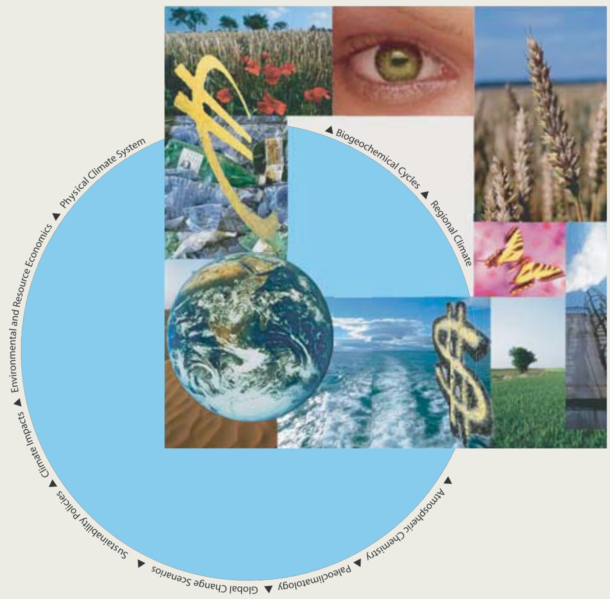

Summary

Agriculture marks a major human interference to the earth's terrestrial surface. Crops "feed the world", but at the same time, their production is related to a wide range of adverse environmental impacts. Facing a growing human population together with changing food preferences, both the demand for crop products as well as the impacts of crop production will continue to rise. Modelling future changes in the extent and distribution of croplands is an important prerequisite to evaluate potential future pathways of agricultural development. This thesis is organised in accordance with the requirements to integrate the simulation of cropland changes in a new framework for global land-use modelling (LandSHIFT), with a focus on irrigated land. We identified neuralgic points for research, including i) the analysis of the current state of large scale land-use modelling, ii) the simulation of global crop yields, iii) the mapping of global crop distribution and iv) the implementation of a method to simulate the spatial distribution of irrigated land.

In order to reflect the current state of continental to global land-use modelling, we classified 18 available modelling approaches according to their integration of geographic and economic knowledge. We found that economic approaches are strong in the formalisation and quantification of drivers on the demand side while geographic approaches are rather suited to account for the supply-side limitations of land resources. Though integrated models seek to combine these strengths, core problems of global land-use modelling have not yet been resolved: this particularly includes scaling issues and the consideration of intrinsic feedbacks.

Modelling the spatial dynamics of cropland on the global scale requires two important inputs: the spatial distribution of crop specific cultivation potentials in terms of attainable yields, and a defined initial distribution of major crops. This work explicitly addresses both aspects:

First, we adopted the agro-ecosystem model DayCent to simulate the yields of major field crops on the global scale. The initial step was to develop a computational framework to operate the DayCent model on a global grid, and to compile the required input data for soil, climate and crop management with global coverage. Secondly, a procedure had to be designed to compute crop planting dates consistent with the current climate conditions. Finally, the DayCent model was parameterised and calibrated to simulate the yields of major crops on a global 30 arc minutes grid. The results show that the Daycent model is capable of reproducing the major effects of climate, soil and management on crop production. Average simulated crop yields per country agree well with FAO data ($R^2 \approx 0.66$ for wheat, rice and maize; $R^2 = 0.32$ for soybean), and spatial patterns of yields mostly correspond to observed crop distributions and sub-national census data.

To derive the global crop distribution at a defined point in time, we mapped 17 major crops plus grazing land on a spatial resolution of five arc minutes. The distribution is characteristic for the early to mid 1990ies. The mapping algorithm integrates FAO country level data with a remote sensing product and the best available sub-national census data. The resulting map was quantitatively compared against data from USDA, GIEWS and another global crop map. The comparison demonstrates consistency with existing expert knowledge, and also a general agreement with the other available crop map (if not compared on a pixel-by-pixel basis).

Using the previous results as an input, we implemented a method specifically tailored to simulate the spatial dynamics of irrigated areas in LandSHIFT. We assume that changes in irrigated areas are driven by crop demands and an exogenously specified irrigated area expansion per country. In order to assess the suitability for additional irrigated areas, we evaluated a set of landscape factors by means of Multi Criteria Analysis. As an important feature, we considered the feedback of basin level water scarcity on the potential for additional irrigated areas. Our method was successfully calibrated and validated by using a ROC metric. The actual allocation of both rain-fed and irrigated crops in each time step is realised as modified MOLA algorithm. First, the specified irrigated area expansion is allocated. The remaining demand is then fulfilled by rain-fed production. As a first application, we simulated different scenarios of irrigation expansion for the African continent. Although there is still potential to expand irrigation in large parts of Africa, we see that some regions are likely to experience severe increases in water stress. A couple of future research priorities should be addressed, particularly the issue of multiple cropping, climate variability and crop specific irrigation requirements as well as the crop specific mapping of irrigated areas.