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The role of rainfed agriculture in securing food production in the Nile Basin

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ABSTRACT

A better use of land and water resources will be necessary to meet the increasing demand for food in the Nile basin. Using a hydro-economic model along the storyline of three future political cooperation scenarios, we show that the future of food production in the Basin lies not in the expansion of intensively irrigated areas and the disputed reallocation of water, but in utilizing the vast forgotten potential of rainfed agriculture in the upstream interior, with supplemental irrigation where needed. Our results indicate that rainfed agriculture can cover more than 75% of the needed increase in food production by the year 2025. Many of the most suitable regions for rainfed agriculture in the Nile basin, however, have been destabilized by recent war and civil unrest. Stabilizing those regions and strengthening intra-basin cooperation via food trade seem to be better strategies than unilateral expansion of upstream irrigation, as the latter will reduce hydropower generation and relocate, rather than increase, food production.

1. Introduction

Major socioeconomic and geopolitical transformations are affecting the allocation of one of the world's most disputed resources: the water of the Nile River. At present, most water in the Lower Nile is being utilized, mainly for irrigation by downstream Egypt. Attempts to convert existing water allocation, primarily based on the 1959 treaty between Egypt and Sudan, to a more equitable share for all countries have not been successful (Nicol and Cascão, 2011). The regional balance of power is, however, changing: (i) the political upheaval after the Arab spring has weakened the dominance of Egypt (Nicol and Cascão, 2011); (ii) in an increasingly multi-polar world, access to infrastructure loans to build dams and irrigation infrastructure upstream has diversified (Broadman, 2008; Foster et al., 2009); and (iii) foreign investors have taken a renewed interest in the basin's agricultural resources, buying and leasing agricultural land all over the basin (Cotula et al., 2009; von Braun and Meinzen-Dick, 2009). Amid these transformations, reallocation of Nile water is a hot issue (Cascão, 2009; Waterbury, 2002; Whittington et al., 2005), with many countries seeking to utilize more water for hydropower and food production.

Increased food availability in the basin is urgent. According to the 2012 report of the United Nations, "The State of Food Insecurity in the World" (FAO et al., 2012), 100 million people in the countries of the basin are undernourished, which amounts to almost a third of the local population. Undernourishment has increased in northern and sub-Saharan Africa over the past decade, bucking the world-wide trend. Except for Egypt, none of the 11 Basin countries are self-sufficient in food (Omiti et al., 2011). Within the context of high and volatile commodity prices that favour net producers over buyers (Breisinger et al., 2010; Swinnen and Squicciarini, 2012), this reliance on global markets is a dangerous gamble: recent political instability in the Nile region has been directly linked to food price hikes (Arezki and Bruckner, 2011), and these risks will only increase. The population of the Basin countries is expected to grow by a third, from 367 million in 2012 to 488 million in 2025 (UNDP, 2011). At the same time, world-wide competition for land, water, energy, and, ultimately, food is increasing (Godfray et al., 2010). Developing countries like those in the Nile, with purchasing powers much lower than that of other

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major food importing countries, are most vulnerable to global shortages (Rutten et al., 2013).

We aim to support the complex policy challenge of the Nile basin by clarifying the science behind the discourse on water, energy and food security, exploring the possibility of national to regional food self-sufficiency as alternatives to an increasing reliance on global markets. We approach this from a hydro-economic perspective and argue that with the water resources of the Nile itself almost fully and productively allocated, the real solution to future food self-sufficiency for the Basin lies outside the domain of water allocation and irrigated agriculture and in the rainfed areas of South Sudan and the Lake Victoria region. According to the United Nations Food and Agriculture Organization (FAO), the potential area suitable for cultivation in South Sudan alone is as high as 30 million hectares, which is ten times the cropped area of Egypt. Only about 10% of that potential is currently being used for agriculture. Recent world-wide assessments of food production have stressed intensification in existing areas, rather than expansion to new areas, as the best way of increasing food production (Foley et al., 2011; Godfray et al., 2010; Tilman et al., 2011). The Nile basin seems to be an important exception, with a combination of both intensification and expansion being warranted.

2. Methods

2.1. Approach

For our research, we derived a baseline of water use (Fig. 2), agricultural crop production and gross margin (GM) in the Nile basin around the year 2005, using an area-based hydro-economic model in *simulation mode* (WaterWise (Siderius et al., 2016); see Section 2.2 and SI1). For this, a present–day spatial distribution of land use systems (FAO, 2009) was made consistent with country-specific FAO crop statistics (FAO, 2004) on actual cropped area (SI2). Crop production and agricultural gross margin (GM) of the water-limited production was then calculated for both rainfed and irrigated crops.

Next, we estimated food requirements in the basin for the year 2025. Future food self-sufficiency correction factors per country were based on the projected population increase up to 2025 (UNDP, 2011) and a population-average calorie requirement of 2300 kcal/person per day (Tontisirin and de Haen, 2001). As such, a minimum intake was imposed, without regard for household access, dietary preferences, or nutritional value. We assumed that agricultural production in the Nile catchment part of each country will grow at the same pace as each country's average and that the proportion of food crops to cash crops remains the same. Future food self-sufficiency targets for the Nile basin could then be derived by multiplying baseline agricultural production with these correction factors (Table 2).

Finally, we applied the hydro-economic model in *optimization mode*, to select those investments in agriculture (area-wise expansion or intensification of rainfed agriculture and new irrigation schemes) and hydropower (new reservoirs) that generate the highest GM using the available land and water resources. We explored where and how food production can best be increased and whether food self-sufficiency for the basin and its individual countries can be achieved by the year 2025.

2.2. WaterWise model

Our model resembles existing hydro-economic models developed for the Nile (Block and Strzepek, 2010; Block et al., 2007; Jeuland, 2010; Whittington et al., 2005; Wu and Whittington, 2006). Similarly to the model of Whittington et al. (2005) it describes the whole Nile basin, including all existing irrigation schemes and hydropower reservoirs, and most of the proposed hydropower plans. Water gets transmitted through the river network using a routing scheme in combination with the variable storage method for the dynamics of large water bodies (swamps, reservoirs), with use in one location limiting options elsewhere. Economic parameters, like the pricing of hydropower, are like those in earlier optimization studies. However, in contrast to the latter we did not limit our analysis to the river system alone, i.e. optimizing hydropower and irrigation yields, but included yield from rainfed land use. Land use is an endogenous variable in our model and land-use changes and the impact on downstream flows are thereby integrated into the optimization. The general idea behind the model is that it should be capable of exploring a wide range of land and water management options, for various scenarios with respect to basin cooperation. Such an exploratory functionality necessitates a relatively simple model formulation for both hydrology and agronomy. It should then be realized that the model results are just indicative of a search direction. Further studies are needed for more accurate assessments.

The model optimizes GM by choosing the optimal combination of land and water use options for each of 1371 so-called hydrotopes, units of similar soil and meteorological characteristics, given available water resources:

$$Y_{TOT} = Y_{LU} + Y_{HP} - C_{LWM}$$

with [2]

$$Y_{LU} = \Sigma_{\mathrm{z,u,y}}\left(Prod_{\mathrm{z,u,y}} \times P_{\mathrm{y,u}} - C_{\mathrm{LUu}} \times Ac_{\mathrm{z,u,y}}\right)$$

$$C_{LWM} = \Sigma_{\mathrm{z,u,y}}\left(C_{IRRIz,u} \times Ac_{\mathrm{z,u,y}}\right)$$

where Y_{TOT} represents total gross margin (in USD/yr), Y_{LU} the profit from land use (USD/yr) based on production (*Prod*, in ton) times price of product (*P*, USD/ton) minus non-water costs (C_{LU}, USD/ha) times the cropped area (*Ac*, in ha), in year *y* per land use *u* in hydrotope *z*. Y_{HP} is the GM of hydropower (USD/yr). C_{LWM} are the costs of local water-management measures for supporting land use, i.e., the variable costs of local irrigation measures (in USD/ha), depending on the amount of water used. Variable costs of water relate to pumping costs, which is a combination of labor, capital and energy costs. For the variable costs of water we used a regional estimate of 0.01 USD/m^3 (Hellegers and Perry, 2006).

Crop production and related water fluxes for all land and water use options in each hydrotope are pre-processed by water-crop modules run in an offline mode (SI2). In the Nile application a soil moisture accounting model of the bucket type is used, very similar to the AQUACROP model of the FAO (Raes et al., 2011), but more advanced in simulating soil storage and drainage, while simplifying the dynamic crop growth. Rainfall can contribute to runoff, drainage, or groundwater storage, after correcting for evapotranspiration. The calculation scheme for the evapotranspiration follows the FAO single crop coefficient method (Allen et al., 1998), applied separately to the vegetated and non-vegetated part. Crop production is simulated with a slightly modified form of the K_y approach of FAO (Doorenbos and Kassam, 1979), where the ratio between actual and potential evapotranspiration is translated into a mean yield ratio. Actual yield in each hydrotope is then calculated by multiplying this mean yield ratio with a predefined potential yield. This relatively simple method has the advantage of being robust and requiring a minimum of data.

WaterWise optimizes GM of food production by i. converting non-arable land into arable land, by ii. converting existing arable land into high-intensive variants and/or iii. by increasing the area