Agricultural resource scarcity and distribution

A case study of crop production in Africa

Midterm report

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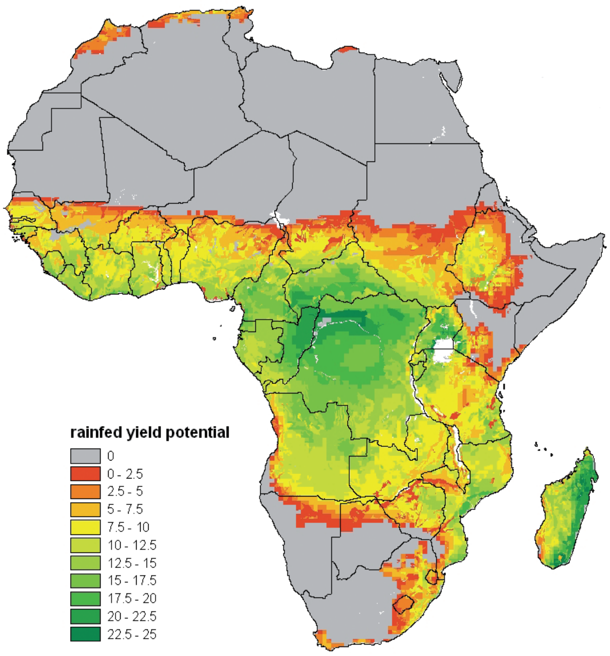

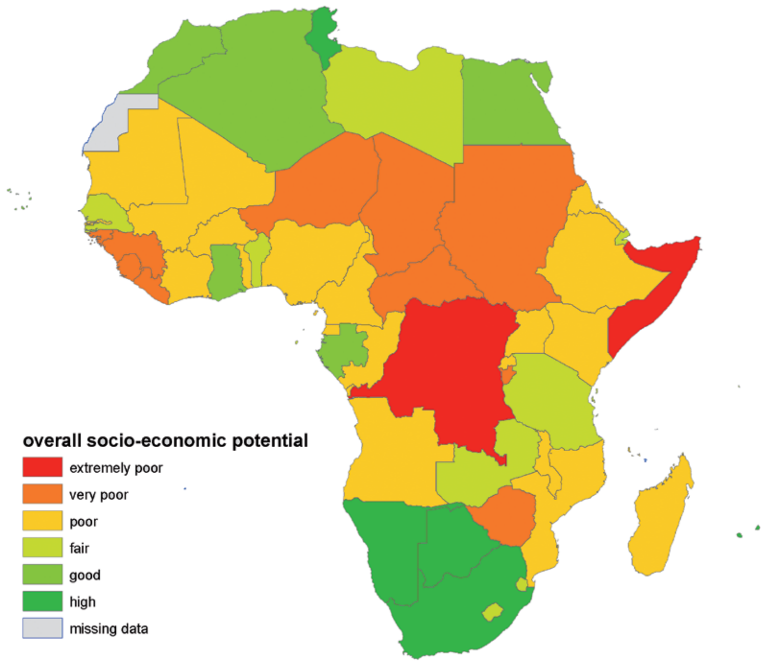

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J.G. Conijn[1], E. Querner[2], M.-L. Rau[3], H. Hengsdijk[1], T. Kuhlman[3],
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Executive summary

The Food and Agriculture Organization (FAO) estimates that 70% more food needs to be produced by 2050 to meet the growing global demand driven by a larger and more affluent population and associated changes in consumption patterns. The increased demand for biomass required for a transition towards a bio-based economy further adds to the urgency to increase agricultural production. At the same time, biodiversity loss still continues and major agricultural resources are limited at a global level, such as fossil fuels and phosphor, or at regional level such as water.

While it is commonly recognized that much improvement in resource efficiency can be attained, detailed insight is lacking as to where these increases in production and improvements can be realised. This report describes a spatial framework that enables the integration of biophysical data, agro-ecological knowledge and socio-economic information to quantify production potentials, resource use efficiencies and supporting socio-economic conditions at various geo-graphical scales, e.g. going from grid cell to province, regional, national and global level. The framework is still under development and this report presents the first results of the framework applied to Africa.

In this report we focus on current yields of cereals (and in particular of maize) and associated resource inputs, i.e. land, nitrogen and phosphorus fertilizer, and animal manure availability across Africa and calculated production potentials and the soil water balance of maize and wheat under rainfed conditions optimally supplied with nutrients and protected against pests and diseases. Maize yield gaps were determined per grid cell by combining current yield levels with calculated rainfed yield potentials. Average annual fresh water availabilities on the continental and national levels were calculated and seasonal water discharge was studied by connecting upstream/downstream parts of a river basin in a case study area (Limpopo watershed). Finally, spatial socio economic indicators relevant for rural development in general and agricultural production in particularly were identified and explored.

The number of undernourished people in Africa has been relatively stable at about 210 million during the last decade. Increase in food production has been insufficient to substantially reduce the number of undernourished people. The growth in cereal yields (1.3%) did not keep pace with population growth in Africa which increased with 2.4% per year from 819 to 965 million during the period 2000 – 2007. Cereal food production increased further by expansion of the harvested cereal area with 13 million hectares. Expansion of the cropland has increased the competition with other land use like livestock grazing or preserving nature and biodiversity.

Our study suggests that rainfed cereal yields can be increased with a factor five in Africa, i.e. from the current average of 1.1 to 5.8 tonne dry matter ha^{-1} per crop cycle under rainfed conditions without growth limitations from nutrients, pests or diseases. In addition, the average cropping intensity can be increased under high input levels with about 50%, i.e. from current 0.8 to 1.2 crop cycle per year. To realize these potentials various constraints in both the agro-ecological, economic and socio-institutional domain should be addressed simultaneously.

One important constraint is the availability of nutrients required to realize higher cereal yields. Current average fertilizer nitrogen rates are well below 10 kg N/ha across Africa. Sustainable use of animal manure on cropland may roughly double the amount of N available for crop production but will still be largely insufficient to realize the production potentials. Therefore, large amounts of external nutrient inputs will be needed to increase crop productivity levels in Africa to twice or thrice current levels.

The question whether increasing agricultural productivity will substantially affect water availability for other purposes still remains largely unanswered. In our calculations total evapotranspiration from crop land under rainfed conditions in Africa consumes 1156 km^3 per year, which corresponds with only 6% of the total rainfall on the entire African continent (20,000 km^3 y^{-1}) and 15% of the total calculated fresh water availability (7500 km^3 y^{-1}). The majority of the rainfall is consumed by other ecosystems. At the national or smaller scales, however, crop water requirements relative to fresh water availability can be high. Also the inter- and intra-annual variability in water use and availability is important: local water scarcity can be high due to distinct differences between wet and dry years/season, even in high water 'surplus' countries.

A hydrological model is being developed for watersheds in Africa to address the spatial and temporal water use and availability. Simulations (case study: Limpopo river basin) reveal that the modelling approach is technically feasible and can be used to identify regions and periods in which the water resources are scarce. Moreover it can be used to assess the effects of increasing agricultural productivity and land use change upstream on water resources downstream. From the information on historic stream flows in the Limpopo River it's clear that discharges were reduced dramatically over the last 50 years. The increase in water use upstream in Zimbabwe and South Africa has a great effect on river flows downstream in Mozambique. Such changes in river flows indicate that future analyses should consider the main underlying changes within a river basin, such as large scale irrigation systems and storage dams.

In this report a variety of socio-economic indicators have been identified and elaborated that influence agricultural production and the potential agricultural growth, The review of existing literature provides evidence that African agricultural productivity corresponds with the widely held presumptions of the importance of socio-economic factors for promoting agricultural production and productivity growth. The empirical analysis of relationships between socio-economic factors and agricultural productivity is heavily constrained by lack of data and measurement issues. In addition to endogeneity, the causal direction of the relationship constitutes a major issue and results for one country and product or group of products cannot necessarily be generalised to draw overall conclusions. However, based on a qualitative integration of five different indicators on fertilizer use, market access, human development, governance and farm support in terms of public spending on agricultural R&D the socio-economic potentials of African countries are mapped. This map points to countries where socio-economic conditions are such that investments in food production are likely to bear fruit.

The framework offers interesting possibilities of linking different databases in a spatial context and allowed to increase insights in current production and input use, agricultural production potentials and associated water requirements in relation to current rainfall distribution. Combining socio-economic with agro-ecological spatially disaggregated data is still in development, but shows much promise for the future to support agricultural/rural policy decision-making.

1. Introduction

The Food and Agriculture Organization (FAO) estimates that 70% more food needs to be produced by 2050 to meet the growing global demand driven by a larger and more affluent population and associated changes in consumption patterns (FAO, 2009). The increased demand for biomass required for a transition towards a bio-based economy further adds to the urgency to increase agricultural production (FAO, 2008). At the same time, biodiversity loss still continues (CBD, 2010) and major agricultural resources are limited at a global level, such as fossil fuels (Meadows, 2004) and phosphor (Cordell, 2010), or at regional level such as water (Rijsberman, 2006; CAWMA, 2007). Therefore, increased agricultural production should be accompanied with improvements in resource use efficiencies (Keating *et al.*, 2010). While it is commonly recognized that much improvement in resource efficiency can be attained, detailed insight is lacking as to where these increases in production and improvements can be realised. This is so because production potentials, resource availability and socio-economic conditions vary both spatially and temporally. Anticipated climate change is for instance expected to increase global temperatures and climate variability that will affect agricultural productivity across the globe. This poses additional challenges to agriculture in realising increased production and resource use efficiencies for which adaptation and mitigation measures should be identified that are spatially and temporally explicit.

The production and resource use efficiencies of agricultural production systems are determined by many factors. Crops being the primary production are at the base of agriculture and are taken as entry point in our analysis. Biophysical factors, i.e. climate, soil and crop characteristics and water availability determine the production potential of a location, while socio-economic factors such as infrastructure, access to credit and governance are important for realizing the potentials. These factors and their interaction strongly determine the design of agricultural production systems (Dixon *et al.*, 2001; Bindraban *et al.*, 2009) with widely varying production potentials and resource use efficiencies. To better identify promising interventions for improving agricultural productivity a framework is needed that integrates biophysical data, agro-ecological knowledge and socio-economic information to quantify production potentials, resource use efficiencies and supporting socio-economic conditions at various geo-graphical scales, e.g. going from grid cell to province, region, national and global level. By combining relevant spatial information (e.g. climate and soil) and models, various options can be explored *ex-ante* looking for opportunities to meet the increased demand for food and biomass and the decreased use of resources. The output of such a framework enables to identify which production systems can contribute to the growing demand for agricultural products and what the associated resource requirement will be. Will the availability of resources be sufficient to realise this growing demand for agricultural food and biomass or are adjustments needed in the demand for food and biomass? How much synergy can be generated between increased production and improved resource use efficiencies or are undesired trade-offs inevitable and with what consequences? Insight in these questions will provide science-based information on options for rural and agricultural development for informed policy decision making by policy, business and civil society organizations.

The Seventeenth session of the Commission on Sustainable Development (CSD-17) and the FAO Food Summit on Food Security in 2009 reiterated the message regarding the urgent need to address the multiple challenges the world is facing in terms of food security, climate change and degradation of ecosystems. The 'The Hague Conference on Agriculture, food security and climate change' November 2010 in the Netherlands voiced the message that food security requires agricultural production systems to change in the direction of higher productivity and production, higher resource use efficiency and lower output variability in the face of climate risk, especially with respect to Africa. There is an apparent concern that the combination of a growing demand for food and for biomass for non-food applications should not jeopardize the realization of both the Millennium Development Goal on poverty and hunger (MDG1) and on environmental security (MDG7). Hence, different policy forums have addressed the need to increase production and resource use efficiencies, but comprehensive research tools to support the policy dialogue are scarce. A framework can help the Netherlands Ministries of EL&I and Foreign Affairs/DGIS to provide insight and options as to how and to what extent the mix of these various goals can or cannot be obtained simultaneously. The Netherlands has much knowledge and expertise in the domain of world food supply, agriculture and development and would like to make a well informed contribution to international dialogues and to actual implementation programs.

The framework in this study is designed for global analyses (using global databases) but here we have taken Africa as the study area because agricultural productivity increase is insufficient to secure food availability to the rapidly growing population, a large fraction of which is poor and hungry. Also, many authors claimed that Africa has a large potential for producing non-food agricultural commodities including bio-energy crops for other parts of the world (e.g. Field *et al.*, 2008). In this study we look specifically into productivity and resource efficiency in agriculture with the aim to offer policy options for 'producing more with less inputs' and to gain insights in local and regional balances of available and required resources. The methodology used in this study, briefly described in Chapter 2, is based on work carried out in the 1990's (WRR, 1995; Luyten, 1995; Penning de Vries *et al.*, 1995) and that recently has been updated and applied for Africa (Bindraban *et al.*, 1999, 2000, 2009). In the current framework different models and global databases with information on soils, weather and land use are linked (described in Chapter 3). Spatial databases on current agricultural practices (harvested areas, yields, nutrient application) are combined with the results of a crop-soil model to quantify production potentials of wheat and maize. Initial results of this assessment for Africa are presented in Chapter 4. In addition, the framework is used to zoom in at local level, i.e. the level of a river basin with an application in the Limpopo river basin (Chapter 5). By zooming in at a river basin hydrological processes can be better accounted for determining water availability for crop production at local scales. In addition, the framework is expanded with socio-economic data providing insight in supporting (or constraining) conditions influencing development and agricultural growth in Africa. Associations of production potentials and socio-economic factors have been analysed using spatial information of socio-economic drivers of agricultural development (Chapter 6). Finally, conclusions from the various analyses presented in the preceding chapters for agricultural and rural development are described Chapter 7.

The aim of this project report is to present the initial results using the spatial framework:

(1) To quantify and map current yields of cereals and associated resource inputs, i.e. land, nitrogen and phosphorus fertilizer, and animal manure availability across Africa.
(2) To quantify and map production potentials of maize and wheat under rainfed conditions optimally supplied with nutrients and protected against pests and diseases and associated resource inputs, i.e. land and water across Africa.
(3) To quantify and map yield gaps by comparing rainfed production potentials of maize with the current maize production in Africa.
(4) To quantify average annual fresh water availabilities on the continental and national levels and effects of agricultural water use on seasonal water discharge by connecting upstream/downstream parts of a river basin using the Limpopo as a case study area.
(5) To report on the spatial socio economic indicators relevant for rural development in general and agricultural production in particularly.

2. General description of the framework

Sjaak Conijn and Huib Hengsdijk

2.1 General methodology

The core of the applied methodology links data from spatial databases and applies different types of models to calculate production, input requirement and environmental impact. Information on soil properties and climate conditions are linked with different models in this report: a dynamic crop-soil model (section 2.2) is used to calculate yields of different crops, while a one-dimensional groundwater model (Chapter 5) is used to simulate the hydrology of a river basin. By incorporating different databases and models into our analytical framework, we can study various aspects related to agriculture and resource use depending on predefined objectives. To prepare for future analyses of the entire world, we use whenever possible databases with a global coverage containing spatial explicit information. The level of aggregation at which we combine the information is a grid cell, i.e. a discretely uniform spatial unit of the globe, such as a square kilometer, that is referenced by its geographical x and y coordinates. Information from spatial databases can be scaled up from the grid cell to other scales, such as country or river basin, continent and ultimately the entire globe. The scaling up of information over areas beyond that of a single grid cell enables to analyse the effects of spatial diversity in environmental and socio-economic conditions on agriculture (Figure 2.1).

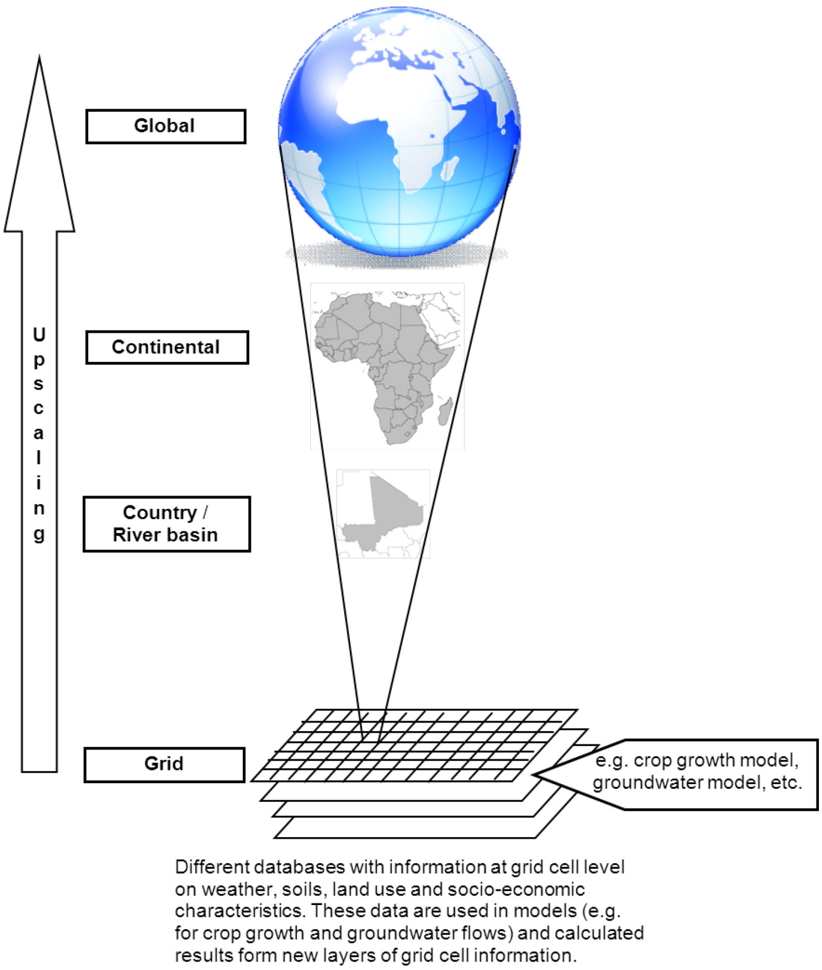

Figure 2.1. Schematic presentation of the framework.

2.2 Crop-soil model

To quantify crop production in the framework the model LINPAC is used (a LINtul model for Perennial and Annual Crops) that partly originates from the LINTUL (Linear INTerpolation of Utilization of Light) models of Spitters (1987) and Spitters and Schapendonk (1990) which are further described in Bouman *et al.* (1996). Recently, the model for annual crops was extended with perennial crops (Jing et al, 2010).

Application of LINPAC in this study consists roughly of three steps. First, the suitability of each day of the year for crop growth is determined as function of daily temperature and soil moisture conditions. This means that daily temperatures should be within a crop-specific range, i.e. not too cold or hot for crop growth, while soil moisture conditions need to be sufficient to allow sowing and dry soil conditions indicate the end of a suitable growing period. These calculations are based on average daily weather conditions and all suitable days together in a year form the average growing season(s). Within these growing seasons the number of cropping cycles of a specific crop and the start(s) and end(s) of these cycles are calculated by taking into account the temperature sum required to complete the crop' s development. Therefore, the calculated number of days with crop growth is usually less than the number of suitable days for crop growth, because crop development does not always fit precisely in the growing season. If the length of the determined growing season is too short relative to what the crop needs to complete its development, a 'no–cropping' situation is simulated which results in the simulation of only the soil water balance without a crop vegetation.

Second, for calculating crop yields, dry matter production is calculated as the product of light interception and light use efficiency (LUE, g dry matter per MJ intercepted radiation). Light interception depends on leaf area index (LAI, m^2 leaf per m^2 ground) and the accumulated dry matter production is distributed among above- and belowground and (non-) harvestable parts. Dry matter distribution is governed by the developmental stage of the crop (DVS, dimensionless) which is driven by temperature.

Third, the soil water availability for the crop is determined by calculating infiltration, evapotranspiration and percolation. The soil profile is divided in two horizontal layers, i.e. from soil surface to the actual rooting depth and from actual rooting depth to a crop- or soil-specific maximum rooting depth. Water infiltrates in the soil as a result of precipitation plus (possible) irrigation minus runoff which is a function of soil texture, slope and precipitation/ irrigation. Percolation equals the amount of water in excess of the maximum storage capacity of each soil layer and infiltrates into the next layer. Percolated water at the bottom layer is assumed to be lost for the crop. Evapo-Transpiration (ET, mm) is calculated in two steps: (i) potential ET is calculated with the Penman-Monteith equation and divided over potential soil evaporation (E, mm) and crop transpiration (T, mm) and (ii) actual ET is a function of this potential E and T and the soil water availability in the rooted soil layer. If the actual T falls below the potential T, water stress occurs resulting in a reduction of both LUE and LAI growth rate and in an acceleration of leaf senescence.

LINPAC operates with a daily time step to simulate the effects of day-to-day variability in climate, including precipitation and results are aggregated to annual values.

3. Weather, soils and land use

Sjaak Conijn, Huib Hengsdijk, Ben Rutgers, Raymond Jongschaap and Prem Bindraban

3.1 Meteorological data

Weather has a large impact on agricultural production and knowledge of spatial and temporal variation in weather is therefore important. The Climate Research Unit (CRU; http://www.cru.uea.ac.uk/cru/data/hrg/) provides various databases that differ in spatial and temporal coverage and in the number of weather variables. We used (i) a dataset of mean monthly surface climate over global land areas, excluding Antarctica ('CRU CL 1.0'), (ii) the period 1961-1990[1] and (iii) six variables, i.e. radiation, mean temperature, wind speed, vapor pressure, precipitation and the frequency of wet days (i.e. number of days with more than 0.1 mm rainfall per month). These data have been derived by interpolation from on-the-ground station data to a 0.5 degree latitude/longitude grid (New *et al.*, 1999). In Africa a 0.5x0.5 degree grid cell measures approximately 54x54 km.

Temperature and precipitation show large spatial differences in Africa (Figs. 3.1 and 3.2). High temperatures and low rainfall are common in desert areas such as the Sahara and large parts of Somalia, whereas frequent rains dominate in the tropical (forest) zone West- and Central-Africa, including Madagascar. In most regions of Africa clear gradients can be distinguished, especially of increasing total rainfall going from North to South in the Sahelian region, and vice versa in the Southern part of the continent. The differences in weather conditions in Africa strongly determine production possibilities of agriculture especially due to the availability of water for crops. The combination of high temperatures (e.g. average maximum temperature > 30 °C) and low rainfall (< 300 mm y^{-1}) characterize (too) dry areas for crop growth under rainfed conditions, as can be found in the Sahara, large parts of Somalia and to a lesser extent the Kalahari and the south-west part of Southern Africa. Higher rainfall in other parts of Africa permits crop growth during a part or even the entire year (e.g. in Central Africa).

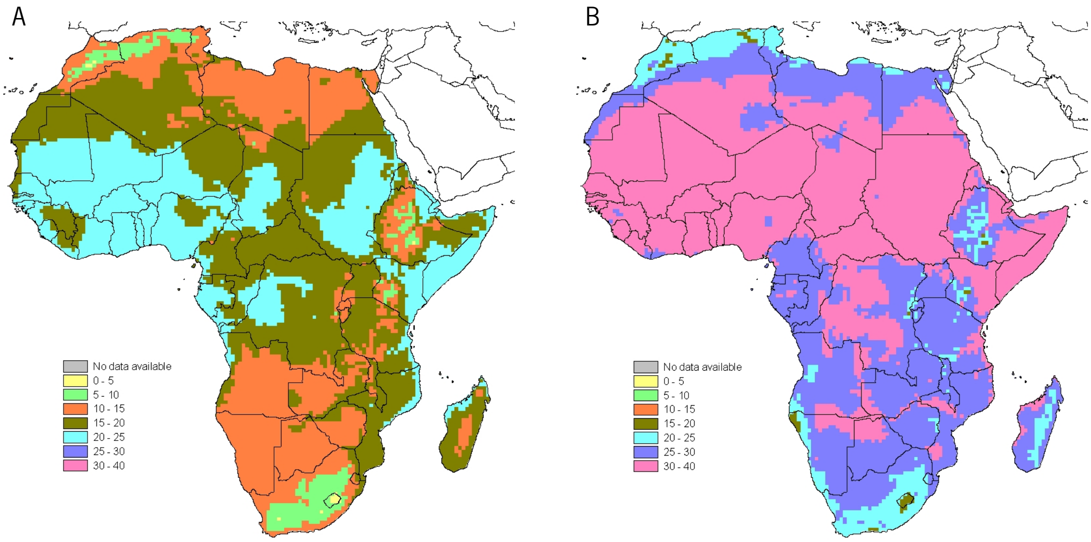

Figure 3.1. Average (A) minimum and (B) maximum temperature (°C) in Africa for the period 1961 – 1990 (based on 'CRU CL 1.0').

1 More recent data from CRU were not available at the start of the analysis, but will be used in future work.

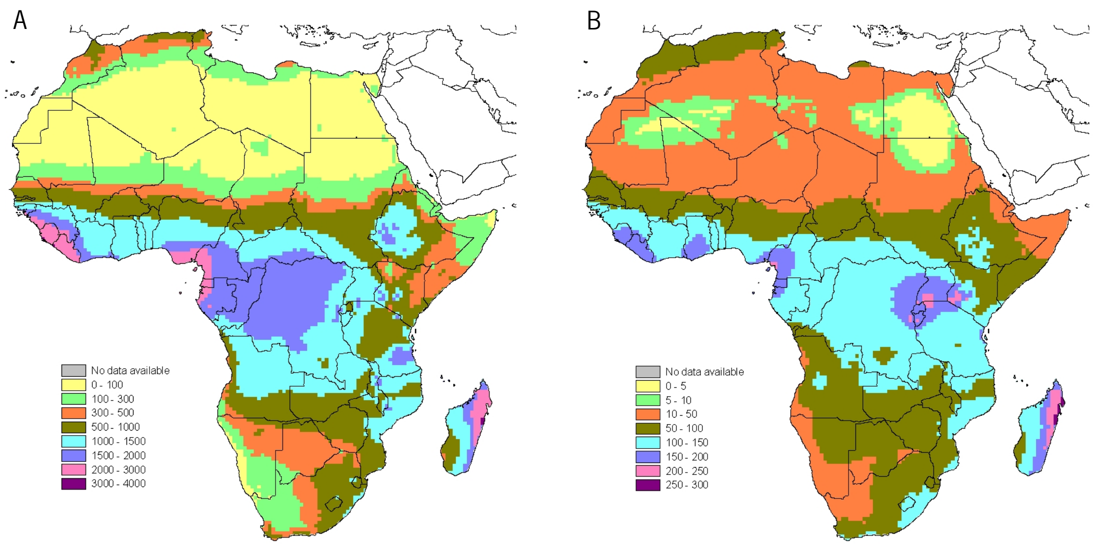

Figure 3.2. Average (A) precipitation in mm per year and (B) number of wet days per year in Africa for the period 1961 – 1990 (based on 'CRU CL 1.0').

3.2 Soil data

Soils are known to have large effects on agricultural production and because spatial variability in soil characteristics is often high the resulting productivity potential may vary strongly over short geographical distances. In this study, the spatial distribution of soil types is obtained from the Digital Soil Map of the World (DSMW; FAO, 1996). This gridded map has a resolution of 5x5 arc minutes in latitude/longitude coordinates, which corresponds to an area of approximately 9x9 km at the equator. The legend of this map contains globally 4,931 unique Soil Mapping Units (SMU). Each grid cell of the map is characterized by one SMU and described by the percentage occurrence of a number of soil units (up to 8 soil units per SMU), totaling 100% of the grid cell. Most grid cells thus contain more than one unique set of soil conditions that may affect crop production. Soil properties from the DSMW, relevant for our analyses, comprise texture class, slope class, soil depth, soil moisture storage capacity of plant-available water and a soil induced reduction factor. The first four properties are derived from algorithms provided by the FAO (1996); see Appendix IV).

Soil depths less than 25 cm and soil moisture storage capacities below 50 mm m^{-1} are conditions that generally hamper crop growth, because these shallow soils do not allow deep rooting and can only contain little amounts of water. Figure 3.3 shows that these conditions are not wide-spread in areas with suitable climatic conditions.

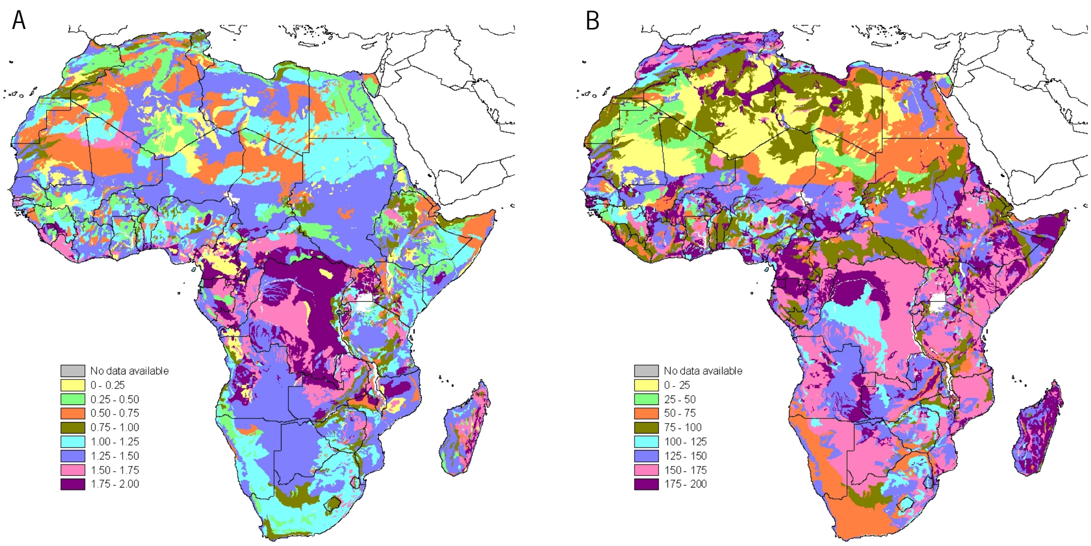

Figure 3.3. *(A) Soil depth in m and (B) soil moisture storage capacity of plant-available water in mm m^{-1} as average values at 5x5 arc minutes grid cell level in Africa (based on FAO, 1996). Note: large inland waters in Africa have a white color (such as Lake Victoria, Lake Malawi, Lake Chad, etc.).*

3.3 Land use data

To more precise assess the biophysical production potentials of current arable areas spatially explicit information on land use is needed. The studies of both Erb *et al.* (2007) and Monfreda *et al.* (2008) describe global land use around the year 2000 and provide gridded maps with a resolution of 5x5 arc minutes. The map published by Erb *et al.* (2007) represents a number of aggregated land use cover types based on remote sensing and national census data (Fig. 3.4a). Table 3.1 provides the distribution of total land use in Africa based on this data source. They calibrated the crop land data from remote sensing using national crop land values from FAOSTAT, but underestimated crop land in Niger and Tanzania (approximately 15 Mha). Their total crop land area for Africa (206.5 Mha) equals that of FAOSTAT for the year 2000 (222.0 Mha) if corrected for this underestimation.

Table 3.1. *Total land use in Africa in million ha (Mha) based on the 5x5 arc minutes resolution land use map of Erb et al. (2007).*

Infrastructure[1]	Crop land[2]	Forestry[3]	Grazing land[4]	Non-productive land[5]	Untouched area[5]	Total
12.6	206.5	588.3	1253.8	814.4	97.7	2973.3

Legend (from Erb et al. 2007):

1 *Buildings or transport infrastructure and also containing vegetation cover, e.g. in recreational areas, cemeteries and vegetation along roads and highways.*

2 *Including annual and permanent crops and fallow land following the definition of the FAO.*

3 *Used and unused forest ecosystems (closed forest, fragmented forest, and other wooded land).*

4 *Including a wide range of ecosystems, from artificial and semi-natural grasslands, natural grasslands, shrublands, savannas to tundras with huge differences in grazing suitability.*

5 *Comprising wilderness, i.e. untouched by human activities, areas with an aboveground net primary production below 20 g C/m^2, including areas with snow cover*

The map of Monfreda *et al.* (2008) describes crop land use as total harvested crop area by summing individual crop maps, based on remote sensing and sub-national census data (Fig 3.4b). Total harvested crop areas may exceed grid cell areas due to multiple harvests per year (e.g in parts of Nigeria and Egypt). The total harvested crop area in Africa estimated by Monfreda and colleagues, i.e. 166 Mha, is lower than the total harvested area of arable and permanent crops published by FAOSTAT (184 Mha: average value of 1997 – 2003; extraction date: 6-12-2010). The difference is probably caused by different sources used: Monfreda and colleagues used sub national data when available, whereas FAOSTAT provides data at national level.

Differences between Erb *et al.* (2007) and Monfreda *et al.* (2008) are related to differences in underlying data and definitions (Figure 3.4). For example, Erb *et al.* (2007) mapped crop land irrespective of its current use (e.g. including fallow land), whereas Monfreda *et al.* (2008) mapped harvested crop areas. The difference in estimated total area of crop land (222 Mha including the correction of 15 Mha; Erb *et al.*, 2007) and harvested crops (166 Mha; Monfreda *et al.*, 2008) illustrates the effect of different definitions used. According to FAOSTAT the crop land area (i.e. arable land and permanent crops) was almost 40 Mha larger than the harvested areas of all arable and permanent crops in 2000. Both maps do highlight that on average a rather low percentage of the area within a grid cell is used as crop land. The low percentage crop land indicates a highly scattered crop production in many countries, which may have important implications for transport and infrastructure. Highest fractions used for agriculture are found in parts of Morocco, Algeria, Tunisia, Egypt, Togo, Nigeria, Niger, Cameroon, Sudan, around Lake Victoria and South Africa.

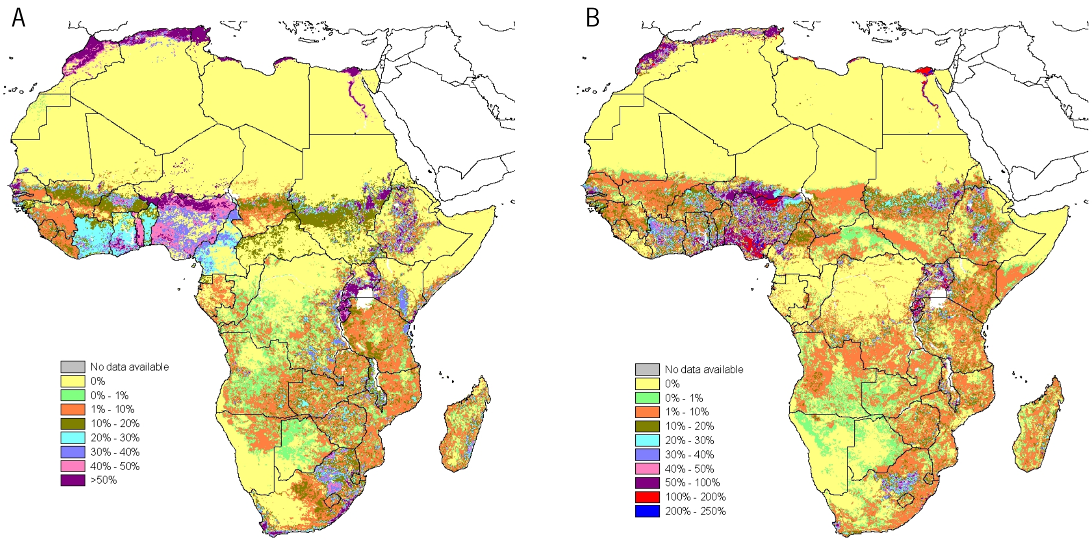

Figure 3.4. *(A) Crop land from Erb et al. (2007) and (B) harvested crop areas from Monfreda et al. (2008) both expressed as percentage of the total area in a 5x5 arc minutes grid cell.*

In some parts of Africa information from both maps is conflicting; where Erb et al (2007) reports no crop land, Monfreda et al (2008) present harvested areas in the same grid cell. Important regions of this inconsistency are found near the borders of Kenya, Somalia and Ethiopia, in Gabon and along the border with the Sahara.

The more detailed maps of selected crops or crop groups of Monfreda *et al.* (2008) are described in section 4.1 ('Statistical Yield data') and used in this study to calculate yield gaps (section 4.2). The map of Erb *et al.* (2000) is used for calculating production potentials for current crop land in Africa and related soil water balance (sections 4.2 & 4.4).

4. Crop yields and resource inputs

4.1 Statistical yield data

Detailed information of the spatial distribution of crops and actual yields is needed to identify options for increasing agricultural production. Based on statistical data of the period 1997 – 2003 Monfreda *et al.* (2008) provide spatially explicit information on harvested crop areas and yields with a 5x5 arc minutes resolution. In total 175 crops were mapped and the harvested areas of all crops grown within a grid cell were summed to arrive at the total area harvested (Figure 3.4b). We focus in this report on cereals which is the most important crop group in terms of food supply and crop land use. Information on other crops/crop groups like oil crops, pulses and root and tubers is not considered in this report.

The crop group cereals comprises major crops like maize, wheat, rice, sorghum, millet, barley, rye, oats and triticale. In Appendix I the cereal area and average yield are provided per country by aggregating harvested cereal areas and associated yields of all 5x5 arc minutes grid cells per country. In addition, average FAOSTAT country data of 1997-2003 are given to compare with the data from Monfreda *et al.* (2008), while average FAOSTAT country data of 2006-2008 are given to assess the most recent changes in cereal area and yields.

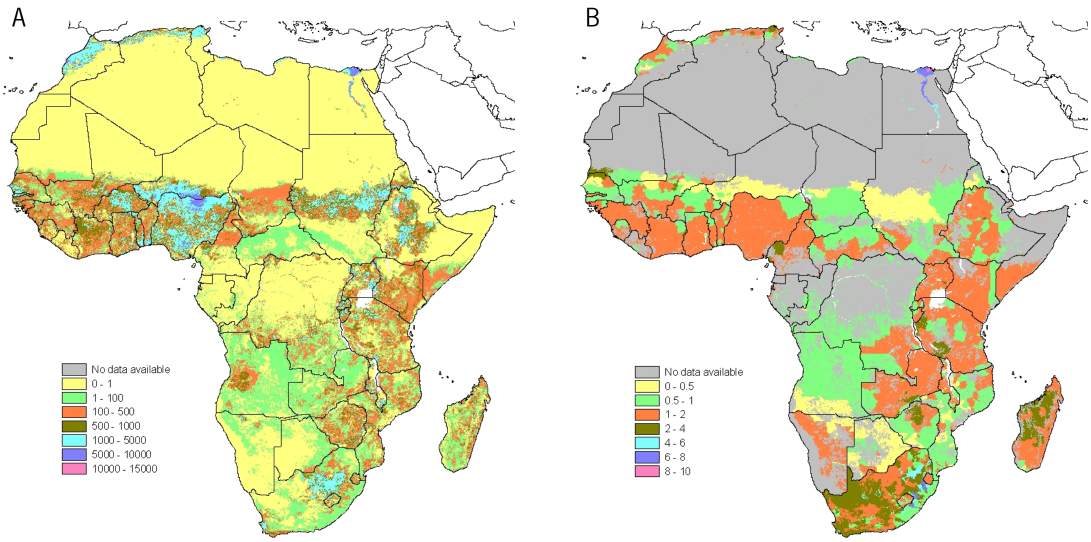

Figure 4.1. (A) Harvested cereal area in ha per 5x5 arc minutes grid cell and (B) average cereal yield in tonnes fresh weight ha^{-1} *per harvest. Source: Monfreda et al. (2008).*

In many African countries the cereal area in a 5x5 arc minutes grid cell is rather low (Figure 4.1a; < 500 ha, i.e < 6% of average grid cell area of about 8200 ha), indicating the scattered production in Africa (compare Figure 3.4, section 3.3). In rare cases harvested cereal areas exceed the 5x5 arc minutes grid cell areas due to multiple harvests per year. More striking is the 14% difference in total harvested cereal area between Monfreda *et al.* (2008) and FAOSTAT (1997-2003), i.e. 79.4 vs 92.0 Mha, respectively (Table 4.1). One of the causes of this discrepancy may be the use of sub national versus national data sources, as already mentioned in section 3.3.

Table 4.1. Comparison of data based on Monfreda et al. (2008) and FAOSTAT (for two different periods).

Cereals in Africa	Monfreda *et al.* (2008; Table 3)	FAOSTAT 1997-2003	FAOSTAT 2006-2008
Harvested area (Mha)	79.4	92.0	104.6
Yield (tonnes FW ha^{-1} per harvest)[1]	1.3	1.27	1.39

[1.] *FW = fresh weight.*

Overall, cereal yields on the African continent are very low, i.e. less than 2 tonnes ha^{-1} per harvest (Figure 4.1.b; Table 4.1). Only at the border of Mauritania and Senegal, in parts of Tanzania and Zimbabwe and in South Africa and Madagascar yields range between 2 and 4 tonnes ha^{-1} and more than 6 tonnes ha^{-1} are realized in the Nile delta of Egypt because of extensive irrigation. Country averaged yields exceed 2 tonnes ha^{-1} per harvest only in South Africa and Egypt (Figure 4.2). Differences between data from FAOSTAT and the aggregated yields from Monfreda *et al.* (2008) are small in most countries except for Gabon where FAOSTAT yield is 0.5 tonnes ha^{-1} higher and for Somalia with FAOSTAT yield being 0.4 tonnes ha^{-1} lower.

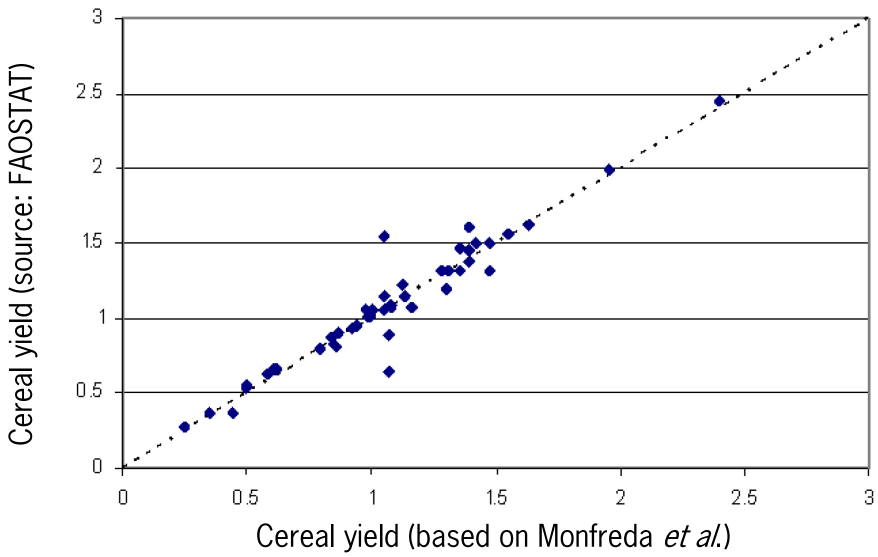

Figure 4.2. Country averaged cereal yields in tonnes fresh weight ha^{-1} per harvest based on the FAO database (average of 1997-2003) and Monfreda et al. (2008). Data for Egypt with a yield of 7.1 (FAOSTAT) and 7.2 (Monfreda et al.) are not shown. The dashed line is the y=x line.

According to FAOSTAT the harvested cereal area increased with almost 13 Mha in the period 2000 to 2007 (= 1.9% per year) and cereal yields increased with almost 0.1 tonnes (= 1.3% per year; Table 4.1). Consequently, total cereal production in Africa increased by 3.2% per year and outpaced population growth in Africa which increased with 2.4% per year from 819 to 965 million in the same period (according to the population statistics of FAOSTAT). A large share of the cereal production increase was associated with an expansion of the cropping area rather than a yield increase. Total food energy supply per capita increased with 0.6% in the same period, which is consistent with the increase in cereal production exceeding the population growth rate. Total harvested area in Africa increased in the same period with 27 Mha which is equivalent to 2.0% per year, almost equal to the percentage increase in cereal area, indicating that the increase of cereal area was not realized at the expense of other crops.

Total arable and permanent crop land in Africa also increased with 24 Mha (1.5%) which is less than the increase in harvested crop areas, suggesting a more intensive use of available crop land. The production increase was insufficient to substantially reduce the number of undernourished people in Africa; a total of 203.2 million in 2000-2002 and 202.5 million in 2005-2007 for sub-Saharan Africa; for northern Africa 5.6 and 6.1 million, respectively (FAOSTAT; http://www.fao.org/ economic/ess/food-security-statistics/en/). The expansion of crop land for the production increase might have increased the competition with other land use like grazing (Van Keulen and Breman, 1990) or could have come at the expense of maintaining biodiversity (Gibbs, 2010).

4.2 Cereal production calculations

The various climatic and soil characteristics at the level of grid cells (sections 3.1 – 3.2) have been used in the crop-soil model LINPAC (section 2.2) to calculate geographically explicit potentials of crop production. LINPAC integrates the information available at grid cell level and accounts for non-linear relations and interactions that affect crop production potentials. These calculated production potentials and resource requirements are aggregated to higher levels, for example, country, region or continental by summation of outputs from grid cell level. In the calculations only one crop is used per grid cell and in this study two separate model runs were performed by using: (i) always maize and (ii) maize or wheat. The first run is used for comparing simulated maize yields with current maize yield levels (Figure 4.4) and the second run is used to simulate maize/wheat yields for all suitable production areas in Africa under average rainfed conditions (Figure 4.3). In the latter model run wheat was selected for all grid cells above 30 ° N and below 30° S and maize was the first choice for the other grid cells. If no maize yield was simulated, for example, because of too low temperatures, wheat was selected as second crop choice. Consequently, wheat yields are simulated where maize 'failed', especially at higher altitudes. This procedure allows making optimal use of the genetic differences between crops: the simulation of a C3 crop (wheat) and C4 crop (maize) under the cooler and warmer climate conditions of Africa, respectively. It is assumed that the crops face no nutrient limitations and that crop yields are not affected by pests, weeds and diseases. This production level is often called the rainfed yield potential or water-limited yield potential (Lobell *et al.*, 2009). More information on the crop-soil model and the weather and soil input data is provided in section 2.2 and Appendix IV.

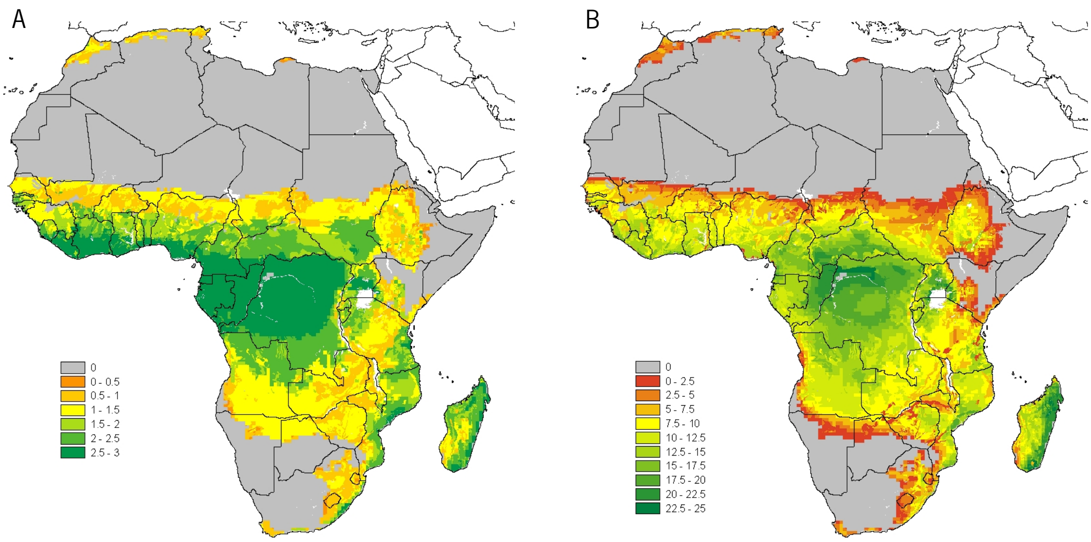

Figure 4.3. *(A) Number of possible cropping cycles per year and (B) calculated potential yield in tonnes dry matter ha^{-1} y^{-1} of maize/wheat production under rainfed conditions. Note: the two grey rectangles north-west of the Congo River are due to missing weather data.*

The number of cropping cycles that can be completed within a year varies greatly across Africa (Figure 4.3a) and is closely associated with rainfall variability (Figure 3.2a). We have adopted a maximum number of three cropping cycles which can be found e.g. in Central Africa where the climate permits year-round crop cultivation. The number of cropping cycles in Figure 4.3a refers to averages at grid cell level and ranges between 0 and 3 (including all values in between) due to different soil conditions per grid cell.

Based on the number of possible cropping cycles and the yield per cropping cycle, the total production per year is calculated as average per grid cell (Figure 4.3b). Highest production is found near the Congo River with almost 25 tonnes dry matter ha^{-1} y^{-1} and lowest values of less than 2.5 tonnes dry matter ha^{-1} y^{-1} in areas with low rainfall, like the Sahel. Areas with low to moderate productivity of less than 7.5 tonnes dry matter ha^{-1} y^{-1} are not widespread in Africa where most grid cells suitable for cropping have yields exceeding 7.5 tonnes dry matter ha^{-1} y^{-1}, generally associated with more than one cropping cycle (Figure 4.3a and b).

Figure 4.3b shows the rainfed yield levels for the entire territory of Africa, i.e. crop yields are also calculated for areas that currently are covered by forests or used as grazing land. To calculate the average production from crop land we combined the data of Figure 4.3b and Figure 3.4a and only used grid cells with crop land. The average calculated number of crop cycles of all grid cells with crop land in Africa is 1.2 per year and the average maize/ wheat yield per cycle equals 5.8 tonnes dry matter ha^{-1}. Around the year 2000, the actual average number of crop cycles was 0.8 and cereal yield was 1.1 tonnes dry matter ha^{-1} per harvest for Africa (Table 4.1, where we used a dry matter content of 89% to convert the statistical data (fresh weight) to dry matter, according to Monfreda *et al.*, 2008). Hence, our results suggest that application of sufficient nutrients and effective crop protection measures cropping intensities can be increased with about 50% and the average yield level (per crop cycle) can be increased by a factor five, indicating that a substantial production increase is technically feasible by increasing current productivity and cropping intensities in Africa.

Figure 4.4 shows the actual yields and calculated yield gaps for maize defined as the difference between the simulated rainfed yield potentials and actual yields of maize, the latter being based on actual harvested maize areas and related maize yields provided by Monfreda et al (2008). In many grid cells this yield gap is large and varies from circa 2.5 to over 12.5 tonnes ha^{-1} per harvest. There are also grid cells for which negative values were calculated, indicating that current yields exceed the rainfed yield potentials. This occurs mostly in (i) irrigated situations (e.g. Egypt) because calculated yields are based on non-irrigated conditions and (ii) areas near arid zones for which LINPAC calculated a no-cropping situation while the data of Monfreda et al (2008) reported maize areas with low yields. Latter difference is partly the result of the high input level assumed in the model calculations where the crop will develop a large leaf area index leading to increased water consumption. Consequently, in arid zones the available water is depleted rapidly and insufficient water remains to complete the crop cycle. In a low(er) input level situation, e.g. by using a lower seed density, less water is transpired by the crop and more water remains in the soil available for completing the entire crop cycle (e.g. Christianson and Vlek, 1991). The lower seed density associates with lower yields, but the higher seed density might lead to crop failure due to water stress. This interaction of the cropping intensity and water availability has significant implications for the calculated yield gap in and near arid zones that should be further investigated. In addition, there are other reasons that explain the negative yield gap in and near arid zones: e.g. land use data from Erb *et al.* (2007) and Monfreda *et al.* (2008) are inconsistent for the area near the borders of Kenya, Somalia and Ethiopia. While Monfreda and colleagues indicate a substantial maize area in this part of Africa, Erb and colleagues characterizes this part as grassland with shrubs (savanna) with hardly any maize cropping. Additional data from the USDA on corn production in Kenya in 2002 seems to disagree with Monfreda *et al.* (2008) and is more supportive to Erb *et al.* (2007). It is yet to be studied to what extent such data discrepancies are associated with calculated negative yield gaps elsewhere in Africa.

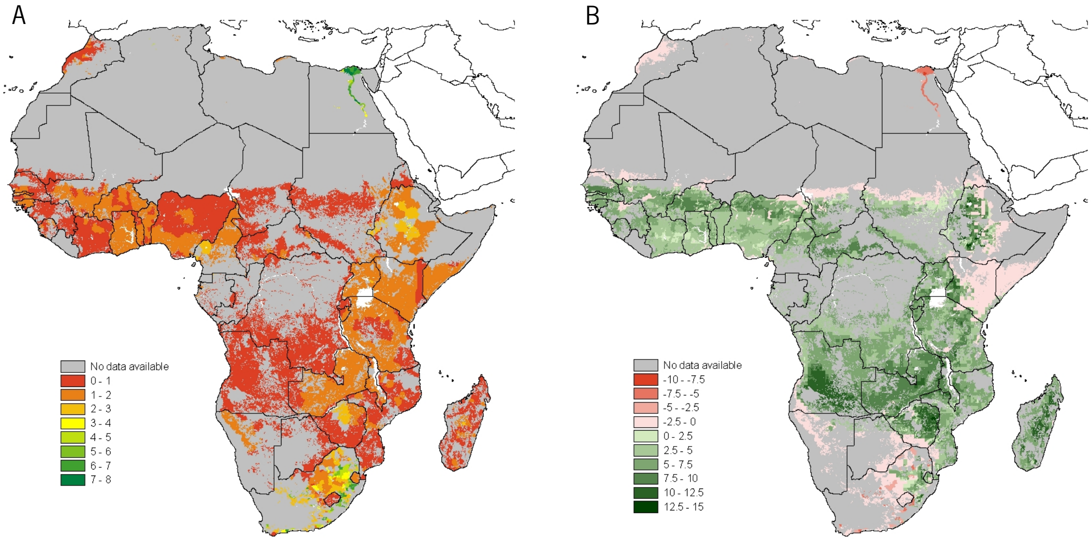

Figure 4.4. *(A) Average maize yield around the year 2000 in tonnes dry matter ha^{-1} per harvest (Monfreda et al., 2008) and (B) calculated yield gap with maize yield potentials under rainfed conditions.*

4.3 Nitrogen and phosphorus inputs

Crops require nutrients for their growth, especially nitrogen (N), phosphorus (P) and potassium (K). Nutrient inputs are necessary for (i) maintaining soil fertility e.g. after removal of nutrients with the crop harvest and (ii) increasing crop yields. Geographic information on nutrient input is needed to analyse current production levels and options for improvement. Potter *et al.* (2010) published global gridded maps of fertilizer N and P applications and manure N and P production per ha of a grid cell with a resolution of 30x30 arc minutes. The maps on fertilizer application were based on the global crop maps of Monfreda *et al.* (2008; section 4.1) and information on 'fertilizer use by crop'. Manure production maps have been constructed using livestock densities and calculated manure production per livestock category. The fertilizer N and P application rates have been recalculated and converted at 5x5 arc minutes resolution and expressed per ha crop land per grid cell using data from Ramankutty et al., 2008 (Figure 4.5). The very low fertilizer application rates in Africa of mostly less than 10 kg N ha^{-1} and less than 2 kg P ha^{-1} is remarkable but in line with the low cereal yields (Figure 4.1b). More fertilizer exceeding 50 kg N ha^{-1} is applied in parts of South Africa, Zimbabwe and especially in Egypt where these rates are associated with high production levels. An application of 10 kg N ha^{-1}, i.e. the maximum value applied in most grid cells in Africa (Figure 4.5a) and an assumed recovery of 70% results in a cereal grain yield of only 0.5 tonnes dry matter ha^{-1} using a weighted average N content of 1.5% (van Duivenbooden *et al.*, 1996). Consequently, at most agricultural soils N removal with harvested crops exceeds fertilizer N inputs at current yield levels (Smaling, 1994; Sheldrick and Lingard, 2004). This clearly indicates the need for more N inputs in African agriculture to increase production while maintaining soil fertility.

In addition to chemical fertilizer (Figure 4.5) also animal manure can be applied to crop land to improve soil fertility. Based on Potter *et al.* (2010) a map was made of manure production expressed per ha crop land at a 5x5 arc minutes resolution (Figure 4.6; manure comprises both faeces and urine). High values were calculated for many grid cells (e.g. > 50 kg N ha^{-1} in the Sahel region) mostly due to a combination of moderate animal manure production (5 – 20 kg N per ha of a grid cell) and a low percentage of crop land (compare Figure 3.4a). These data allow – though roughly – to estimate the possible contribution of manure to fertilizing crop land. A complicating factor is that part of the produced manure is from grassland (non-crop land). Collecting this manure for use at crop land would result in the net removal of nutrients and a soil fertility decline of non-crop land, which is unsustainable. Collecting manure from animals fed with crops or crop residues and returning these nutrients to crop lands is a more sustainable soil (fertility) management. Based on the current share of animal products in African diet and information on animal diets (Jing *et al.*, 2010) it is estimated that a maximum of only 20% of the produced manure originates from crops or crop residues. Approximately 10% of the total manure N (Figure 4.6a) has the equivalent value of chemical fertilizer for crop production under the condition that (i) 20% of the available manure is collected for use on crop land and (ii) the use efficiency of manure N is 50% compared to that of fertilizer N. Adding this amount of N to the current fertilizer N application rates (Figure 4.5a) would roughly double the amount of effective N (average for Africa; see Appendix II) and would lead to a total nitrogen input to support a cereal yield level of approximately 1.0 tonne dry matter ha^{-1}, which is in the same order of current overall cereal productivity in Africa. Generally, increasing cereal productivity in Africa and maintaining soil fertility is not possible without the use of external nutrient inputs.

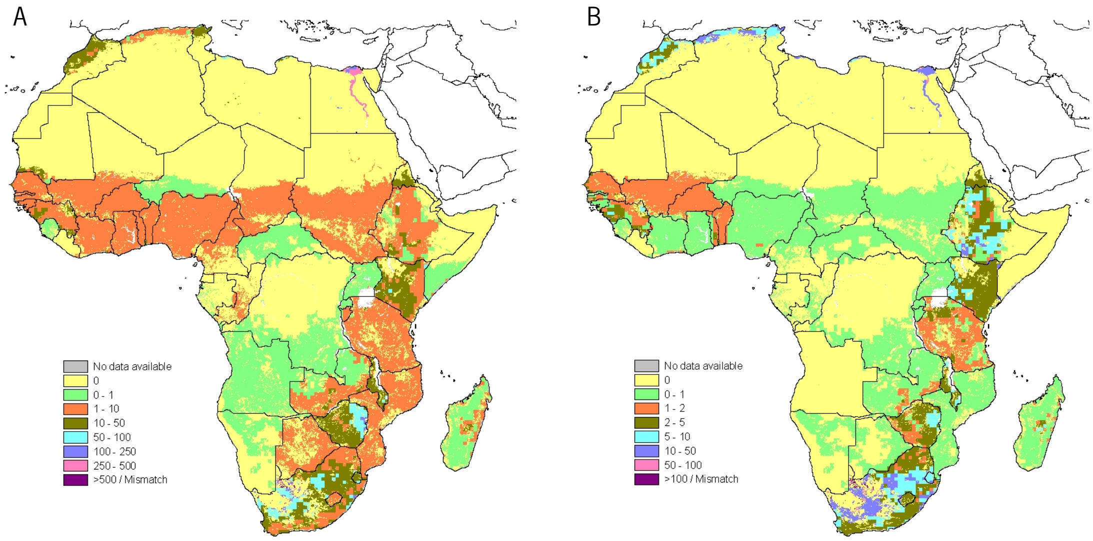

Figure 4.5. *Average chemical fertilizer application of (A) nitrogen and (B) phosphorus in kg y^{-1} per ha crop land in a grid cell. Note: mismatch refers to grid cells with fertilizer use and very small crop areas which lead to excessive rates of application.*

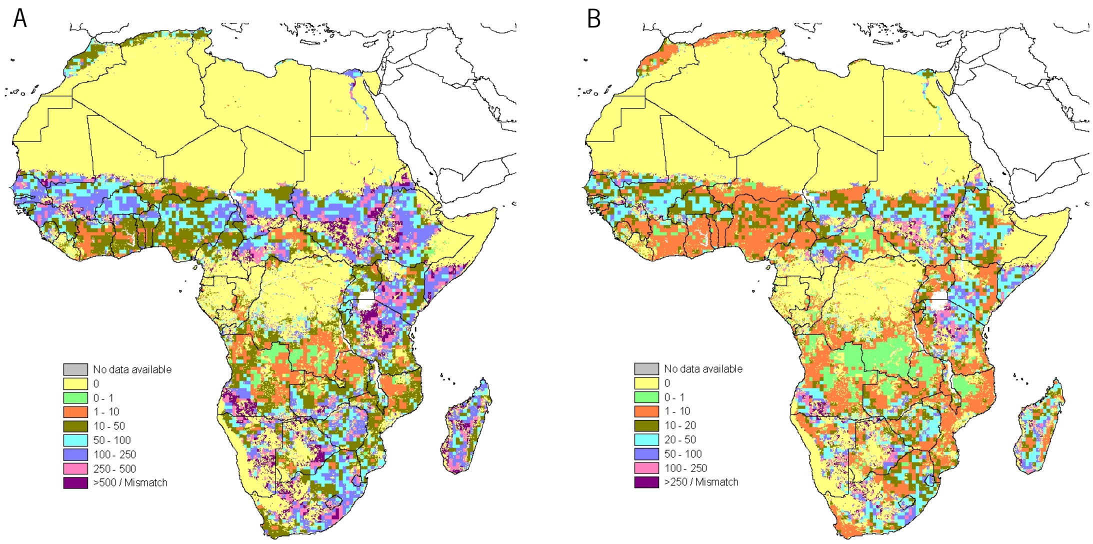

Figure 4.6. *Theoretical availability of manure (A) N and (B) P in kg y^{-1} per ha crop land in a grid cell. Note: mismatch refers to grid cells with animal manure and very small crop areas.*

4.4 Soil water balance

The soil water balance under rainfed condition comprises rainfall, runoff, soil evaporation, crop transpiration and percolation beyond the rooting depth of the crop. Capillary rise from groundwater was not considered in this section (it is taken into account in Chapter 5); runon has also not been taken into account. The crop-soil model LINPAC calculates daily the water balance components and aggregates them to average annual values per grid cell. Results of the soil water balance are used in two ways: (i) to determine water availability for plant growth and (ii) to estimate the net water surplus (rainfall minus evapotranspiration), which could be made available for other use. Obviously, these two are interrelated, i.e. higher crop water use associated with higher crop productivity (CAWMA *et al.* 2007; p. 279-310) will reduce the water availability for other purposes.

Referring to the calculations of rainfed maize/wheat production using average weather conditions (Figure 4.3b), we selected all grid cells where crop growth is considered possible according to our analysis. In that case, the amount of water consumed by evapotranspiration per year exceeds 40% of the annual average rainfall in most grid cells and in some grid cells it can even be larger than 80% (Figure 4.7a). Runoff relative to rainfall is mostly below 40% with large areas even below 20%, whereas higher values (> 40%) are found in e.g. Ethiopia associated with the sloping landscape (Figure 4.7b). Clearly, relatively high evapotranspiration coincides with relatively low runoff, and vice versa.

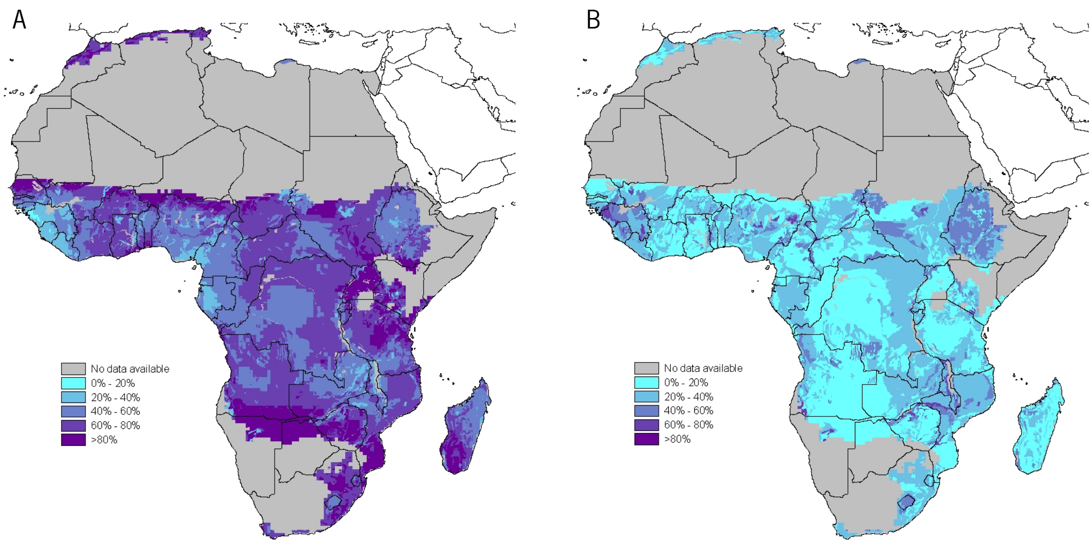

Figure 4.7. Calculated annual (A) evapotranspiration and (B) runoff as percentage of rainfall per grid cell. In grey-colored areas cropping is not feasible, mostly because they are too dry (compare Figure 4.3b).

Based on the calculated water balances of (i) all suitable grid cells with maize/wheat production and (ii) non-cropped areas for which only soil evaporation is calculated, the share of total evapotranspiration relative to total rainfall equals circa 61% in entire Africa, 38% is 'lost' by runoff and percolation beyond rooting depth and 1% remains in the soil profile until rooting depth. The calculated value for runoff and percolation as fraction of rainfall compares well with both the global estimate of 0.39 that contributes to blue water resources and the average value of 0.38 for farms in semi-arid tropical regions in sub-Saharan Africa (CAWMA, 2007; p. 6 and 326 respectively). The global value refers to all (non-)vegetated areas, including grasslands and forests. In our calculations the evapotranspiration is calculated for cropping systems with annual crops (i.e. maize or wheat), but due to multiple cropping cycles annual evapotranspiration totals may approach those of perennial systems like grassland or forests.

In theory, the total runoff and percolation (in our analysis: 7500 km^3 per year in Africa) becomes available as fresh water resources through discharge in rivers and refill of aquifers. Based on a total population of 1.0 billion in Africa (2010, FAOSTAT/UNEP) the average per capita water availability is approximately 7300 m^3 y^{-1}, although large differences exist among countries (Figure 4.8). For Africa, total renewable fresh water resources of circa 4000 km^3 y^{-1} has been estimated based on surface water flows and recharge of groundwater (CAWMA, 2007; p. 70). Theexplanation of the large difference between the two estimates of (renewable) fresh water resources requires further study.

In our calculations total evapotranspiration from crop land only (Figure 3.4a) consumes 1156 km^3 per year in Africa for maize/wheat rainfed yield potentials. CAWMA (2007) reported an average evapotranspiration of 1071 km^3 per year for all food and feed crops in sub-Saharan Africa and 225 km^3 per year for Northern Africa and Middle East together. Our crop land evapotranspiration equals 6% of the total rainfall on the entire African continent (20,000 km^3 y^{-1}) and 15% of the total fresh water availability mentioned above (7500 km^3 y^{-1}). Changes in the crop water requirements under rainfed conditions, e.g. due to increased productivity or cropping intensity, are thus not severely affecting the calculated overall amount of water available for other functions expressed as annual average at a continental scale. At the national or smaller scales, however, crop water requirements relative to remaining fresh water availability can be high (for example > 100% in Uganda, Morocco and Tunisia) because of the combination of low rainfall and high shares of crop land area in the total area of a country (Appendix III). Also the inter- and intra-annual variability in water use and availability is important: local water scarcity can be high due to distinct differences between wet and dry years/season, even in high ‘surplus’ countries (see next chapter).

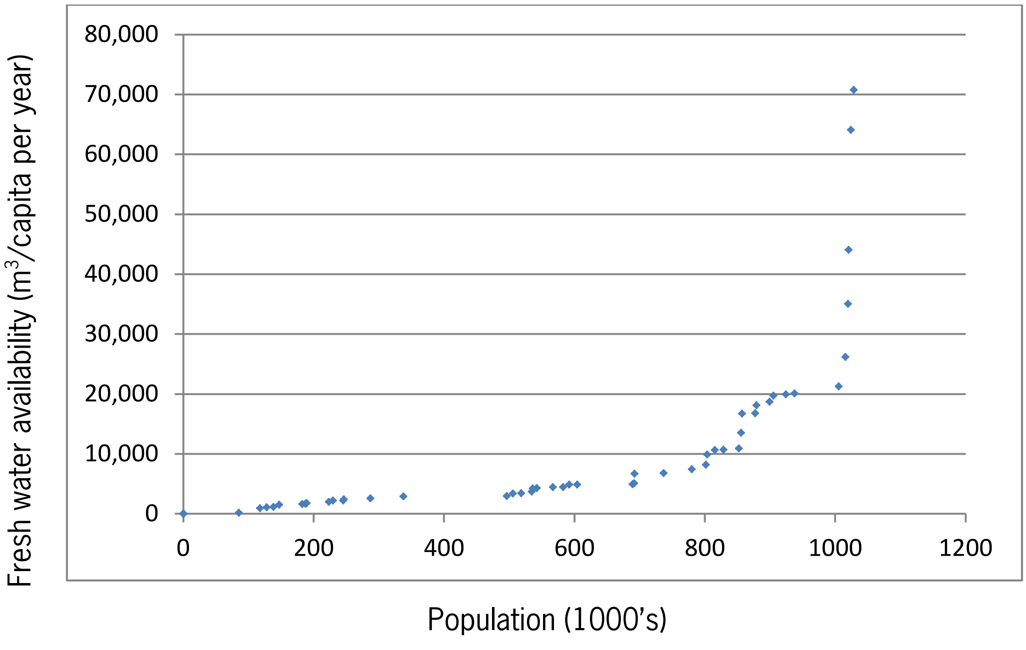

Figure 4.8. Fresh water availability, calculated as sum of runoff and percolation per capita, plotted against cumulative population size of countries in Africa. Each marker refers to a country; Gabon (circa 190,000 m^3/capita per year and a population of 1.5 million) has been excluded.

5. The water balance of a catchment area

Erik Querner

5.1 Introduction

The growing demand for food and biomass will increase the pressure on water resources. Therefore, the availability and distribution of water resources should be made explicit at spatial (e.g. regional and continental levels) and temporal scales (e.g. dry and wet seasons). Water resources are often considered in terms of mean annual river flows. In Africa, river flows change often dramatically from one season to the next. As a result actual water scarcity may be overlooked as mean river flows can mask seasonal and spatial water shortages. Knowledge on the seasonal variability in meteorological data and related stream flow at basin scale is needed.

The analysis in this chapter focuses on the use of GIS data, hydrological tools and models to study the possibilities to increase agricultural production and the possible consequences of increased production for local water availability. The underlying question is to improve the understanding of spatial and temporal water availability. Generally, higher production requires more water through increased crop evapotranspiration, thus reducing water availability for other users. Possibilities for using surplus water in downstream areas of the basin can then be quantified.

The objective of this chapter is to demonstrate tools that quantify the space-time variation in water availability and water use in a river basin, based on the framework in Fig. 2.1. River flows in a basin depend on hydrological and topographical conditions from the upstream catchment. These flows are estimated with the aid of the one-dimensional groundwater model SIMFLOW (Querner, 1986). The model simulates the rather complex process of rainfall-runoff involved in such a manner that it is sufficiently accurate without requiring too much input data and computing time. Drainage that becomes available as river flow is simulated.

Solutions are needed to go from water scarce to water secure. The Dutch approach formulated by the Commission “Water Management in the 21st Century” (RWS, 2000) for the Netherlands as: retain, store and then discharge (vasthouden, bergen en dan pas afvoeren) is very much appropriate for the African situation. Small-scale water solutions, like water harvesting, are a major key to increase agricultural productivity. There is a need to reduce the risk of water scarcity: assure a reliable water supply for the farmers. The focus should be on a broad range of solutions to secure the water availability for the farmers. In some regions it means large-scale irrigation schemes, but with the high costs large schemes are costly and slow to develop. The disadvantage may be that an uncontrolled use of the water resources may lead to falling groundwater tables and reducing river flows, which has consequences downstream in the river basin.

5.2 A GIS and modelling approach for Africa

Figure 5.1 shows a typical situation in a river basin, with its water users and water flows in groundwater and surface water. Water is used among others by the different crops and other vegetation. Surface runoff can take place and drainage from groundwater to surface water. Water consumed upstream in the basin by crops and vegetation is not available any more in the downstream part. Therefore the approach should explicitly take into account the water excess and water use in a spatial context within the river basin. In this way understanding of the temporal availability of water and water use is improved which is needed to enable better quantification of agricultural production potentials and associated consequences for other water users. The case study Africa requires a modelling approach that takes into account groundwater and surface water and considers as much as possible the available data as described in Chapter 3, but also data from other sources specifically used for modelling the hydrological system. Important additional data are ground level data from the Digital Elevation Model (DEM) and data derived from the DEM, like the network of rivers and streams.

Figure 5.1. Schematic presentation of land and water users in a river basin.

The river flow in a river basin depends on hydrological and topographical conditions from the upstream catchment. The flow can be estimated with the aid of analytical methods, but these methods cannot take into account the hydrological conditions or situations where intensive rainfall alternates with long dry periods. For such situations it is best to use a simple groundwater model as shown in Fig. 5.2. The model should simulate the rather complex processes involved in such a manner that it is sufficiently accurate without requiring too much input data and computing time. The SIMFLOW model is used to simulate the dynamics of the local shallow ground water flow. Being physically based the model can be used in situations with changing hydrological conditions, e.g. due to variation in daily weather. For a more detailed description of the model, see Querner (1986, 1997).

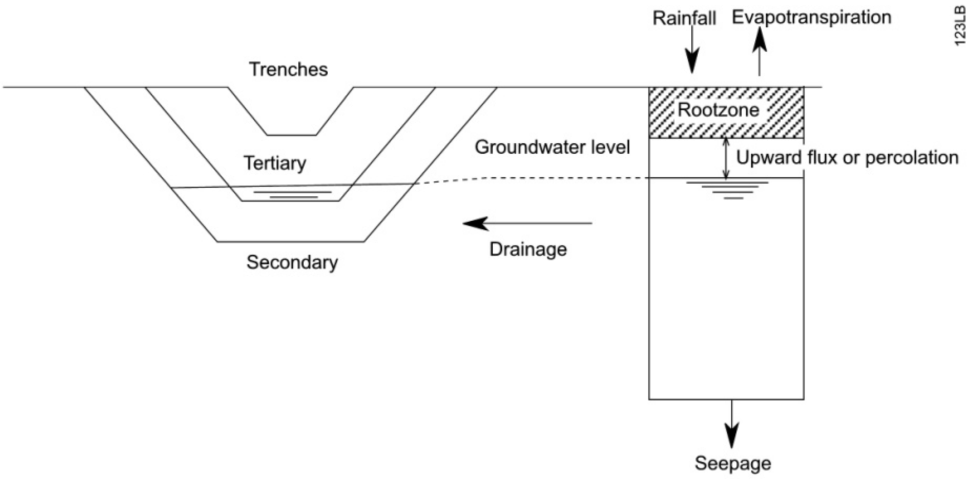

Figure 5.2 Schematisation of water flows in the SIMFLOW model. The main feature of this model is the interaction of the groundwater with different drainage subsystems (Querner, 1986).

Unsaturated zone

The unsaturated zone is represented by means of two reservoirs, one for the root zone and one for the underlying soil (Fig. 5.2). If the equilibrium moisture storage for the root zone is exceeded, the excess water will percolate towards the saturated zone. If the moisture storage is less than the equilibrium moisture storage, then water will flow upwards from the saturated zone into the unsaturated zone. The height of the water table is calculated from the water balance of the soil below the root zone, using a storage coefficient that is dependent on the depth to the groundwater. The unsaturated zone is modelled one-dimensionally per cell and differentiated in a number of land use types. Actual evapotranspiration is a function of the crop and moisture content in the root zone. Surface runoff can be taken into account. The net precipitation (gross precipitation minus runoff) and the estimated potential evapotranspiration for a reference crop are used as input. The potential evapotranspiration for different crops or vegetation types are based on the reference crop and known crop-specific factors.

Saturated zone and drainage

The saturated zone interacts with the unsaturated zone and the surface water, while there may be leakage or seepage over the lower boundary. In the modelling approach of this study regional groundwater flow between cells and storage of water in the deeper aquifers is not considered. The amount of leakage or seepage is the link between the regional and local flow. The presence of watercourses affects the interaction between surface water and groundwater. In the model, three drainage subsystems are used to simulate the drainage (Fig. 5.2). The interaction between surface and groundwater is calculated for each drainage subsystem, using a drainage resistance and the difference in level between groundwater and surface water (Ernst, 1978).

Surface water

Direct flow routing, considering hydraulic flow equations involving storages in dams and rivers, is not considered, but river flows are visualized for designated locations, considering the upstream cells (groundwater discharge and water use) as presented for the Limpopo basin in Fig. 5.5 and 5.6.

5.3 Data requirements

The required data are obtained primarily from the data described in Chapter 3, the results of calculations with the crop-soil model in section 4.2 (Figure 4.3) and available GIS data, based on the schematization of the area in grid cells of 5x5 arc minutes. For each cell the land use is known as a percentage of the cell, being grassland, crops and forest (Erb et al. 2007). Furthermore the soil type (fine, medium or coarse) is used to give an indication of the maximum moisture content of the root zone, the storage coefficient and possible capillary rise, while calculated growth cycles were taken into account (section 4.2). For the meteorological data (section 3.1), we used daily precipitation and potential evapotranspiration.

Additional GIS data

For the elevation of the ground level a 1x1 km grid DEM was used (SRTM, 2011; Far et. al., 2007). The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate a high-resolution digital topographic database. SRTM consisted of a specially modified radar system that flew on board of the Space Shuttle Endeavour during an 11-day mission in February of 2000. From the SRTM data the USGS (2011) derived hydrographical information (HydroSHEDS) in a consistent format for regional applications. We used the HydroSHEDS data as well in the analysis of sub basins and hydrological characteristics.

Using a GIS analysis the drainage resistances for the interaction between groundwater and surface water were derived from the total length of the rivers and streams in each cell. The large rivers are considered when the catchment size is more than 350 km^2 and they are assumed as the secondary drainage system for the interaction between groundwater and surface water (Fig. 5.2). The smaller streams are used for the drainage resistance towards the tertiary system. A third system (trenches in Fig. 5.2) includes surface drainage to local undulations in the ground level or local depressions. From the elevation data and the location of the main streams, the seepage flow as used in the model (Fig. 5.2) was estimated. For those cells with the main river crossing them, river water can infiltrate into the soil and water can be used for crop irrigation.

The required data for the modelling approach is extracted from the (GIS) data bases in ASCI format. The SIMFLOW model reads the general (non-spatial) data and then per cell its specific characteristics and carries out simulations cell by cell. The amount of drainage per day and per cell is used for further analysis of the river flows further downstream at the basin scale. The analysis is generic and can be carried out for other catchments in Africa. At first a test is done with data for the Limpopo River basin.

5.4 River basins of Africa

Using the digital elevation model and HydroSHEDS data, Africa is subdivided into the major river basins or sub basins. Stream networks and sub-basins are identified and can be used for the flow routing through the streams and rivers. Using the DEM of Africa (SRTM, 2011) having a spatial resolution of 1x1 km, the river basins of Africa were delineated. For the size of the sub basins, Africa is subdivided into 63 sub basins as shown in Fig. 5.3. The areas of the basins are in the range of 40,000 km^2 within Nigeria to 1 Mln km^2 for a basin in Libya. Figure 5.3 shows large basins as the Zambezi or Nile in a number of sub basins or for their major tributaries.

Figure 5.3 Distinguished main river basins for Africa (blue lines) and country boundaries in thin dotted black lines.

5.5 Model application for the Limpopo basin

5.5.1 Description of the Limpopo basin

To test the model we applied it to the Limpopo river basin, situated in Mozambique and upstream parts in Zimbabwe, Botswana and South Africa. The Limpopo river basin (Fig. 5.4) has an area of about 412,000 km^2. The main tributary of the Limpopo is the Elephants River. Land use in the basin is mainly grassland, savannah and shrub land (68%); cropland covers about 26%, of which only 1% is irrigated. Wetlands cover 3% and the remaining area is forest and urban areas (LBPTC, 2010). Agriculture in the Limpopo River basin is typically extensive with low input levels.

However, irrigated agriculture accounts for more than 50 % of the total water use in the Limpopo River basin (LBPTC, 2010).

Rainfall in the basin is seasonal and unreliable. In dry years, the upper parts of the river flow for 40 days or less. The upper part of the drainage basin is arid, the Kalahari Desert, but becomes less arid further downstream. The middle reaches drain the Waterberg massif, a region with semi-deciduous forest and low density human population. The lower reaches are fertile and densely populated. Floods after the rainy season are an occasional problem in the lower reaches, most notably were the catastrophic floods in February 2000.

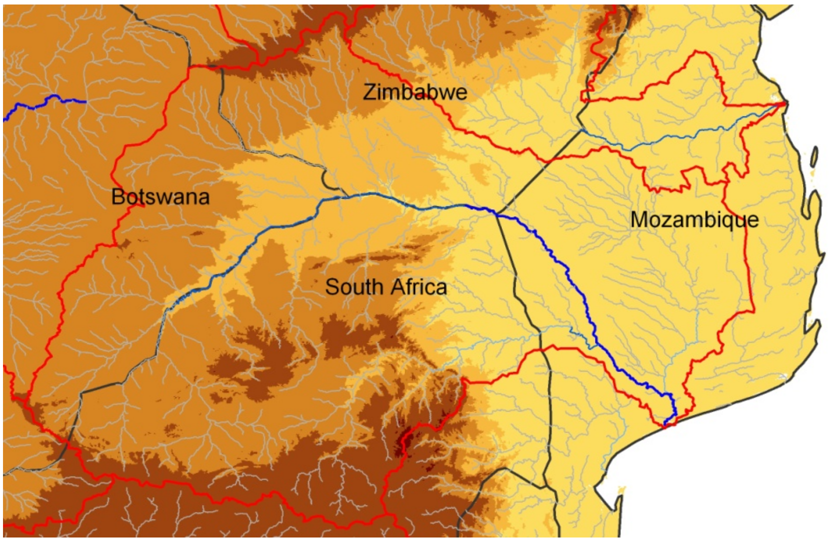

Figure 5.4 The Limpopo river basin situated in Mozambique and the upstream parts in Zimbabwe, Botswana and South Africa.

In a study carried out some 30 years ago, the recession of the stream flow during successive dry seasons over a number of years was analysed (NDW, 1989). In this study it was found that a significant increase in water abstractions from the river in upstream countries had taken place. This situation was partly masked because of droughts that affected the whole region. However, it is clear that the Limpopo in Mozambique virtually has no flowing water in the dry season, even in years with normal rainfall. Such situations did not happen before 1975. In the Limpopo basin there are now 13 dams with a storage capacity exceeding 100 Mm^3; one in Mozambique; eight in South Africa; three in Zimbabwe and one in Botswana. The largest one is the Massingir dam (present capacity is 1200 Mm^3) in Mozambique. Apparently, in Zimbabwe the river has been developed nearly to its full potential, implying that all the river water is used and the remaining stream flow towards the Limpopo River is minimal. There is no information regarding the present water uses in Mozambique and information on planned future developments in the upstream countries is largely lacking. Both Botswana and South Africa are separately planning new water developments and the construction of new storage dams. In the present study the effects of dams on the calculation of river flow have not been taken into account.

5.5.2 Model application

The Limpopo basin is represented in the model schematization by 5086 cells. For a calculation period of 2¼ years, it takes about 2 minutes of computing time. The calculation time is reasonable when considering either sub Saharan Africa or the entire African continent. In this analysis the data on surface runoff from the crop model has not been taken into account.

The meteorological data used are daily values for one year, based on average precipitation and potential evapotranspiration for the period 1961-1990. These data are expanded to a period of 2¼ years. When running the model, the first 1¼ year is used for initialization of the model variables, because at the start of the calculations assumptions are needed for the soil moisture content and the initial groundwater level in each cell.

For the gauge near Beitbridge along the South-African and Zimbabwe border measured flow data was available of the Limpopo (Fig. 5.5; Department of Water Affairs). The simulated discharges are compared with the measured data in Figure 5.6 at Beitbridge. The low flows in the dry period are the same, but because the simulations are on the basis of one year with average daily precipitation data, the comparison with actual river flows of a particular year is not possible. The reaction of the river flow on precipitation events is more pronounced for the calculated flows, because no water storage in the rivers (or storage dams) is considered. The high flows are in the same order and for the low flows both measured and calculated flows show that the river runs dry for a couple of months.

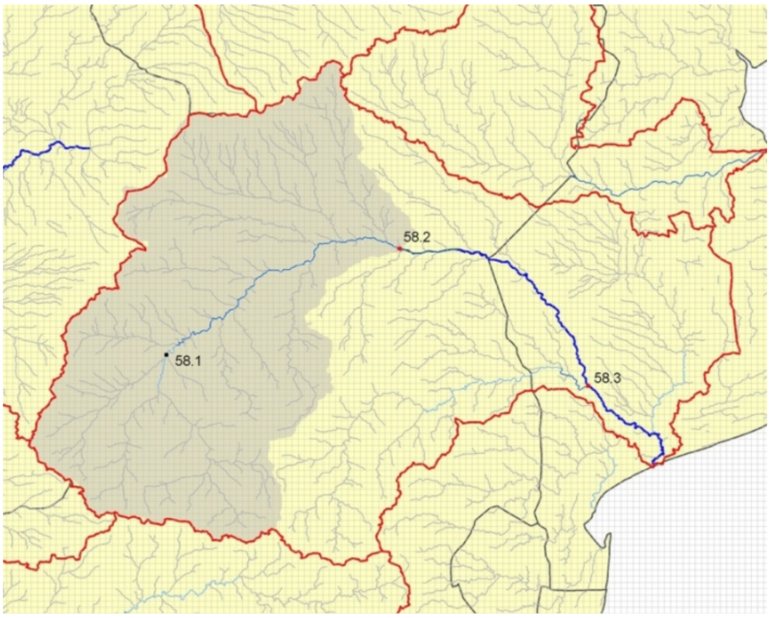

Figure 5.5 Limpopo basin and the upstream sub basin for the gauge at Beitbridge (catchment 58, location 2).

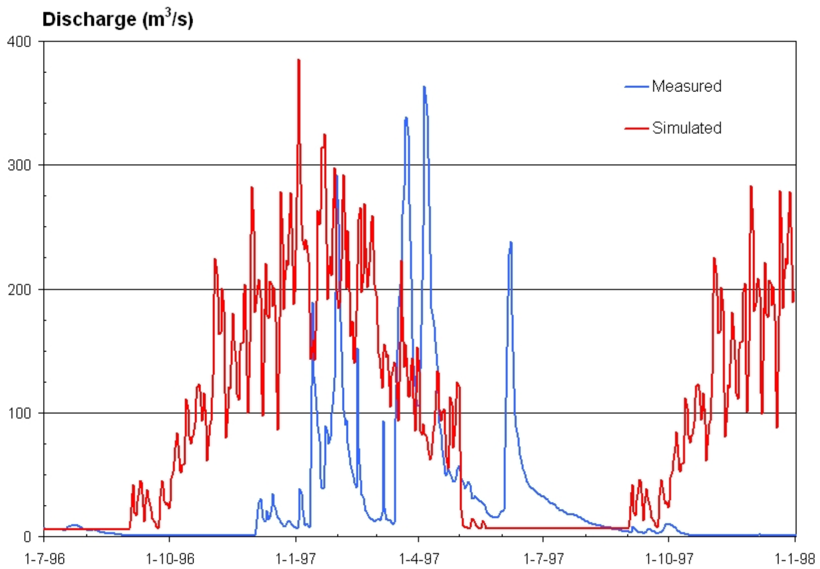

Figure 5.6. Measured and simulated river flows for Beitbridge.

5.6 Concluding remarks

The modelling approach focuses on developing a method to simulate temporal and spatial variability in water availability for different river basins across Africa. These river basins vary between 40,000 km^2 and 1 Mln km^2. For such large areas simple methods are needed in order to keep the required data and calculation time reasonable. There are differences between measured and calculated flows of the Limpopo River near Beitbridge, but the lower and higher flows are modelled quite well.

From the information on historic stream flows in the Limpopo River it's clear that discharges were reduced dramatically over the last 50 years. The increase in water use upstream in Zimbabwe and South Africa has a great effect on river flows downstream in Mozambique. Such changes in river flows indicate that future analyses should consider the main underlying changes within a river basin like large scale irrigation systems and storage dams.

6. Socio-economic aspects

Marie-Luise Rau, Tom Kuhlman and Gerdien Meijerink

6.1 Introduction

In addition to natural resources and geographical factors, such as soil quality and rainfall, socio economic aspects influence development and growth in developing and transition countries. The key challenge is to raise agricultural productivity and production, especially in food importing poor countries, in order to promote development and growth, thereby reducing poverty. Agricultural production is important for many reasons. Referring to the recent empirical studies on agricultural productivity in Africa mentioned further below, the increase in average annual productivity rate is estimated to be between 0.58 and 1.8% during the time period 1965-2009. Fuglie (2010), however estimates a negative agricultural productivity rate for the 1970s, but this is the only study estimating a productivity loss during the last decades. Despite the general consensus about agricultural productivity growth in Africa, Haggblade *et al.* (2009: p. 4) stress that '*Africa remains the only developing region where the per capita agricultural production has fallen over the past four and a half decades and has the lowest agricultural productivity today (…).*' They look at the per capita agricultural production and their agricultural productivity rates thus take into account population growth, which has been considerable in Africa, especially when comparing with Asia and Latin America (see also section 4.1 for recent increases in cereal yield and food energy supply per capita in Africa).

Next to providing sufficient food supply, increasing productivity of agricultural production can improve the prospects for growth and competitiveness on the agricultural market, income distribution and savings as well as employment. The World Development Report (World Bank, 2008) looks at the role of agriculture for growth and development in detail. For poverty reduction, agriculture and the agricultural productivity can be expected to play a particularly important role in countries where a great portion of the population depends on agriculture. Furthermore, an increase in domestic food production will help these countries become less dependent on imports and reduce the vulnerability to world market price volatility.

An increase of food supply can be achieved in different ways: i) increasing agricultural productivity, whereby productivity is defined as the output from agricultural production per unit of inputs (labour, land and other inputs) and ii) expansion of the agricultural area. Analysing agricultural productivity in Sub-Saharan Africa in the period 1961-2006, Fuglie (2010) showed that growth in agricultural output is mainly explained by expanding crop land rather than improved productivity (recent trends in cereal production increase showed some 60% explained from expansion; section 4.1). Boosting productivity and reducing production costs (at least in the long-run) usually involves technology investments at the firm-level as well as country-level investments in infrastructure and other trade-facilitating services. Importing food is another option to ensure food security and thus the quantity of food available. However, as indicated earlier, countries that become dependent on food imports can face high food prices on the world market, as happened during the recent food crisis. It is important to note that food security also concerns accessibility and affordability as well as the quality and safety of food, and these issues can have a considerable influence on the impoverished in particular.

There are a host of socio-economic factors that influence agricultural production and the potential agricultural growth in order to enhance food security. Here, we use the framework of Bindraban *et al.* (2009) as a starting point to describe socio-economic factors relevant for economic development in general and in particular growth in food production. Table 6.1 gives an overview of socio-economic factors and also provides indicators which can be used for measurement and comparison across countries. While some of the socio-economic factors and indicators presented are of general nature, others have a clear link to agriculture, for example agricultural value-added or employment in agriculture. Where possible we attempt to make this link, and the link goes from primary production and inputs to the distribution of food products. However, the causal relationship between the indicators and the actual and/or potential agricultural production is complex and usually not straightforward. For example, undernourishment could be a result of low agricultural output and productivity, but could also contribute to low agricultural output and low productivity.

As shown in Table 6.1, we differentiate between different aspects, i.e. economic aspects directly related to the firm-level or farm-level, socio-economic aspects, socio-institutional aspects and governance/market institutions. The following paragraphs will further elaborate on their significance for agricultural production, productivity and development based on available information in the literature. The used literature specifically focuses on agricultural productivity in African countries. We have collected available information about the respective socio-economic indicators. For generating maps of these indicators we use grid data at the local or regional level or translate country level information into gridded GIS formats. The list of the indicators we collected and their respective data sources are given in Table V.1 in Appendix V. The data and corresponding maps can be provided by the authors. In general, spatially explicit socio-economic data are very scarce.

Table 6.1. Overview of socio-economic factors and associated indicators.

Aspects	Factors	Indicators
Economic Firm/farm-level	Capital Land Labour Technology	Access to capital: bank infrastructure/micro-credit Number of tractors, fertilizer use - technology Import/export of raw materials - intermediate inputs Land tenure/ownership and farm size Labour employed in agriculture, labour productivity
Socio-economic	Economy Infrastructure Population Consumption/health	GDP per capita, income per capita, poverty gap Percentage contribution of agriculture to GDP (AgriGDP) Agricultural value added per worker, production growth Night lights – proxy for population, urban and rural divide and energy availability Roads – logistic performance index Population: population growth (rural versus urban), mortality Demand of food: daily nutrient intake, malnutrition Amount of food aid relative to domestic production
Socio-institutional	Information, education Values, human relation Communities Administration	Human development index Number of agricultural universities as knowledge centres, patents Spending on agri-food research (R&D), universities, Property right index
Governance and market institutions	Entry/Exit Market functioning Protection	Ease of Doing Business - Index by the World Bank Corruption index, Corruption Perception Index Trade policy – domestic policies: UNCTAD trade openness index, World Bank's rate of protection estimate

Source: modified from Bindraban et al. (2009).

Using the available data, maps are generated for the respective socio-economic indicators. The goal is to combine the socio-economic maps with maps that provide spatial information about the current and potential agricultural production across Africa. Identifying socio-economic indicators available in GIS data format at the detailed regional or local level constitutes the first step of such an analysis. Applying these socio-economic indicators, the analysis aims to shed light on whether the agricultural potentials are likely to be realised given the prevailing socio-economic situation, and which accompanying investments in the socio-economic domain are required. For the analysis, local data about the socio-economic situation would be ideal because of considerable differences and specificities found in certain areas but not in others. The socio-economic situation in Africa is rather complex and diverse. Thus, the local circumstances need to be taken into account when analysing the agricultural production potential as well as strategies to promote agricultural production growth and development in general.

The remainder of this chapter is structured as follows: First, the socio-economic factors and indicators are briefly described. This is followed by a section on the data collection and associated issues. With the disaggregated level of detail desired and the costs of collecting such data (for example the national census or surveys of firms and/or households), it is not surprising that many data are not readily available and thus could not been obtained for many indicators by the data collection efforts undertaken within this project in 2010. Disaggregated data are available for four indicators, only, and their respective maps are presented and analysed below, in addition to country-level indicators.

6.2 Literature review of socio-economic aspects and indicators

6.2.1 Economic aspects at the farm-level

First of all, economic aspects at the farm-level matter for agricultural productivity. We concentrate on the production activity at the farm-level, but it should be noted that other activities further up or down along the supply chain are also important. For example, packing and processing of agri-food products, especially fruit and vegetables for example, could be considered in addition to primary production. Farm-level aspects are closely related to production methods factors, including input use and technical conditions. The basic conventional inputs into agricultural production can in general be summarised as labour, land and capital, with capital referring to production inputs as well as technology. The Food and Agricultural Organisation (FAO) collects data information about such conventional production factors for farms around the world and publicly provides the data in their statistical database on agricultural production. The data provided is usually at country-level. While covering a variety of relevant farm-level indicators, the FAOSTAT database does not report about ownership structure and farm size, neither at the local and regional level nor at the country-level.

Wiebe *et al.* (2003) examined trends in agricultural productivity in Sub-Saharan Africa by identifying sources of agricultural growth and bottlenecks. According to their review, they conclude that about 75% of the variation in agricultural productivity in Sub-Saharan Africa can be explained by the use of conventional inputs. Sub-Saharan Africa has the overall lowest level of mineral fertilizer use in comparison to other countries world-wide (World Bank, 2008), and thus an increased fertilizer use could potentially boost productivity if applied in an appropriate and sustainable way. Information about fertilizer use is available in FAOSTAT at country level and Potter *et al.* (2010) has provided fertilizer use data at grid cell level (see section 4.3). It seems to be an important indicator for agricultural productivity. Nin-Pratt and Bingxin (2008), for example, report agricultural productivity increases following changes in the crop choice on the one hand and an adjustment in the use of inputs on the other hand. Focusing on fertiliser, they state that the use of fertiliser in African as a whole overall decreased but increased in most of the best-performing countries.

Fertilizer and machinery use are important determinants of agricultural productivity in African countries, but so are land and labour, especially land and labour productivity. Labour productivity is defined as economic output or yield per worker, and land productivity refers to the (economic) yield per land area in hectare[1]. Looking at crop production in the period 1961-2005, Block (2010) analysed labour and land productivity across African countries. Looking at labour productivity, Block specifically accounts for the quality of workers measured by the number of years of education and training in the estimation and finds that labour quality explains about one third of the productivity

1 Labour employed in agriculture assumes full-time employment, but people are often not full-time farmers with particularly man more involved in off-farm work to supplement the household income. In addition, the food products harvested are often used for own consumption and may be exchanged for other products. This is usually not registered in the statistics and difficult to track down. While agricultural yield may be underestimated, the agricultural labour force may be comparatively large, and such measurement issues bias estimates of productivity downwards.

growth rate estimated. This result supports the more general reasoning that the education and skills of workers are important determinants of agricultural productivity. The same applies to the quality of land, which is first and foremost regarded as a natural resource characteristic but also encompasses socio-economic aspects. As Brindraban *et al.* (2009) elaborate in more detail, access to land and secure tenure or ownership are prerequisite for farmers to invest in technology, both better production methods as well as management, so as to increase land productivity. However, there are many open questions with regard to the organisation of land entitlements, and in many cases the local situations in African countries do not fit the common land model and approaches. Place (2009), for example, analysed the link between land tenure and agricultural productivity in the African context by reviewing existing empirical studies. The studies reviewed show a significant heterogeneity and no overall conclusion can be drawn about the causal relationship. Results crucially depend on the local context and the overarching macro and sectoral conditions within which tenure systems operate.

6.2.2 Socio-economic aspects

There are several studies analysing the relationship between nightlight and GDP. Noor *et al.* (2008), for example, find that GDP is comparatively low in areas with low nightlight intensity. From their statistical analysis across African countries and over time, they conclude that nightlight is a good proxy for poverty and most importantly adds useful information in countries where economic data or poverty data is largely missing, like in Angola, Chad or Yemen. The absence of luminosity would indicate low income and a relatively high level of poverty. Chen and Nordhaus (2010) show how luminosity data can be used as a proxy for economic statistics. Focusing on Africa, Henderson *et al.* (2009), for example, use nightlight data to analyse income growth developments in this region over the last 17 years. In particular, the nightlight data measured by satellite data imply that the increase in total GDP in areas that are inland more than 100 kilometres away of an ocean or navigable river was 4.4% greater than on the coast. The authors cannot say anything about the long-run benefits over centuries of being on the coast but their analysis reveals that during time periods of rapidly growing trade coastal areas in Africa grew more slowly than non-coastal areas. Figure 6.1 (a) shows the nightlight map of Africa. Several clusters of high nightlight intensity can be identified, and these clusters often correspond with centres of high population density, compare Figure 6.1 (b).

Population is considered as a socio-economic indicator, and Figure 6.1 (b) illustrates the population data provided by the United Nations Environment Programme (UNEP). Especially, population growth rates seem to be particularly interesting as food demand increases in areas with high population growth, and the increased demand for food could stimulate agricultural production. On the one hand, population figures can be used to identify where current food demand is high and hence to a certain degree points to the size of the potential local food market. Given population growth, the future demand for food could be estimated. On the other hand, population size/growth also point towards areas where food security is or could become a critical issue if food demand exceeds supply. In his empirical analysis, Block (2010) elaborates on the link between population and agricultural productivity. Given that population growth outpaces the expansion of agricultural land area, he argues that the area per agricultural worker *ceteris paribus* declines and thus the challenge of increasing productivity per worker becomes more difficult.

Bindraban *et al.* (2009; p. 54) state: ‘Complementary infrastructure built by the villages, national governments, or non-governmental organisations is crucial to remove existing limitations which hamper the participation of the private sector and increase the costs of input and output marketing. Critical investments include rural transportation; rural water infrastructure, village production infrastructure (…).’ Improving roads and transport networks is expected to have a positive effect on agricultural productivity. Poor infrastructure reduces the farmers’ access to markets and agricultural inputs, such as fertilisers and machinery, including spare parts. Developing transport networks between cities and rural areas will help farmers to benefit from new technologies and agricultural inputs as well as raising incomes if they can sell their crops at markets. It is not only the transport network per se but most importantly the quality of infrastructure related to maintenance as well as service provision. The logistic performance index could be used as a proxy. However, the logistic performance index gives national information at country level and not at the disaggregated local level. In order to add the spatial dimension, information of road networks (for example number and length of paved roads, railways, number of crossroads) has been combined with distance measures or the time spent to travel to the next central place. In their project for geo-spatial indicators, Miller *et al.* (2002a and b) develop the indicator of infrastructure intensity, which constitutes a good example for composite infrastructure indicators. Their indicator of infrastructure intensity contains spatial information related to roads and rail, central places and industry location, thereby going beyond transportation and logistics. In fact, the indicator goes far beyond measuring infrastructure and approximates the accessibility to input and output markets (compare section on governance and market institutions).

Dorosh *et al.* (2010) provide some empirical evidence in their analysis of the link between road infrastructure and different crop production systems in Africa (low-input, high-input/rain-fed, and irrigated production). Their results reveal a strong correlation between crop production and an infrastructure index, which reflects road networks and the proximity to markets (measured by travel time). For all crop production systems, the coefficients of the elasticity are negative such that longer travel time correlates with lower crop production. For low-input rain-fed crop production, the influence of infrastructure on yield is most prominent with the highest estimated coefficient of the infrastructure index. For any crop production system, access to the urban market has the largest impact on crop production. In the separate regressions for East and West Africa, the authors find different results: while the results for East Africa are similar to those for Sub-Saharan Africa in total, the results for West Africa are overall less pronounced. Dorosh *et al.* explain that the difference in the estimated impact shows a marginal decreasing impact of infrastructure on crop production. That is, the more densely and better connected the road network the smaller the marginal benefit for crop production. Given this decreasing marginal impact, infrastructure improvements can be expected to be more beneficial in East Africa, where the road network is relatively limited.

Good health is essential for people to utilize available opportunities and determines labour productivity. In addition to a large number of health indicators such as number of infected and ill people as well as information on health care, infant mortality often relates to health problems and child malnutrition may be used as an indicator. Both the mortality and malnutrition of children constitute important poverty indicators and are part of the composite human development index published by the World Bank. Infant mortality refers to the rate of the number of children dying before their first birthday in every 10,000 live births. Child malnutrition is the number of underweight children under five years old per 1,000 children under five years old. Indicators that measure the health and poverty situation can be expected to be negatively correlated with agricultural production and productivity, but as mentioned above, the relationship can also be the other way round. For developing countries in general, the negative correlation has been shown in many studies; for example, by Pasada Rao *et al.* (2004) who examined agricultural productivity in Sub-Sahara Africa during 1970 and 2000.

6.2.3 Socio-institutional aspects

Bindraban *et al.* (2009: p. 31) state that 'of particular importance for increasing agricultural productivity in Sub-Sahara Africa are the access to the necessary means of production as well as to adequate and improved knowledge and information.' The human development index, which the World Bank publishes for individual countries every year, contains data information about education, literacy and skills. These indicators are proxies for human capital, which is used in agricultural production in addition to physical capital inputs (e.g. fertiliser and machinery). Human capital is either embedded in the inputs that go into the production or enhances the way inputs are used and combined with each other (Zepeda, 2001).

While the importance of physical capital investment (e.g. investment in roads) has long been recognised, human capital investment has been found to be critical for development. As Bindraban *et al.* (2009: p. 59) explain, '*the building of human capital and the provision of specific training will be critical to enable households to take advantage of the created opportunities and participate in new (market) developments*'. In this regard, the database for Agricultural Science and Technology Indicators (ASTI) by the International Food Policy Research Institute (IFPRI) provides useful information at the country level. The ASTI database covers a variety of information ranging from the number of universities and research institutes to the amount of funding for agricultural research since 2001.

Improvements of crop varieties and their cultivation would be particular beneficial to boost smallholder and traditional agricultural production systems, which does not include commercial and irrigated farming systems based on purchased inputs. In Africa productivity increases have so far been limited for these agricultural systems, while some successes could be achieved in root crop production, especially cassava; for an overview see for example Johnson, el al. (2003). The InterAcademy Council (2004) looks into agricultural research in Africa and emphasizes the need for research focusing on alleviating yield-reducing factors such as the use of stress-resistant varieties and cultivation practices, which fit into local niches and which farmers can actually afford to apply. This research usually involves extensive farmer participation. Relatively few farmers in Africa have access to either irrigation or affordable chemical inputs, and pre- and post-harvest losses can be large. Hence, actual yields are typically a fraction of the potential yields, even for improved varieties.

Some studies provide empirical evidence of the influence of research and development (R&D). The recent study by Block (2010), for example, finds that expenditure on agricultural research plays an important role for explaining agricultural productivity growth, followed by policy distortions both at the macro and sectoral level. Taking into account the lagged return of R&D over time, Alene (2010) also reports a strong positive relation between R&D and agricultural productivity. More specifically, the annual rate of the return on investment in agricultural research during the period 1970-2004 is estimated at 33%.

6.2.4 Governance aspects and market institutions

Information about governance and market institutions is provided as country-level data rather than local data. This seems to make sense since national governments usually organise institutions and address aspects of governance, but it should be noted that the enforcement and functioning can be very different at the local level. International organisations are often involved in the provision of such data, and the information collected is usually aggregated over the set of specific indicators so as to obtain indexes, which can be ranked and are often published in annual reports, for example the Doing Business Indicator by the World Bank and the Corruption and Corruption Perception Index by Transparency International. The respective indexes are not directly linked to agricultural production, and the link to the productivity in the agri-food sector needs some explanation. We generally distinguish two (quantifiable) elements of markets to reflect the effectiveness of markets in Africa: market infrastructure and market institutions. Market infrastructure concerns the delivery and distribution of inputs and outputs, and is thus closely related to some of the socio-economic aspects mentioned above (e.g. roads and logistics). Note that, the farmers' access to input and output markets can considerably influence their adoption of productivity-enhancing technologies and their responses to economic policies (Bindraban *et al.* 2009, p. 34). Market institutions refer to the rules that regulate markets and their functioning, including governance aspects.

Fulginiti *et al.* (2004) conduct a statistical analysis of African agricultural production over the period 1960-1999, and their results confirm the significant role of institutions for agricultural productivity in Sub-Saharan Africa. More specifically, their work shows a positive effect from political rights and civil liberties and a negative effect of conflict and war). The negative effect of conflict and war appears to be surprisingly low. Looking at the period 1985-2002, Block (2010) for example estimates that the average African agricultural productivity growth was about 0.74 percentages points lower in war times, and thus the influence of war appears to be rather small. According to Pasada Rao et al (2004), the number of war deaths during 1970-2000 does not systematically determine agricultural productivity.

Historically, African economies have been heavily distorted by national policies, whereby agricultural producers and more specifically exporters have particularly suffered from over-valued exchange rate. Overall, Africa has lost market share in almost all its traditional agri-food export crops (World Bank, 2008). As Haggblade *et al.* (2010) explain, low agricultural productivity coupled with high transportation costs and growing world market liberalisation make it increasingly difficult for African farmers to compete in the global markets. Bindraban et al (2009: p. 32) state that '*agricultural exports are widely considered an important motor for development. But the institutional framework and rules for international trade needs considerable attention to enable African countries to further enhance their agricultural exports*.' In addition to trade policies, domestic agricultural policies generally influence the farmers' decisions about their production intensity, product mix as well as input use. The impact of agricultural policies are usually measured in terms of the rate of protection or assistance that determines the differences between domestic and international prices, and the price gap is obviously given at the national county level.

For the World Bank, Anderson and Valenzuela (2008) estimate the rate of protection for agriculture in 13 African countries. Their estimates are available in an on-line database and have been applied in recent empirical studies on agricultural productivity in Africa. For example, Block (2010) finds that agricultural productivity is significantly correlated with a relative measure of assistance, which is defined as the protection in the agricultural sector relative to the protection in the non-agricultural sector. Moreover, Headey *et al.* (2010) report a positive contribution of agricultural policy reform on productivity. In contrast, Nin-Pratt and Bingxin (2008) establish a negative correlation between agricultural policy reform and the performance of the agricultural sector. More specifically, they construct a policy indicator which contains the rating of key macro-economic components (e.g. exchange rate, real interest rate and budget deficit) and agricultural policy components (taxes and subsidies for agri-food products), and subsequently compare their policy indicator with agricultural productivity growth in Sub-Saharan African countries in the period 1994-2003. The scale used in the rating of the indicator is between 0 and 4, whereby a smaller value implies a better policy situation. The authors found a negative correlation between agricultural policy reform and productivity such that agricultural policy reform had a negative impact on productivity, and according to the authors, this result can be explained by the elimination of subsidies on fertilizer.

With regard to trade policy, it is generally accepted that trade liberalisation and globalisation stimulate export but as mentioned above, African agri-food exports have not increased. In particular, the high world market price for some agri-food commodities did not contribute to increased exports of such commodities. While farmers respond to relative prices, for example shifting into the production of respective agri-food products if prices increase relative to other products, the supply response by African farmers seems to be limited due to several constraints. These constraints can be generally related to the limited access of input and output markets, resulting in the inability to benefit from trade opportunities. In addition, while overseas markets are opened up to producers that can take advantage of the opportunities, domestic markets are opened to foreign producers who compete with local products. The United Nations Conference on Trade and Development (UNCTAD) provides the trade openness index that measures the protection of trade policy measures such as export subsidies, tariffs and tariff rate quotas, and estimates are available for agricultural markets world-wide as well as individual countries, including African countries.

6.3 Data collection and associated issues

For the data collection, it was decided to exclusively look at existing databases that cover a large share or if possible all African countries. For the data collection effort within this project, this decision has been made to ensure consistency and comparability of the indicators across countries and regions. Considerable measurement issues appear when using individual data sources such as the national census of countries or case studies, which look at the regional or local level in detail. For example, socio-economic indicators may be defined differently, and the quality of the data collection can be quite controversial. The latter is particularly relevant when looking at countries with limited financial resources for statistical data collection, with structural and governance issues.

International organisations such as FAO or World Bank provide such comparable information for African countries, but their data are usually national data, sometimes also sub-national data. For example, the doing business indicators by the World Bank are given at the country-level, but also at the more detailed level of administrative units; for the East African indicator or the indicators of some individual African countries in more detail (Burundi, Kenya, Rwanda, Tanzania, Uganda, Nigeria and Morocco) see http://www.doingbusiness.org/. It seems that information about socio-economic aspects is often collected in order to evaluate the Millennium Development Goals and to monitor progress to achieve them. Therefore, the respective data collection efforts remain national rather than regional or local.

The data collected in this project refers to grid cells of 5x5 arc minutes, covering the African continent. As mentioned, the national country-level data are assigned to the grid cells per country in order to generate the respective maps according to the FAO country codes. Here, it should be noted that transferring the data can lead to gaps if the definition of countries in terms of borders and/or administrative units used in the data and the FAO country codes do not match. The countries are described by their FAO codes and each grid cell refers to a unique FAO country code. In general, data on the socio-economic indicators for African countries is limited, and most data are not available at the local grid cell level. In the data collection, we found sub national data of only four socio-economic indicators and converted them into maps by using the FAO country codes. More socio-economic information is available at the country-level and can be easily provided both in tables and maps for the entire African continent.

The data contains the latest information available, whereby sometimes also time series and thus information of change could be obtained. The socio-economic indicators in GIS-format, however, are provided for the situation of the respective year. As already mentioned with regard to population, growth rates may be particularly interesting and should ideally be considered when comparing with the production potential that may be possible in the future. Furthermore, looking at productivity changes, technology adaption and/or investments into agricultural production requires a time dimension since the effects are likely to occur with a time lag. Furthermore, effects could also be observed over time. This would increase the effort of data collection, but the effort to consider changes or trends rather than the current situation could improve the analysis to be conducted.

There are a variety of possible socio-economic indicators, irrespectively whether they relate to the country-level or local level. Due to the large variety of the different indicators, questions about the correlation amongst the various indicators and endogeneity issues arise. The influence of the individual indicators should ideally be ascertained. This would involve an analysis to distil the potentially large number of indicators to a set of the most influential and statistically significant indicators (e.g. factor analysis to group indicators with similar information and regression analysis). The issue of endogeneity means that food production or output and the socio-economic aspects depend on unobserved local factors. For example, infrastructure such as roads could have been built to connect a centre of mining activities with the port, and in the area of the mining centre agricultural production would also be higher than elsewhere to provide food for the people living and working there. In this case, the relationship would obviously not per se be between food production and infrastructure. While accounting for such issues, an in-depth analysis would be necessary to provide the theoretical foundation for investigating causal relations.

Different individual indicators are often combined to generate one overall indicator for a more general topic such as food security, vulnerability or sustainability. Moreover, when aiming at providing indicators in GIS format the spatial dimension sometimes seems to be added to country-level data by using available indicators at the detailed regional level or by approximating the distribution. Indicators that consist of a combination of specific indicators are certainly useful, but they have the great disadvantage that their interpretation is not straightforward and the specific contribution of the respective components is difficult to single out. Hence, analysing causal relations and conducting some sort of impact assessment seems to rely on individual and thus unique indicators rather than an overall composite indicator.

6.4 Comparative analysis of maps

We have detailed local data (5x5 arc minutes grid-cells) for only two socio-economic indicators: nightlight and population density. This information is mapped in Fig 6.1 (a) and (b). As already mentioned above, comparing the two maps reveals that several clusters of high nightlight intensity correspond with centres of high population density. This is to be expected, as densely populated areas will also show density of lights. There are differences, however: poor areas have a lower nightlight density, as can be seen in Ethiopia and northern Nigeria, for instance, and also around the Great Lakes in eastern Central Africa. One might say that, roughly speaking, nightlights represent the number of inhabitants times income per capita, or, in other words, aggregate income per cell. The pattern of nightlights also gives insights about infrastructure since roads and other amenities tend to be found where both people and money are.

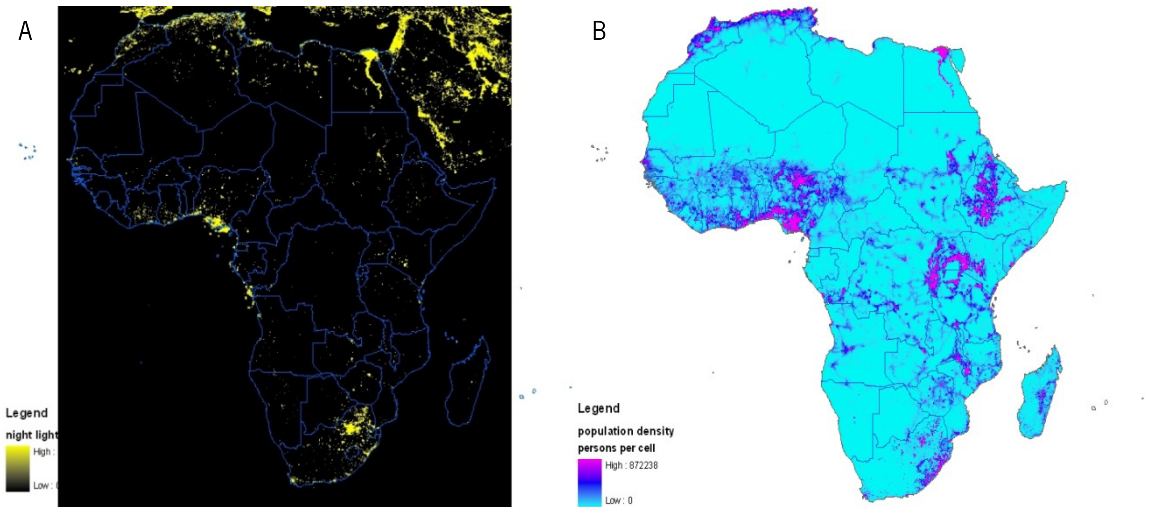

Figure 6.1. *(a) Nightlight map of Africa in 2002 (Source: Defence Meteorological Satellites Program (DMSP), 11/2010: http://dmsp.ngdc.noaa.gov/html) and (b) Population distribution across Africa in 2000 (Data source: UNEP/GRID-Sioux Falls, 11/2010: http://na.unep.net/siouxfalls/datasets/datalist.php.*

The information about child malnutrition and infant mortality is given at the level of administrative units, and in the maps the same values thus prevail in adjacent cells within one administrative unit; see Figure 6.2 (a) and (b). Data are not available for some regions (white areas), most notably Southern Sudan.

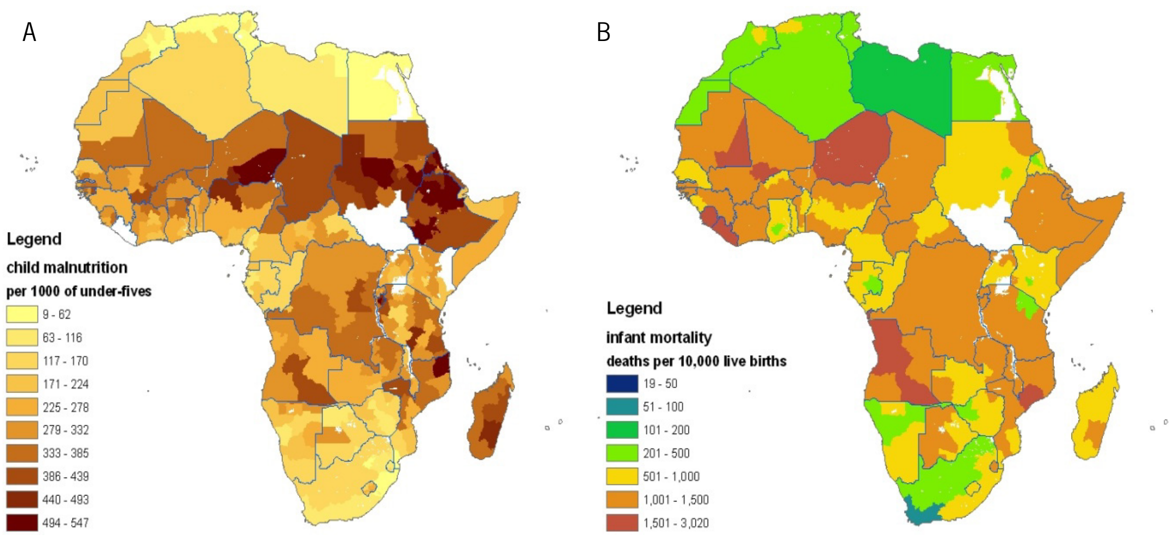

Figure 6.2. *(a) Infant mortality rates, adjusted to 2000 (number of children dying before their first birthday/10 000 live births) and (b) Child malnutrition, values adjusted to 2000 (number of underweight children under 5 years old / 1000 children under 5 years old). Data are from 1995 or later for 96% of the countries while all data are from 1990 or later. Data source: Socioeconomic Data and Applications Centre (SEDAC), Centre for International Earth Science Information Network (CIESIN) Columbia University. Areas with white colour indicate missing data.*

Much more information is available at country level. These data are presented in Table V.2 - V6 in Appendix V. Combining the available data information into indicators for socio-economic potential is a challenging tasks. As already mentioned, collinearity of indicators and the uncertainty about the direction of causality are particular difficult issues. In addition, challenges occur because of the units in which the indictors are expressed, varying from growth rates to monetary values to ranks, as well as because not all indicators are available for all countries.

Following the broad categories of indicators presented in Table 6.1, we have prepared the five indices, as described below. The maps of the five indices are presented in Figure 6.3, 6.4. and 6.5 and values are presented in Appendix V.

1. Farm level index: Fertilizer use has been taken as the most appropriate indicator here. This indicator is a proxy for the degree to which modern farming methods are being adopted in a country. The indicator expresses the quantity of plant nutrients used per unit of arable land. Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). Organic manure is not included. For more detailed data of nitrogen and phosphor application rates on the grid cell level: see chapter 4.

2. Market access index: This index is intended to show how easily farmers can market their produce both internally and on the world market. It is composed of a logistical performance indicator (itself a composite for the efficiency of logistical processes and the quality of transport infrastructure in a country), a dummy variable indicating whether or not the country is landlocked, and an indicator showing restrictions on exports from the country concerned imposed by other countries.

3. Socio-economic index: This index uses the Human Development Index (HDI) of the United Nations, which combines national income per capita in purchasing-power parities, education level and health situation. The index gives an idea of the quality of the labour force as well as the existence of a domestic market for food.

4. Institutional index: This index gives the overall characteristics of the public sector in a country. We have taken six indicators calculated by Kaufmann *et al.* (2010). These represent (1) voice & accountability (i.e. civil liberties), (2) political stability/absence of violence, (3) rule of law (e.g. independence of judiciary and the degree to which laws are adhered to), (4) government effectiveness, (5) regulatory quality, and (6) control of corruption. Since the indices are all calculated in the same way, we have simply added them up into a single index.

5. Farm support index: There are various ways in which a government can support or hinder agricultural development. For our index, we have taken the public funding agricultural research and development and gross subsidies to agriculture with each of these indicators being expressed in terms of Euro per inhabitant per year. Subsidies to agriculture is negative in many African countries indicating that the farming sector is taxed for the benefit of other sectors and/or hampered by price controls in order to keep food prices low for urban people.

These five indices present an image of the various aspects that need to be considered when assessing the socio-economic potential for agricultural development in a country. However, what is needed is an overall impression of the socio-economic poten0074 6-098 ial. D hue to the aforementioned limitations, it is not possible to calculate such an overall index from the five indices presented above. However, a rough index can be built by means of qualitative judgment based on the partial scores of the five indices, modulated by expert knowledge. A formula to calculate such an index would be more arbitrary than the qualitative method we followed because i) the partial scores would have to be weighed, for which there is no scientific basis; and ii) not all partial indices are known for all countries. The overall index of socio-economic potential, which contains the five indices as explained, is presented in the map in Figure 6.6.

The overall index of socio-economic potential is especially influenced by the scores on the human development index (HDI), which reflects the development level of the people, and the governance index, which represents the quality of government institutions. Fortunately, these two indices are available for almost all countries and territories in Africa. The other three indices do not cover all countries and are used to establish the overall index where it is not clear-cut in which of the six classes a country should fall based on human development index and governance index alone.

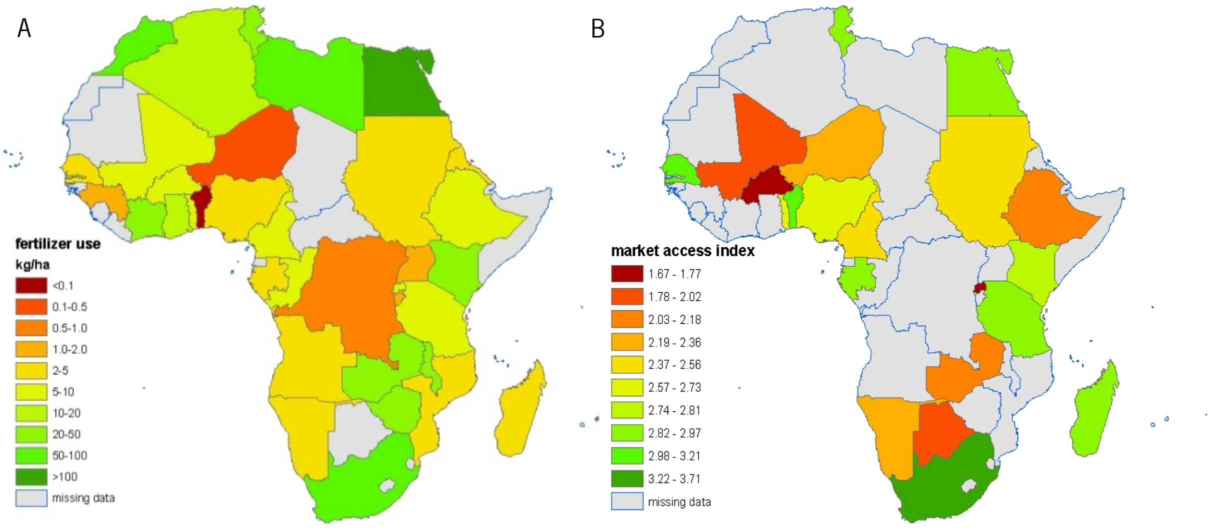

Figure 6.3. *(A) Fertilizer use (kg/ha of arable land), FAOstat, year: 2007, and (B) Market access index built from a logistic performance index, World Bank (2010): logistic performance index, year: 2010, landlockedness, World Bank, 2010), and restrictions imposed by other countries on the agricultural exports of the country concerned (Kee et al. (2009): World Bank's overall trade restrictiveness index (OTRI), year: 2008. Raw data: Table V.2 and V.3 in Appendix V.*

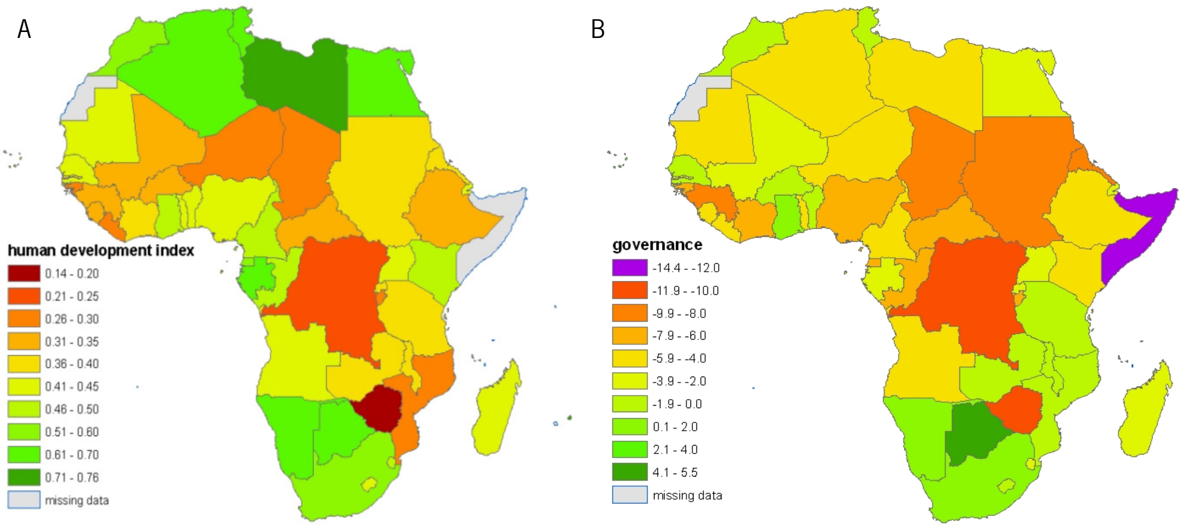

Figure 6.4. *(A) Human development index (HDI) by United Nations Development Programme (UNDP), year: 2007), HDI database, January 2011: http://hdr.undp.org/en/statistics/hdi; and (B) Governance index, own calculation following Kaufmann et al. (2010), World Bank data for of several years. Raw data: Table V.4 and V.5 in Appendix V.*

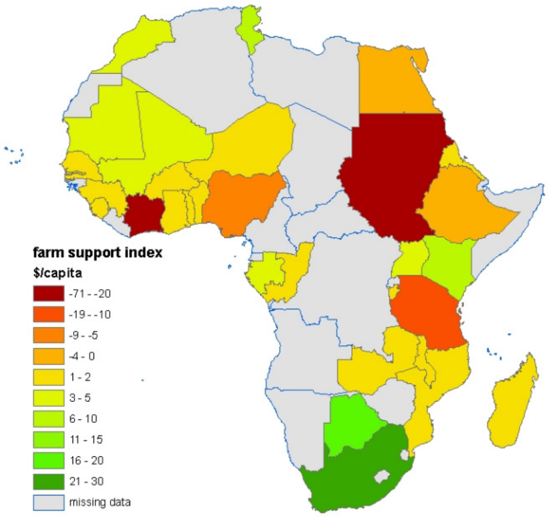

Figure 6.5. *Farm support index containing data on public funding for research and development in agriculture (database of Agricultural Science and Technology Indicators (ASTI), January 2011: http://www.asti.cgiar.org/data/). Raw data: Table V.6 in Appendix V.*

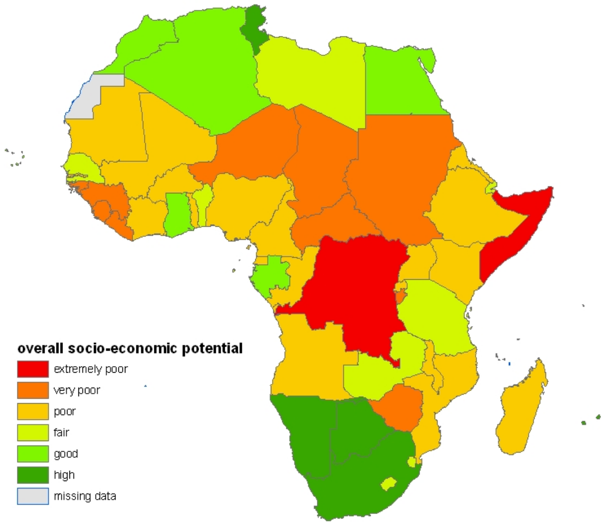

Figure 6.6. *Overall socio-economic potential. Index build from the five different indicators: fertilizer use, market access, human development, governance and farm support in terms of public spending on agricultural R&D. Raw data: Table V.7 in Appendix V.*

As shown in Figure 6.6, the highest class of the index of overall socio-economic potential includes countries with a high human development index (above 0.6 on a 0 – 1 scale) and at least a positive governance index. These indicator criteria vary in Africa from -14 for a failed state to +5.5 for a French overseas territory. South Africa is an exception with a human development index (HDI) just below 0.6 but one of the highest governance scores in Africa and moreover very high scores on the farm-level, farm support and market access indices. On the other hand, Tunisia is characterised by a high human development index and a governance index just below 0 before the recent revolution (2010); two of the other three indicators are also favourable, while the third is missing.
The countries that are considered to have a 'good' socio-economic potential are those with a HDI score between 0.5 and 0.6, provided they have at least a positive score on the governance index. Some countries with higher HDI scores but poor governance are also classified here, provided they do not go below -5. The reasoning is that such countries provide good markets for agricultural products and have a high-quality labour force, which makes development possible, even though the country is not particularly business-friendly and poorly governed. An exception has been made here for Ghana, whose HDI is only 0.47 but its score on the governance index is the highest in the region.

Moderate potential characterises those countries which are quite restricted by their socio-economic conditions, yet are not without at least some redeeming characteristics. Examples are Tanzania, which is poor and discriminates against its farmers, but has otherwise a relatively high quality of governance; or Libya, which is rich but has an appalling governance record that reduces its attractiveness for investors both domestic and foreign.

Low potential is assigned to countries which are below average in either human development or governance (or both) even by African standards – but not far below. In this group are very poor countries such as Mali and Mozambique as well as resource-rich countries which are constrained by severe governance problems, such as Nigeria and Ivory Coast.

Below the group of a relatively low socio-economic potential lies the category of countries with a 'very poor' potential and these countries have both a very low HDI score and a low governance score, often because of current or recent experience of civil war. Even in this category, there are resource-rich and potentially wealthy countries such as Guinea and Chad. Finally, the bottom of the barrel is occupied by two failed states, which in their socio-economic potential – at least in the short and medium term – are far below even the previous group. Congo and Somalia are in this group, although at a subnational level the picture might look somewhat different – if only adequate figures were available.

6.5 Concluding remarks

In this chapter a variety of socio-economic indicators have been identified and elaborated, in combination with a review of the existing literature. The evidence provided in the studies looking at African agricultural productivity corresponds with the widely held presumptions of the importance of socio-economic factors for promoting agricultural production and productivity growth. The empirical analysis of relationships between socio-economic factors and agricultural productivity is heavily constrained by lack of data and measurement issues. In addition to endogeneity, the causal direction of the relationship constitutes a major issue and results for one country and product or group of products cannot necessarily be generalised to draw overall conclusions.

Detailed spatial data of socio-economic indicators are not readily available. Within the project, spatial data at the detailed local level, as required, could only be obtained for two socio-economic indicators: nightlight and population density, which are closely related. At a lower, regional, spatial resolution, data are also available for two health-related indicators: child malnutrition and infant mortality. All other socio-economic variables are available at national level only.

Ideally, these maps should explain the difference between current yields and potential rain-fed yields as described in Chapter 4. Of course socio-economic factors cannot explain all of this difference, for example, because irrigation (which accounts for the highest actual yields) has not been taken into consideration in Figure 4.3. Yet, Figure 6.6 certainly explains why, for instance, yields in Uganda are so much lower than in South Africa, even though Uganda has a much richer natural resource base and associated higher agricultural production potentials The maps also point to the countries where socio-economic conditions are such that investments in food production are likely to bear fruit.

Combining the scores at national level in Figure 6.6 with the nightlight map of Figure 6.1 (a) would give a fair approximation of socio-economic potential at local level. This could be expressed as a reduction (in percentage points) of the yield potential calculated in Figure 4.3b. This can be explored in further research efforts within this project.

7. Conclusions

The number of undernourished people in Africa has been relatively stable at about 210 million during the last decade. Increase in food production has been insufficient to substantially reduce the number of undernourished people. The growth in cereal yields (1.3%) did not keep pace with population growth in Africa which increased with 2.4% per year from 819 to 965 million during the period 2000 – 2007. Cereal food production increased further by expansion of the harvested cereal area with 13 million hectares. Expansion of the cropland has increased the competition with other land use like livestock grazing or preserving nature and biodiversity.

Our calculations suggest that rainfed cereal yields can be increased with a factor five in Africa, i.e. from the current average of 1.1 to 5.8 tonne dry matter ha^{-1} per crop cycle under rainfed conditions without growth limitations from nutrients, pests or diseases. In addition, the average cropping intensity can be increased under high input levels with about 50%, i.e. from current 0.8 to 1.2 crop cycle per year. To realize these potentials various constraints should be addressed simultaneously.

One important constraint is the availability of nutrients required to realize higher cereal yields. Current average fertilizer nitrogen rates are well below 10 kg N ha^{-1} across Africa. Sustainable use of animal manure on cropland may roughly double the amount of N available for crop production but will still be largely insufficient to realize the production potentials. Therefore, large amounts of external nutrient inputs will be needed to increase crop productivity levels in Africa to twice or thrice current levels.

The question whether increasing agricultural productivity will substantially affect water availability for other purposes still remains largely unanswered. In our calculations total evapotranspiration from crop land under rainfed conditions in Africa consumes 1156 km^3 per year, which corresponds with only 6% of the total rainfall on the entire African continent (20,000 km^3 y^{-1}) and 15% of the total calculated fresh water availability (7500 km^3 y^{-1}). The majority of the rainfall is consumed by other ecosystems. At the national or smaller scales, however, crop water requirements relative to fresh water availability can be high. Also the intra-annual variability in water use and availability is important: local water scarcity can be high due to distinct differences between the wet and dry season, even in high water 'surplus' countries.

A hydrological model is being developed for watersheds in Africa to address the spatial and temporal water use and availability. Simulations (case study: Limpopo river basin) reveal that the modelling approach is technically feasible and can be used to identify regions and periods in which the water resources are scarce. Moreover it can be used to assess the effects of increasing agricultural productivity and land use change upstream on water resources downstream. From the information on historic stream flows in the Limpopo River it's clear that discharges were reduced dramatically over the last 50 years. The increase in water use upstream in Zimbabwe and South Africa has a great effect on river flows downstream in Mozambique. Such changes in river flows indicate that future analyses should consider the main underlying changes within a river basin, such as large scale irrigation systems and storage dams.

In this report a variety of socio-economic indicators have been identified and elaborated that influence agricultural production and the potential agricultural growth. The review of existing literature provides evidence that African agricultural productivity corresponds with the widely held presumptions of the importance of socio-economic factors for promoting agricultural production and productivity growth. The empirical analysis of relationships between socio-economic factors and agricultural productivity is heavily constrained by lack of data and measurement issues. In addition to endogeneity, the causal direction of the relationship constitutes a major issue and results for one country and product or group of products cannot necessarily be generalised to draw overall conclusions. However, based on a qualitative integration of five different indicators on fertilizer use, market access, human development, governance and farm support in terms of public spending on agricultural R&D the socio-economic potentials of African countries are mapped. This map points to countries where socio-economic conditions are such that investments in food production are likely to bear fruit.

The framework offers interesting possibilities of linking different databases in a spatial context and allowed to increase insights in current production and input use, agricultural production potentials and associated water requirements in relation to current rainfall distribution. Combining socio-economic with agro-ecological spatially disaggregated data is still in development, but shows much promise for the future to support agricultural/rural policy decision-making.

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Appendix I.
Harvested area and yield of cereals in Africa

Table I.1. Harvested area of cereals per country (in 1000 ha) and average yield of cereals per country (in tonnes fresh weight ha[-1] per harvest). The crop land database refers to the data of Monfreda et al. (2008) at 5x5 arc minutes grid cell level, which we have aggregated to country level; FAOSTAT refers to the statistical database of the FAO with crop data which were downloaded in spring 2010 (http://faostat.fao.org/site/567/default.aspx#ancor).

SubRegion	Country	Harvested area			Yield		
		Crop land database	FAOSTAT 1997-2003	FAOSTAT 2006-2008	Crop land database	FAOSTAT 1997-2003	FAOSTAT 2006-2008
Northern Africa	Algeria	1953	2112	2795	1.05	1.06	1.33
	Egypt	2644	2704	2976	7.19	7.13	7.49
	Libyan Arab Jamahiriya	290	326	343	0.62	0.66	0.62
	Morocco	4812	5299	5254	0.92	0.93	1.08
	Sudan	7409	8402	9156	0.50	0.54	0.65
	Tunisia	814	1089	1158	1.48	1.31	1.41
	Western Sahara	0	3	3	No data	0.78	0.77
Western Africa	Benin	632	874	903	1.08	1.08	1.25
	Burkina Faso	2405	3081	3519	0.87	0.90	1.05
	Côte d'Ivoire	1418	804	809	1.39	1.60	1.71
	Gambia	136	134	213	1.05	1.15	0.94
	Ghana	1232	1377	1409	1.36	1.31	1.33
	Guinea	675	1172	1823	1.36	1.47	1.51
	Guinea-Bissau	118	141	143	1.08	1.07	1.46
	Liberia	110	138	160	1.14	1.15	1.44
	Mali	1848	2596	3424	0.99	1.01	1.13
	Mauritania	174	190	235	0.86	0.81	0.76
	Niger	6802	7529	9314	0.35	0.37	0.46
	Nigeria	16093	17689	19152	1.13	1.23	1.50
	Senegal	882	1207	1231	0.85	0.82	0.91
	Sierra Leone	218	353	1111	1.16	1.07	1.01
	Togo	686	720	797	1.01	1.05	1.13
Middle Africa	Angola	951	936	1487	0.58	0.63	0.49
	Cameroon	816	838	1107	1.63	1.63	1.34
	Central African Republic	165	169	212	1.00	1.01	1.15
	Chad	1436	1877	2541	0.61	0.66	0.77
	Congo	10	18	27	0.79	0.79	0.78
	Equatorial Guinea	0	No data	No data	No data	No data	No data
	Gabon	18	18	20	1.05	1.54	1.66
	Sao Tome and Principe	0	1	1	No data	2.15	2.35
	Zaire	2055	1977	1976	0.79	0.79	0.77

SubRegion	Country	Harvested area			Yield		
		Crop land database	FAOSTAT 1997-2003	FAOSTAT 2006-2008	Crop land database	FAOSTAT 1997-2003	FAOSTAT 2006-2008
Eastern Africa	Burundi	206	206	222	1.31	1.32	1.31
	Comoros	0	16	16	No data	1.33	1.31
	Djibouti	0	0	0	No data	1.70	1.67
	Eritrea	331	343	430	0.50	0.55	0.46
	Ethiopia PDR	5090	7376	8589	1.30	1.19	1.48
	Kenya	2005	1975	2149	1.48	1.50	1.61
	Madagascar	1160	1404	1527	1.96	1.99	2.35
	Malawi	726	1559	1701	1.28	1.32	1.78
	Mozambique	1455	1935	2038	0.84	0.87	0.79
	Rwanda	221	261	326	0.94	0.95	1.12
	Somalia	387	550	536	1.07	0.64	0.41
	Tanzania, United Rep. of	2425	3145	5026	1.39	1.38	1.20
	Uganda	1313	1393	1725	1.55	1.56	1.53
	Zambia	649	707	816	1.39	1.46	1.95
	Zimbabwe	1416	1763	2157	0.98	1.06	0.60
Southern Africa	Botswana	104	104	82	0.25	0.27	0.49
	Lesotho	163	196	230	1.07	0.89	0.50
	Namibia	144	296	289	0.44	0.36	0.43
	South Africa	4219	4879	3408	2.40	2.45	3.27
	Swaziland	73	68	49	1.42	1.50	0.84
Northern Africa	Total	17922	19935	21685	1.71	1.64	1.82
Western Africa	Total	33429	38005	44243	0.95	1.01	1.17
Middle Africa	Total	5451	5834	7371	0.84	0.85	0.81
Eastern Africa	Total	17384	22633	27258	1.31	1.27	1.36
Southern Africa	Total	4703	5543	4058	2.23	2.23	2.83
Africa	Total	78889	91950	104615	1.27	1.27	1.39

Appendix II.
Fertilizer N and P use and manure N and P production in Africa

Table II.1. Fertilizer nitrogen consumption and manure nitrogen production per country (both in tonnes N y^{1}). The nutrient database refers to the data of Potter et al. (2010) at 30x30 arc minutes grid cell level, which we have aggregated towards country level; FAOSTAT refers to the statistical database of the FAO with nutrient consumption data which were downloaded in autumn 2010.

		Fertilizer			Manure
SubRegion	Country	Nutrient database	FAOSTAT 1994-2001	FAOSTAT 2006-2008	Nutrient database
Northern Africa	Algeria	12010	38400	34525	444290
	Egypt	670294	972394	1289232	387894
	Libyan Arab Jamahiriya	23623	25562	49487	91096
	Morocco	125085	170358	300407	532660
	Sudan	32367	46500	52130	3156712
	Tunisia	56629	54491	60264	193427
	Western Sahara	80	No data	No data	3178
Western Africa	Benin	14140	16787	0	101897
	Burkina Faso	11061	12851	8198	420444
	Côte d'Ivoire	37774	41588	18159	125753
	Gambia	1181	694	1057	21072
	Ghana	7896	7287	19758	148287
	Guinea	9594	1546	2650	151607
	Guinea-Bissau	1151	350	No data	32998
	Liberia	583	0	No data	12528
	Mali	11858	15476	33875	503448
	Mauritania	3657	2703	No data	208897
	Niger	4776	2731	4490	258419
	Nigeria	97969	115962	206705	1595175
	Senegal	14556	10912	1634	264361
	Sierra Leone	127	535	No data	31633
	Togo	9150	7300	4800	55740
Middle Africa	Angola	1360	1750	6799	216269
	Cameroon	20921	19606	26920	369629
	Central African Republic	400	150	No data	186993
	Chad	10519	7525	No data	362210
	Congo	1411	1818	221	12192
	Equatorial Guinea	72	0	No data	1414
	Gabon	652	100	608	12162
	Sao Tome and Principe	0	0	No data	0
	Zaire	475	1512	2961	160632

SubRegion	Country	Fertilizer			Manure
		Nutrient database	FAOSTAT 1994-2001	FAOSTAT 2006-2008	Nutrient database
Eastern Africa	Burundi	1325	1277	1098	29229
	Comoros	0	100	No data	0
	Djibouti	0	0	No data	21161
	Eritrea	5286	3848	222	134157
	Ethiopia PDR	50611	64381	35978	1672363
	Kenya	64426	56866	76726	746444
	Madagascar	2828	5147	5214	462119
	Malawi	36602	29066	56625	71048
	Mozambique	16174	7000	9544	103132
	Rwanda	195	75	1987	45340
	Somalia	1456	375	No data	493797
	Tanzania, United Rep. of	24130	17272	35140	918366
	Uganda	3815	1662	6334	372753
	Zambia	11348	22115	52731	162655
	Zimbabwe	129960	90162	56611	303809
Southern Africa	Botswana	5951	3171	No data	127271
	Lesotho	4013	2361	No data	55275
	Namibia	129	50	1146	196226
	South Africa	353991	399875	430774	1324856
	Swaziland	4485	1753	No data	39191
Northern Africa	Total	920088	1307706	1786045	4809257
Western Africa	Total	225473	236816	301325	3932259
Middle Africa	Total	35810	32461	37509	1321501
Eastern Africa	Total	348156	299346	338210	5536373
Southern Africa	Total	368569	407210	431920	1742819
Africa	Total	1898096	2283537	2895009	17342209

Table II.2. Fertilizer phosphorus consumption and manure phosphorus production per country (both in tonnes P y[1]). The nutrient database refers to the data of Potter et al. (2010) at 30x30 arc minutes grid cell level, which we have aggregated towards country level; FAOSTAT refers to the statistical database of the FAO with nutrient consumption data which were downloaded in autumn 2010. For unit conversion we used 0.436 g P / g P_2O_5.

		Fertilizer			Manure
SubRegion	Country	Nutrient database	FAOSTAT 1994-2001	FAOSTAT 2006-2008	Nutrient database
Northern Africa	Algeria	55204	11657	15265	76830
	Egypt	92676	59158	87255	65767
	Libyan Arab Jamahiriya	5854	16774	11242	16100
	Morocco	47335	44300	45320	91805
	Sudan	3278	5913	2541	572130
	Tunisia	18660	17868	20291	32780
	Western Sahara	27	No data	No data	617
Western Africa	Benin	4746	4788	0	18381
	Burkina Faso	6909	4400	3314	77949
	Côte d'Ivoire	4691	7921	6235	21760
	Gambia	294	115	197	3675
	Ghana	1394	1807	5570	27115
	Guinea	3093	523	84	26378
	Guinea-Bissau	354	120	No data	5927
	Liberia	85	0	No data	2261
	Mali	5401	5137	5042	92174
	Mauritania	199	11	No data	40167
	Niger	995	544	623	47818
	Nigeria	14408	17020	16185	293579
	Senegal	4193	4517	1572	46934
	Sierra Leone	47	233	No data	5451
	Togo	2739	2260	1409	10559
Middle Africa	Angola	3	546	1120	39399
	Cameroon	3163	3125	3592	67446
	Central African Republic	100	65	No data	34506
	Chad	843	901	No data	65641
	Congo	306	306	106	2247
	Equatorial Guinea	11	0	No data	262
	Gabon	159	51	94	2330
	Sao Tome and Principe	0	No data	No data	0
	Zaire	150	512	233	30901

SubRegion	Country	Fertilizer			Manure
		Nutrient database	FAOSTAT 1994-2001	FAOSTAT 2006-2008	Nutrient database
Eastern Africa	Burundi	388	567	247	5372
	Comoros	0	44	No data	0
	Djibouti	0	0	No data	3948
	Eritrea	2506	922	244	24446
	Ethiopia PDR	43404	36470	28924	294730
	Kenya	23819	29001	41030	134855
	Madagascar	1294	1297	999	81422
	Malawi	5728	4896	7654	13002
	Mozambique	2253	573	569	17130
	Rwanda	72	38	1468	8403
	Somalia	258	0	No data	93221
	Tanzania, United Rep. of	7942	2630	6663	164360
	Uganda	856	327	1431	68219
	Zambia	1605	5781	4223	27953
	Zimbabwe	9801	17712	16114	53893
Southern Africa	Botswana	546	110	No data	22955
	Lesotho	1156	972	No data	10008
	Namibia	87	33	77	35226
	South Africa	91957	100137	84561	234476
	Swaziland	1461	900	No data	6887
Northern Africa	Total	223034	155670	181914	856029
Western Africa	Total	49548	49395	40231	720128
Middle Africa	Total	4735	5506	5145	242732
Eastern Africa	Total	99926	100258	109566	990954
Southern Africa	Total	95207	102152	84637	309552
Africa	Total	472450	412981	421493	3119395

Appendix III.
Results from calculated soil water balance

Table III.1. *Ratios of evapotranspiration (ET, mm y^{1}) relative to total rainfall (mm y^{1}) and total fresh water availability (mm y^{1}) and population size and fresh water availability per capita for each country. Total refers to the entire country area and crop land only to the part of the country used as crop land (Erb et al., 2007). Calculated values refer to conditions of maize/wheat rainfed yield potentials.*

Country	Total ET/total rainfall	Crop land ET/total rainfall	Crop land ET/total fresh water availability	Population size in 2010 (1000's)	Fresh water availability (m^3 $(cap)^{-1}$ y^{-1})
Algeria	67%	16%	51%	35423	1613
Egypt	69%	5%	16%	84474	138
Libyan Arab Jamahiriya	81%	6%	29%	6546	2160
Morocco	76%	24%	106%	32381	920
Western Sahara	67%	0%	0%	530	6652
Sudan	67%	7%	22%	43192	7423
Tunisia	72%	43%	157%	10374	1052
Benin	60%	12%	31%	9212	4833
Gambia	63%	15%	47%	1751	1755
Ghana	61%	16%	42%	24333	4393
Guinea	34%	2%	4%	10324	26120
Côte d'Ivoire	59%	14%	34%	21571	8159
Liberia	37%	2%	4%	4102	34985
Mali	59%	5%	13%	13323	10637
Mauritania	50%	1%	2%	3366	13503
Niger	76%	9%	49%	15891	2177
Nigeria	52%	17%	38%	158259	2928
Guinea-Bissau	39%	6%	11%	1647	16695
Senegal	62%	8%	25%	12861	3411
Sierra Leone	32%	2%	4%	5836	19666
Togo	55%	25%	59%	6780	4239
Burkina Faso	68%	9%	33%	16287	3670
Angola	65%	2%	6%	18993	19911
Cameroon	49%	7%	14%	19958	18689
Central African Republic	61%	2%	5%	4506	70730
Chad	67%	4%	12%	11506	10633
Congo	57%	0%	1%	3759	64059
Equatorial Guinea	42%	4%	6%	693	44019
Gabon	42%	1%	1%	1501	188891
Zaire	60%	2%	4%	67827	21205
Burundi	60%	29%	77%	8519	1507
Ethiopia PDR	57%	7%	16%	84976	4876
Djibouti	59%	0%	0%	879	2381

Country	Total ET/total rainfall	Crop land ET/total rainfall	Crop land ET/total fresh water availability	Population size in 2010 (1000's)	Fresh water availability (m^3 $(cap)^{-1}$ y^{-1})
Kenya	74%	9%	35%	40863	2523
Madagascar	60%	4%	10%	20146	16767
Malawi	40%	9%	16%	15692	4404
Mozambique	67%	3%	11%	23406	10878
Zimbabwe	74%	6%	27%	12644	4850
Rwanda	60%	30%	75%	10277	1120
Somalia	84%	2%	13%	9359	3358
Tanzania, United Rep. of	64%	4%	11%	45040	6764
Uganda	75%	27%	106%	33796	1965
Zambia	56%	4%	11%	13257	20075
Eritrea	76%	4%	17%	5224	1632
Botswana	91%	1%	7%	1978	9857
Lesotho	57%	6%	13%	2084	5068
Namibia	82%	1%	8%	2212	18064
South Africa	75%	13%	50%	50492	2880
Swaziland	65%	8%	22%	1202	4229
Total Africa	61%	6%	15.4%	1029252	7280

Appendix IV.
Weather and soil data

The weather and soil data as obtained from CRU and FAO can not be used directly as input for the crop-soil model LINPAC, but have to be prepared, as desribed below.

Soil
Each 5x5 arc minutes grid cell is characterized by one Soil Mapping Unit (SMU) which may represented by up to eight soils with different attributes whose areas are expressed as percentages of the grid cell. Each SMU has been disaggregated in these soils to provide unique soil input for the model. In some soils attributes can have more than one value (e.g. texture class 1/2 indicating that the average texture class ranges between 1 and 2) and in those situations unique soil input is created by taking the upper and lower value of the range separately. In this way the globally original 4,931 SMU's have been converted into 22,225 soil input situations that differ in texture, slope, soil depth, soil moisture storage capacity and/or soil induced reduction factor, which are used individually in the crop-soil calculations. Soil moisture storage capacity is defined as the available water for crop uptake and equals the difference between water contents at field capacity (pF = 2.0) and permanent wilting point (pF = 4.2). It equals thus the maximum storage capacity of crop-available water in the soil. A reduction factor limiting crop growth has been estimated as a function of soil type in case of Acrisols (factor = 0.75), Solonetz (factor = 0.5) and if the phase description in the FAO soil database refers to saline/sodic conditions (factor = 0.25) to account for adverse soil chemical conditions. Results from the calculations of all different soils in a grid cell are aggregated again by determining the area-weighted average result for each grid cell. This procedure to provide results for the whole grid cell was adopted, because spatial information on the different soil conditions within a grid cell is not available in the DSMW.

Weather
As LINPAC runs with a daily time step, the monthly values in the meteorologicalr database were linearly interpolated to obtain daily values for radiation, temperature, vapor pressure and wind speed. For rainfall two procedures were followed depending on the use of the rainfall data. Linear interpolation was applied for determining the average rainfall per day and used (in combination with the other average weather variables) to calculate the average growing season(s). This procedure is not adequate for calculating crop growth because precipitation commonly consists of a series of discrete and random events with decreasing soil moisture conditions in between. Using average daily precipitation values in the calculations of crop growth may underestimate the effect of water stress on crop production. Therefore, a random generator is used to distribute the monthly total precipitation over the number of rainy days in a month. A number of different yearly precipitation patterns is created for each weather grid cell which gives variation in timing and size of precipitation events within each month. These individual distributions are used separately as input for LINPAC to simulate the response to this variation and results were averaged to represent crop-soil output as function of average weather conditions (in this study from 1961 – 1990).

Appendix V.

Socio-economic indicators and their estimated values

Table V.1. List of socio-economic indicators.

Name	Year	Resolution	Source	Remarks
Socio-economic				
Income per capita	2009 or nearest	Country	Calculated from World Bank	Purchasing power parities in current int. US$
Economic growth	2005-09	Country	World Bank	Annual rate for the last four years known
Agriculture as % of GDP	2008 or nearest	Country	Calculated from ASTI database, CGIAR	Annual growth in value added per worker
Growth in agriculture	1998-2008	Country	FAO	
Growth in food production	1997-2007	Country	FAO	Increase in food production index
Night lights	2009	0.5 minutes	U.S. National Geophysical Data Center	Satellite data, corrected for ephemeral lights
Logistic performance index	2010	Country	World Bank	Weighted average of scores on 6 dimensions
Population density	2000	2.5 minutes	UNEP	No. of people per grid cell (aggregated to 5 minutes)
Daily energy intake	2005-2007	Country	FAO	Kcal/person/day
Daily protein intake	2005-2007	Country	FAO	Gram/person/day
Child malnutrition	1990-2002	Region	Center for Intern. Earth Science Information Network (CIESIN)	Underweight under-fives per 1,000 (subnational data)
Socio-institutional				
Human development index	2010	Country	World Bank	Rate, not rank
Poverty gap	2006 or nearest	Country	World Bank	Average shortfall of total population from poverty line
Infant mortality	2000	Region	UNICEF via CIESIN	Deaths in first year per 10,000 live births
Property right index	2009	Country	CPIA	
R&D spending on agriculture	2001 or 2000	Country	CGIAR (http://www.asti.cgiar.org/data)	Public spending, million PPP$ of 2005 production-weighted average

Name	Year	Resolution	Source	Remarks
Market institutions				
Ease of doing business index	2010	Country	World Bank (http://www.doingbusiness.org)	Rank composed of a variety
Corruption Perception Index	2001	Country	Transparency International	Corruption
Assistance to agri. products	2005 or 2004	Country	World Bank (Anderson and Valenzuela, 2008)	Nominal assistance rate to all agri products
Gross subsidies to farmers	2005 or 2004	Country	World Bank (Anderson and Valenzuela, 2008)	$US per inhabitant, for all agriculture country weighted average)
Consumer tax on food	2005 or 2004	Country	World Bank (Anderson and Valenzuela, 2008)	Consumer Tax Equivalent (consumption
Trade openness index (1)	2008	Country	World Bank (OTRI indices by Kees *et al.*, 2009)	Restrictions imposed by a country on its agricultural imports, %
Trade openness index (2)	2008	Country	World Bank (OTRI indices by Kees *et al.*, 2009)	Restrictions imposed on country exports by the rest of the world
Agri-food Exports	2008	Country	FAO	Agri-food raw materials as % of merchandise
Agri-food Imports	2008	Country	FAO	Agri-food raw materials as % of merchandise

Table V.2. Farm-level index: Fertiliser use and other indicators (year: 2007).

Country	Fertilizer use	Agricultural growth	Food production growth
	In kg ($N+P_2O_5+K_2O$) per ha arable land	Value added per worker in % per year	Index-based % per year
Algeria	15.0	1.6	4.8
Angola	3.3	8.5	6.7
Benin	0.0	3.8	2.1
Botswana		-2.0	0.4
Burkina Faso	5.1	1.5	4.5
Burundi	1.9	-2.8	-0.3
Cameroon	8.5	3.7	2.4
Cape Verde		1.4	4.4
Central African Republic		1.8	1.6
Chad		-0.3	1.7
Comoros		0.4	1.5
Congo-Brazzaville	8.4		2.8
Congo-Kinshasa	0.6	-2.0	-0.5
Cote d'Ivoire	24.8	1.7	2.2
Djibouti		0.0	5.4
Egypt	483.0	2.6	2.4
Equatorial Guinea		2.2	-0.1
Eritrea	3.5	0.7	2.1
Ethiopia	7.4	2.7	4.0
Gabon	4.5	2.7	0.7
Gambia	6.3	2.4	0.3
Ghana	10.4	1.2	4.1
Guinea	1.5	6.6	3.1
Guinea-Bissau		2.5	2.6
Kenya	36.4	0.3	4.3
Lesotho		-2.8	-1.0
Liberia			3.3
Libya	61.0		0.0
Madagascar	3.2	-0.8	1.8
Malawi	41.7	-0.1	9.0
Mali	9.8	1.8	5.2
Mauritania		-3.0	2.1
Mauritius	254.0	1.8	-0.9
Mayotte			
Morocco	58.8	2.8	2.1
Mozambique	3.1	3.6	0.5
Namibia	2.5	1.0	3.0
Niger	0.4	0.7	7.5
Nigeria	2.4	-2.1	2.8
Reunion			
Rwanda	7.4	1.4	4.1
Sao Tome & Principe			2.4
Senegal	2.0	0.0	0.3
Seychelles	108.0	2.0	-1.7
Sierra Leone			4.2

Country	Fertilizer use	Agricultural growth	Food production growth
	In kg ($N+P_2O_5+K_2O$) per ha arable land	Value added per worker in % per year	Index-based % per year
Somalia			0.3
South Africa	53.0	4.6	1.4
St. Helena			
Sudan	3.6	1.1	3.2
Swaziland		2.3	1.3
Tanzania	5.3	2.0	4.4
Togo	5.9	0.9	2.0
Tunisia	24.7	1.8	3.7
Uganda	1.4	0.5	2.4
Western Sahara			
Zambia	39.7	0.2	2.3
Zimbabwe	30.2	-0.9	-1.2

Source: FAOstat, year: 2007.

Table V.3. Market access index and its components of indicators.

Country	Seaport	Logistic performance index	Trade distortions	Agricultural Trade		Market access index
	yes=1, no=0	Weighted average of scores on 6 dimensions	Imposed by other countries on export bundle (%)	Export	Import	(logistic performance) + (seaport presence)/2 – (% external trade distortions)
Algeria	1		0.14			
Angola	1	2.3				
Benin	1	2.8	0.08	40.9	35.3	3.2
Botswana	0	2.3	0.34	2.9	12.9	2
Burkina Faso	0	2.2	0.56			1.7
Burundi	0		0.41	81.1	12.8	
Cameroon	1	2.6	0.49		19.6	2.6
Cape Verde	1				29.3	
Central African Republic	0		0.07			
Chad	0					
Comoros	1		0.13			
Congo-Brazzaville	1					
Congo-Kinshasa	1	2.7				
Cote d'Ivoire	1		0.28		20.2	
Djibouti	1	2.4				
Egypt	1	2.6	0.21		20.5	2.9
Equatorial Guinea	1					
Eritrea	1	1.7				
Ethiopia	0	2.4	0.28	82	15.5	2.1
Gabon	1	2.4	0.02	5	17	2.9
Gambia	1			68.5	31.9	
Ghana	1		0.39	68.4	15.8	
Guinea	1		0.39		13.6	
Guinea-Bissau	1	2.1				
Kenya	1	2.6	0.28		12.9	2.8
Lesotho	0					
Liberia	1	2.4				
Libya	1	2.3				
Madagascar	1	2.7	0.19	25.2	11.2	3
Malati	0		0.22	128.2	12.9	
Mali	0	2.3	0.25	28.7	12.9	2
Mauritania	1					
Mauritius	1		0.81	27.7	23.5	
Mayotte	1					

Country	Seaport	Logistic performance index	Trade distortions	Agricultural Trade		Market access index
	yes=1, no=0	Weighted average of scores on 6 dimensions	Imposed by other countries on export bundle (%)	Export	Import	(logistic performance) + (seaport presence)/2 – (% external trade distortions)
Morocco	1		0.34	21	13.9	
Mozambique	1	2.3		15.1	15.2	
Namibia	1	2	0.24	26.3	14.6	2.3
Niger	0	2.5	0.18	19.3	29.7	2.4
Nigeria	1	2.6	0.36	2.6	11	2.7
Reunion	1					
Rwanda	0	2	0.27	68	12.4	1.8
Sao Tome & Principe	1					
Senegal	1	2.9	0.15	20.6	27.2	3.2
Seychelles	1				19.3	
Sierra Leone	1	2				
Somalia	1	1.3				
South Africa	1	3.5	0.25	8.8	6.1	3.7
St. Helena	1					
Sudan	1	2.2	0.26	10.1	7.7	2.5
Swaziland	0		0.97	30.5	21.5	
Tanzania	1	2.6	0.2	46.7	8.6	2.9
Togo	1	2.6	0.44	16.2	15.8	2.7
Tunisia	1	2.8	0.46	14.6	12.1	2.9
Uganda	0		0.36	63.1	14	
Western Sahara	1					
Zambia	0	2.3	0.1	25.4	6	2.2
Zimbabwe	0			21.3	17.4	

Source: Landlockedness/Seaport information by World Bank, year: 2010, logistic performance index by World Bank, year: 2010; trade distortions by Kim & Valenzuela (2008), year: 2004/2005; trade data by FAO, year: 2010.

Table V.4. Socio-economic index: Human development index and its components.

Country	Human development index (HDI)	Income per capita	Income growth	Poverty gap	Agriculture value added	Daily energy intake	Daily protein intake	Life expectancy	Adult literacy rate	Enrolment rate, secondary school
		PPP, current $	% per year, 2005-09	Mean shortfall of population from the poverty line	% of GDP	Kcal/pers. /day in 2005-07	Gram/pers. /day in 2005-07	Years	% of over 15 years old	% of children
Algeria	0.68	8130	4.5		7	3110	86	72.4	72.6	66.3
Angola	0.40	4970	12.2	29.9	7	1950	43	47.0	69.6	
Benin	0.44	1510	3.8	15.7	32	2510	59	61.4	40.8	19.6
Botswana	0.63	12860	4.4		2	2240	64	54.2	83.3	64.4
Burkina Faso	0.31	1170	3.0	20.3	33	2670	80	53.0	28.7	14.4
Burundi	0.28	390	4.3	36.4	35	1680	45	50.4	65.9	
Cameroon	0.46	2200	3.7	10.2	19	2260	58	51.1	75.9	
Cape Verde	0.53	3530	8.0	5.9	9	2550	68	71.0	84.1	56.7
Central African Republic	0.32	750	3.2	28.3	53	1960	46	47.0	54.6	9.6
Chad	0.30	1230	2.4	25.6	14	2040	62	48.7	32.7	10.5
Comoros	0.43	1300	3.8	20.8	46	1860	44	65.3	73.6	
Congo-Brazzaville	0.49	2940	6.1	22.8	4	2510	53	53.6		
Congo-Kinshasa	0.24	300	4.7	25.3	40	1590	25			
Cote d'Ivoire	0.40	1640	2.4	6.8	25	2510	50	57.4	54.6	21.2
Djibouti	0.40	2480	5.3	5.3	4	2260	58	55.4		21.5
Egypt	0.62	5690	7.2	0.5	13	3160	91	70.1	66.4	71.2
Equatorial Guinea	0.54	19350	11.4		2			50.2	93.0	21.6
Eritrea	0.37	640	1.2		24	1590	47	59.5	65.3	26.0
Ethiopia	0.33	930	10.2	9.6	44	1950	56	55.2	35.9	25.3
Gabon	0.65	12460	1.8	0.9	4	2730	81	60.4	87.0	

Country	Human development index (HDI)	Income per capita	Income growth	Poverty gap	Agriculture value added	Daily energy intake	Daily protein intake	Life expectancy	Adult literacy rate	Enrolment rate, secondary school
		PPP, current $	% per year, 2005-09	Mean shortfall of population from the poverty line	% of GDP	Kcal/pers. /day in 2005-07	Gram/pers. /day in 2005-07	Years	% of over 15 years old	% of children
Gambia	0.39	1330	6.6	12.1	29	2350	55	55.9	45.3	41.8
Ghana	0.47	1480	5.8	10.5	33	2850	59	56.6	65.8	47.4
Guinea	0.34	970	3.7	32.2	25	2530	54	57.8	38.0	27.7
Guinea-Bissau	0.29	520	3.1	16.5	55	2290	44	47.8	51.0	9.7
Kenya	0.47	1570	4.0	6.1	27	2060	58	54.2	86.5	49.1
Lesotho	0.43	1950	6.3	20.8	7	2470	69	45.0	89.5	25.2
Liberia	0.30	290	3.8	40.8	61	2160	36	58.3	58.1	19.5
Libya	0.76	16430	4.9		2	3140	77	74.3	88.4	
Madagascar	0.44	1050	6.4	26.5	25	2130	49	60.3	70.7	23.8
Malawi	0.39	760	5.2	32.3	34	2130	55	53.1	72.8	25.0
Mali	0.31	1190	5.8	18.8	37	2580	71	48.4		28.6
Mauritania	0.43	1960	3.2	5.7	13	2820	86	56.7	56.8	16.3
Mauritius	0.70	13270	7.0		4	2940	83	72.6	87.5	80.1
Mayotte								76.1		
Morocco	0.57	4450	6.6	0.5	15	3230	89	71.3	56.4	34.5
Mozambique	0.28	880	8.7	35.4	29	2070	38	47.9	54.0	6.2
Namibia	0.61	6410	4.8		9	2350	67	61.0	88.2	54.4
Niger	0.26	660	2.4	28.1	40	2310	74	51.4	28.7	8.9
Nigeria	0.42	1980	6.7	29.6	33	2710	62	47.9	60.1	25.8
Reunion										
Rwanda	0.39	1060	7.6	38.2	37	2050	49	50.1	70.3	
Sao Tome & Principe	0.49	1850	7.6	8.4	17	2660	60	65.5	88.3	38.1

Country	Human development index (HDI)	Income per capita	Income growth	Poverty gap	Agriculture value added	Daily energy intake	Daily protein intake	Life expectancy	Adult literacy rate	Enrolment rate, secondary school
		PPP, current $	% per year, 2005-09	Mean shortfall of population from the poverty line	% of GDP	Kcal/pers. /day in 2005-07	Gram/pers. /day in 2005-07	Years	% of over 15 years old	% of children
Senegal	0.41	1790	3.0	10.8	16	2320	59	55.6		25.1
Seychelles		16820	0.4	0.5	2	2430	84	73.2	91.8	92.4
Sierra Leone	0.32	790	6.2	20.3	50	2130	52	47.6	39.8	24.9
Somalia								49.8		
South Africa	0.60	10060	4.5	8.2	3	2990	81	51.5	89.0	71.9
St. Helena										
Sudan	0.38	2000	7.8		25	2270	73	58.1	69.3	
Swaziland	0.50	4580	-0.3	29.4	7	2310	63	45.8	86.5	28.6
Tanzania	0.40	1350	6.5	46.8	45	2020	50	55.6	72.6	
Togo	0.43	850	2.8	11.4	44	2150	49	62.5	64.9	22.5
Tunisia	0.68	7820	6.5	0.5	10	3310	93	74.3	78.0	71.3
Uganda	0.42	1190	7.8	19.1	30	2250	49	52.7	74.6	21.6
Western Sahara										
Zambia	0.40	1280	4.8	32.8	21	1890	48	45.4	70.7	43.1
Zimbabwe	0.14	170	-4.0		19	2210	55	44.2	91.4	38.0

Source: UNDP data, year: 2007.

Table V.5. Institutional index: Governance, property right and ease of doing business.

Country	Governance index	Property rights index	Ease of doing business index
	Composite of 6 indicators see Kaufmann *et al.* (2010)	World Bank Index	World Bank index: ranking in 2010
Algeria	-5.0		136
Angola	-5.8	2	164
Benin	-1.4	3	172
Botswana	4.0		50
Burkina Faso	-1.9	3.5	154
Burundi	-6.7	2.5	181
Cameroon	-4.9	2.5	173
Cape Verde	2.9	4	142
Central African Republic	-7.7	2	182
Chad	-8.6	2	183
Comoros	-6.5		159
Congo-Brazzaville	-6.4	2.5	177
Congo-Kinshasa	-10.0	2	179
Cote d'Ivoire	-7.4	2	168
Djibouti	-3.1	2.5	157
Egypt	-2.6		99
Equatorial Guinea	-7.7		161
Eritrea	-8.2	2.5	180
Ethiopia	-5.9	3	103
Gabon	-3.7		158
Gambia	-2.7	3	141
Ghana	0.8	3.5	77
Guinea	-8.6	2	178
Guinea-Bissau	-6.0	2.5	175
Kenya	-4.6	2.5	94
Lesotho	-0.7	3.5	137
Liberia	-5.3	2.5	152
Libya	-5.2		
Madagascar	-3.4	3.5	138
Malawi	-2.0	3.5	132
Mali	-2.4	3.5	155
Mauritania	-5.2		167
Mauritius	4.7		20
Mayotte			
Morocco	-1.7		114
Mozambique	-1.2	3	130
Namibia	1.9		68
Niger	-4.4	3	171
Nigeria	-7.0	2.5	134

Country	Governance index	Property rights index	Ease of doing business index
	Composite of 6 indicators see Kaufmann *et al.* (2010)	World Bank Index	World Bank index: ranking in 2010
Reunion	5.5		
Rwanda	-2.5	3	70
Sao Tome & Principe	-2.2		176
Senegal	-2.0	3.5	151
Seychelles	0.7		92
Sierra Leone	-4.6	2.5	143
Somalia	-14.4		
South Africa	1.7		32
St. Helena			
Sudan	-9.4	2	153
Swaziland	-3.3		126
Tanzania	-1.7	3.5	125
Togo	-5.4	2.5	162
Tunisia	-0.3		58
Uganda	-3.7	3.5	129
Western Sahara			
Zambia	-1.9	3	84
Zimbabwe	-10.4	1.5	156

Source: Governance index calculated following Kaufmann et al. (2010), using World Bank data; Property Rights Index by the Property Rights Alliance, year: 2010, January 2011: http://www.internationalpropertyrightsindex.org; Ease of Doing Business Index by World Bank and International Financial Cooperation (IFC), year: 2010, January 2011: http://www.doingbusiness.org/data.

Table V.6. Farm support index: Public funding for research and development in agriculture and other indicators.

Country	Public sector R&D spending in agriculture per capita	Gross subsidy to farmers per capita	Nominal rate of assistance to agriculture (price gap)	Consumer tax on agricultural products	Consumer tax equivalent per capita	Trade restrictions on agriculture	Farm support index
	PPP US$	US$	US$	US$	US$	US$	[(R&D funding for agriculture) + (gross subsidy to farmers)] / (population) US$ per capita
Algeria						0.54	
Angola							
Benin	1.4	0.30	0.00	0.00	0.00		1.7
Botswana	17.9						17.9
Burkina Faso	1.1	0.83	0.01	0.00	0.00	0.32	2.0
Burundi	0.5						0.5
Cameroon		0.00	0.00	0.02	0.01		
Cape Verde							
Central African Republic							
Chad		0.30	0.00	0.00	0.00		
Comoros							
Congo-Brazzaville	1.2						1.2
Congo-Kinshasa							
Cote d'Ivoire	1.8	-72.53	-0.29	-0.08	-7.97	0.37	-70.7
Djibouti							
Egypt		-4.48	-0.03	0.02	3.30	0.47	-4.5
Equatorial Guinea							
Eritrea	1.5						1.5

Country	Public sector R&D spending in agriculture per capita	Gross subsidy to farmers per capita	Nominal rate of assistance to agriculture (price gap)	Consumer tax on agricultural products	Consumer tax equivalent per capita	Trade restrictions on agriculture	Farm support index
	PPP US$	US$	US$	US$	US$	US$	[(R&D funding for agriculture) + (gross subsidy to farmers)] / (population) US$ per capita
Ethiopia	1.2	-5.71	-0.03	-0.02	-3.41	0.16	-4.5
Gabon	2.7					0.16	2.7
Gambia	1.3						1.3
Ghana	1.8	-1.07	-0.01	0.04	4.39	0.26	0.7
Guinea	0.8						0.8
Guinea-Bissau							
Kenya	4.8	4.85	0.10	0.17	4.23	0.16	9.6
Lesotho							
Liberia							
Libya							
Madagascar	0.5	-0.06	0.00	0.00	-0.14	0.10	0.5
Malawi	1.5					0.24	1.5
Mali	2.6	0.51	0.00	0.00	0.00	0.25	3.1
Mauritania	2.2						2.2
Mauritius	23.3					0.29	23.3
Mayotte							
Morocco	3.5					0.57	3.5
Mozambique		1.59	0.28	0.30	2.07		1.6
Namibia							
Niger	0.4						0.4

Country	Public sector R&D spending in agriculture per capita	Gross subsidy to farmers per capita	Nominal rate of assistance to agriculture (price gap)	Consumer tax on agricultural products	Consumer tax equivalent per capita	Trade restrictions on agriculture	Farm support index
	PPP US$	US$	US$	US$	US$	US$	[(R&D funding for agriculture) + (gross subsidy to farmers)] / (population) US$ per capita
Nigeria	2.2	-7.68	-0.05	-0.01	-0.70		-5.4
Reunion							
Rwanda						0.08	
Sao Tome & Principe							
Senegal	1.9	0.00	0.00	0.16	0.05	0.46	1.9
Seychelles							
Sierra Leone	0.5						0.5
Somalia							
South Africa	5.9	24.52	0.13	0.18	21.96	0.11	30.4
St. Helena							
Sudan	0.6	-21.97	-0.08	-0.04	-8.48	0.53	-21.3
Swaziland							
Tanzania	0.8	-14.44	-0.17	-0.16	-8.90	0.34	-13.6
Togo	1.5	-0.08	0.00	0.00	0.00		1.4
Tunisia	5.5						5.5
Uganda	1.5	0.64	0.00	0.01	1.62	0.13	2.1
Zambia	0.9	0.00	0.00	0.07	2.51	0.04	0.9
Zimbabwe		0.00	0.00	-0.16	-1.06		

Source: Public funding for research and development in agriculture, ASTI database, year: 2000/2001; Gross subsidy to farmers, nominal rate of assistance to agriculture, consumer tax on agricultural products, consumer tax equivalent per capita by Anderson and Valenzuela (2008), year: 2004/2005; Trade restrictions on agriculture by OTRI indices see Kees et al. (2009), year: 2008.

Table V.7. Overall index of socio-economic potential.

Scores: 6= 'high', 5 = 'good', 4 = 'fair ', 3= 'poor', 2= ' very poor ' and 1= 'extremely poor '

Country	Score	Country	Score
Algeria	5	Mozambique	6
Angola	3	Namibia	2
Benin	4	Niger	3
Botswana	6	Nigeria	6
Burkina Faso	3	Reunion	3
Burundi	2	Rwanda	4
Cameroon	3	Sao Tome & Principe	4
Cape Verde	5	Senegal	4
Central African Republic	2	Seychelles	2
Chad	2	Sierra Leone	1
Comoros	3	Somalia	6
Congo-Brazzaville	3	South Africa	0
Congo-Kinshasa	1	St. Helena	2
Cote d'Ivoire	3	Sudan	4
Djibouti	4	Swaziland	4
Egypt	5	Tanzania	3
Equatorial Guinea	3	Togo	3
Eritrea	3	Tunisia	6
Ethiopia	3	Uganda	3
Gabon	5	Western Sahara	0
Gambia	5	Zambia	4
Ghana	2	Zimbabwe	2
Guinea	2		
Guinea-Bissau	3		
Kenya	4		
Lesotho	2		
Liberia	4		
Libya	3		
Madagascar	3		
Malawi	3		
Mali	3		
Mauritania	6		
Mauritius	0		
Mayotte	5		
Morocco	3		

Source: own calculation.