FROM FED BY THE WORLD TO FOOD SECURITY

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Henk Breman, Antonius G.T. Schut,
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Plant Production Systems Wageningen University The Netherlands

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All photos are by Henk Breman, unless otherwise indicated.

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Foreword

The current global development agenda is framed by the Sustainable Development Goals (SDGs). In turn, the SDG agenda, “Transforming Our World – the 2030 Agenda for Sustainable Development”, is built on the foundation that emerged from the Rio+20 Earth Summit in 2012 – "The Future We Want”[1]. The present report is a key contribution to SDG2 which aims to “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”.

Nowhere in the World is the SDG agenda more relevant and urgent than in Africa. Indeed, achieving SDG2 in Africa is one of the most important challenges facing us today. Africa currently faces rates of population growth unprecedented in the history of mankind. A booming population is a double-edged sword. On the one hand, the “youth dividend” – a rapidly growing population in both rural and urban areas – provides a huge demand for nutritious food and has great potential for work. On the other hand, the rising population puts even more pressure on natural resources, particularly in densely-populated fragile areas, which already suffer from land degradation, as a result of continuous cropping without adequate inputs and declining farm sizes.

The core issue addressed in the report is how to accelerate development in Africa. By analysing changes in cereal yields since the 1960s and relating these to both socio-economic and agro-ecological conditions, the authors arrive at a positive perspective. They find strong signs that agricultural development is taking off in many countries and suggest ways these trends can be extended to countries that are lagging behind. Boosting productivity through increasing fertilizer use as part of integrated soil fertility management, emerges as a key first step on the ladder to agricultural growth.

Henk Breman, who for many years was based in Africa, has devoted his career to these important issues. He led the writing of this report with inspiration from No'am Seligman and support from Tom Schut. Their analysis is an important contribution to the debate on the future of Africa – and on how to achieve SDG2.

[1] United Nations, 2015. Resolution adopted by the General Assembly on 25 September 2015. 70/1 Transforming our world: the 2030 Agenda for Sustainable Development. United Nations General Assemby, Washington DC.

I strongly commend this report to you and encourage you to delve deeper than just the abstract. Read on!

Ken E. Giller

Professor of Plant Production Systems, Wageningen University

Co-chair of the SDSN Thematic Network 7 on Sustainable Agriculture and Food Systems[2]

Wageningen, September 2019

[2] http://unsdsn.org/what-we-do/thematic-networks/sustainable-agriculture-and-food-systems/

The authors

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Agrobiologist with a focus on linkages between the environment and rural development. Bridging agro-ecological approaches with conventional technologies for sustainable high productive African agriculture, dovetailing agro-ecological and socio-economic factors. Scientist, teacher-trainer and experienced manager of rural development programs, mainly in Africa. Lived in Mali, Togo and Rwanda, and visited 27 African countries. Having more than 45 years of experience in fields such as agricultural intensification, integrated soil fertility management, crop-livestock integration, animal husbandry, rangeland management and desertification control, agroforestry, fisheries, natural resources management and optimal use of internal and external inputs. AgroBioAfrica (www.henkbreman.com).

Dr. A. G.T. Schut

Dr Tom Schut is trained as soil scientist who focuses on spatial components of agricultural systems in relation to the environment from local to global scales. He works for the Plant Production System group of Wageningen University on a better understanding of biophysical limitations on productivity, to enable a more productive, circular and resource use efficient farming system. He is lecturing on modelling concepts in agricultural and environmental systems. The importance of good nutrient management became evident after work on land degradation, a process that in many places is (in)directly linked to lack of nutrient inputs and poor nutrient management on farms. He currently works on improved crop and farm productivity projects in West- and Eastern African countries.

In memoriam No'am G. Seligman (1929-2016)

No’am died less than a year after this study was started; but without him this publication would not have seen the light of day.

As scientist and department head of the Agricultural Research Organization - Volcani Center (Ministry of Agriculture and Rural Development, Israel), No'am played a leading role in an Israeli-Dutch project that studied crop growth in dry regions in the seventies. It was a groundbreaking effort, in that it combined field experimentation with the development and use of simulation models. During field work at the northern edge of the Negev Desert, it became clear that poor soils limited plant growth more than low rainfall. Simulations, using the models for drylands elsewhere in the world, suggested that the observation could be generalized.

The Dutch Directorate General of International Cooperation (Ministry of Foreign Affairs, The Hague) supported the project financially, on condition that the results would be applied in developing countries. With Egypt and Peru, Mali was chosen as a country where the new methodology was to serve as a basis for rural development projects.

Thus it happened that, in the mid-seventies, the first author and initiator of this study was invited to join a Dutch-Malian research team. Colleagues and friends of No'am, Kees (C.T.) de Wit and Herman van Keulen, from Wageningen University, served as liaisons between the teams in Israel and in Mali. The Malian project “demonstrated the possibilities of applying modelling and simulation tools developed in one region for extrapolation and prediction in others, provided that the relevant input parameters for the local conditions are available” (Alberda et al., 1992).

Photo CABO fotodienst

The present publication and many of its references show that the Malian project has become for the Sahel and for other (semi-)arid African regions what the Israeli project had been for Mali, Egypt and Peru. No’am not only contributed to this study by helping to provide the basis for the approach, but also by maintaining an intensive correspondence with the first author during the last year of his life.

Acknowledgement

The authors thank Jan Bade, Malcolm Blackie, Ken Giller, Suzuki Kanako, Niek Koning and Arie Kuyvenhoven, who contributed to the study through reading successive versions of the manuscript and through their questions, comments, criticisms, and suggestions.

They thank also the numerous people who contributed through sharing their knowledge and through searching for requested information about countries and specific factors.

Thanks Wil Kroon for all your time, taking care of the layout of the book as well as the design of the cover.

Bastiaen Boekelo is acknowledged for his assistance and the preparation of maps, and Peter Abspoel for his editing work.

Abstract

This document presents the results of a search for policies and conditions that can help accelerate agricultural development in Africa. This development has been limited in many countries, as evinced by extreme low fertilizer use, low crop yields, poverty and high food insecurity. The rate of development is quantitatively described for the period 1961–2014 for almost fifty countries, those of the African mainland plus Madagascar, on the basis of data on the average cereal yield and fertilizer use.

The way the rainfall impacts on the fertilizer-yield relationship has been studied, by comparing contrasting rainfall transects in Western and Southern Africa, occupied by respectively 19 and 9 countries. On the basis of data from the period 1981–2014, it is shown that soil fertility dominated over rainfall in determining crop yields.

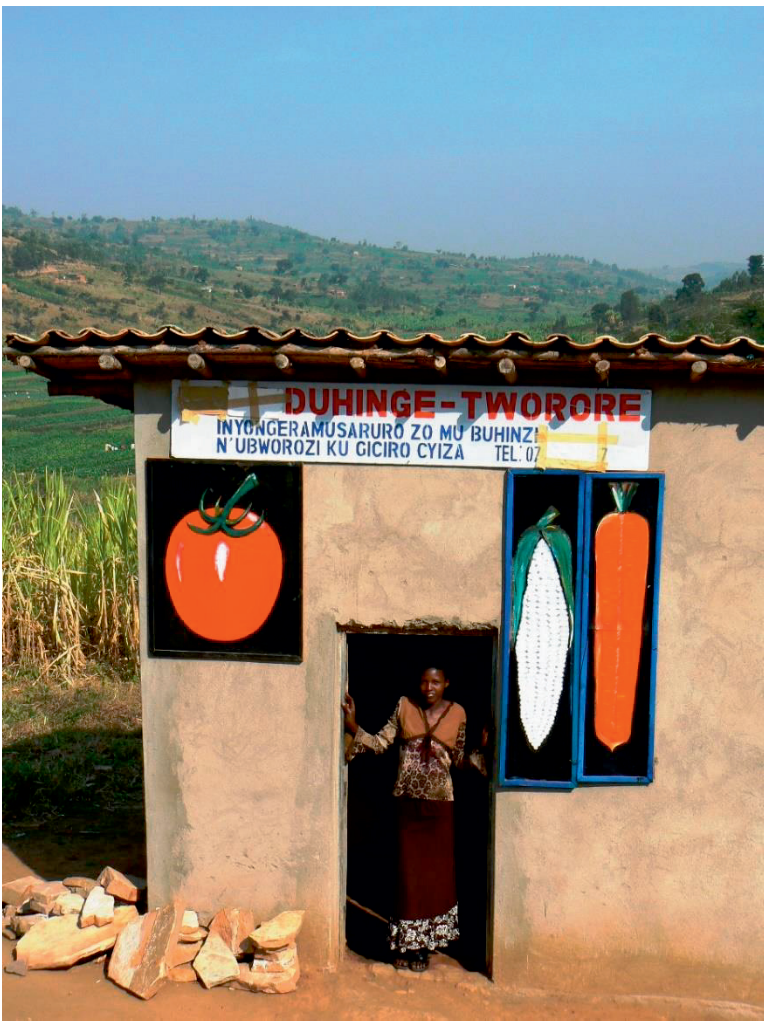
Data on the evolution of cereal yield rates over the entire 1961–2014 period have been used for dividing the 49 countries into two main groups, subdivided into four and two classes. In the first group of countries, the yields per hectare increased, in different degrees. The second group includes one class of countries with stagnating yields since 1961, and one that at present has lower yields than in 1961. Here, any increase in food production has come from area expansion.

All countries have been categorized on the basis of socio-economic as well as agro-ecological conditions. The comparison of classes enables the identification of stimuli and obstacles for agricultural development. The role of policies for change has been studied as well, with a view to identifying policies that can help accelerate agricultural development in Africa. The dominance of poor soils, often combined with difficult climates, explains in part why agricultural development has been slow. In many places, the low average natural production conditions have resulted in a population density that is much too low to allow for a financially beneficial use of fertilizer and other external agricultural inputs. The high costs of transport and trade, and of food and labor, have seriously hindered agricultural development in many African countries. Market oriented production, for the national or the international market, did not become the driver for development, in contrast to countries with more suitable climates and better soils.

A hopeful tendency emerges from this study: African agricultural development is taking off in response to population growth, as is shown by the cereal yield and fertilizer use adoption trends in many countries. Three quarters of the African population lives in countries with positive yield growth rates, with some of them having reached Green Revolution growth rates. Policies and conditions are presented that enable accelerated yield growth, which is a matter of life and death for the last quarter of the population, which lives in countries with no significant or negative yield growth rates, but is also of vital importance for

countries with low productivity growth rates. The promotion of increased fertilizer use combined with integrated soil fertility management in rainfed agriculture has been identified as a first step towards achieving national food security and decreasing poverty. It will provide abundant and low cost food, allowing for cheaper labor, requirements for more economic growth and political stability on the continent. To become effective, these measures should become part of a larger policy package aiming for a rural development in which farmers, business people and governments are truly partners. Agricultural and broad economic development can only be furthered, if all of these stakeholders are unified in their efforts to bring down the costs of trade and transport and to develop a viable agricultural input and product market.

Keywords: cereal yield; fertilizer; rainfed agriculture; soil fertility; agro-ecology; socio-economics; agricultural policy; agriculture for development.



Acronymes

CAADP	Comprehensive Africa Agricultural Development Program
cap.	capita
CAR	Central African Republic
CBR	cost-benefit ratio
CO2	carbon dioxide
CV	coefficient of variation
DAP	di-ammonium phosphate
FSI	food security index
GDP	gross domestic product
GNI	gross national income
HDI	human development index
ISFM	integrated soil fertility management
K	potassium
KCl	potassium chloride
N	nitrogen
NGOs	non-governmental organizations
NPK	nitrogen, phosphorus and potassium
NPP	natural production potential
P	phosphorus
SA	Southern African
SRI	system of rice intensification
SSA	sub-Saharan Africa
TLI	trade logistics index
WA	Western African
WUE	water-use efficiency

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1. Introduction

1.1 Food-insecure Africa

The Green Revolution of the last century has bypassed Africa. Few are the countries where the use of external inputs such as fertilizer[1], improved seeds and pesticides has become common practice. At present[2], the average world fertilizer use on cropland is about 135 kg/ha/year, while the average use by farmers in sub-Saharan Africa (SSA) is barely 15 kg/ha/year. The resulting food insecurity and rural poverty are reasons to question the efficacy of agriculture-related policies.

While most African economies rely heavily on agriculture (Ciceri & Allanore, 2018), food insecurity is more widespread in Africa than anywhere else in the world (e.g. Rakotoarisoa et al., 2011). The 2017 Global Food Security Index (The Economist, 2017), providing data on 113 countries, classified 80% of African countries[3] as countries where food security “needs improvement”. The performance of about 14% of the countries was classified as “moderate”, and that of the remaining countries as “good”. Asia and Latin America were on average between the moderate and good performance, and in general Latin America was more food-secure than Asia. European, North American and Oceanian countries are nearly all in the “best performance” class.

Early starvation is a real risk in a number of African countries, both for human beings and animals.

[1] “Fertilizer” means chemical fertilizer in this text; “manure” and “compost” are used for sources of nutrients from animal and plant origin.
[2] The “present” is 2014, the last year for which rather complete agricultural data are available for the world and separate countries at the World Bank and FAO.
[3] Including those for which no data are available.

Yield stagnation in Africa and yield increases elsewhere have resulted in a growing divide, evinced by differences in the available kilo-calories (kcal) per person (Roser & Ritchie, 2017) and in the number of undernourished in relation to the population. Cereal import dependency is also much larger in Africa, resulting in large food trade bills for African countries (Rakotoarisoa et al. 2011).

Africa has millions of displaced persons. Only a small part of them live outside the continent.

1.2 The Green Revolution bypassed Africa

In the world as a whole, the average food production per person started to increase in the early sixties (Roser & Ritchie, 2017), as the so-called "Green Revolution" unfolded. More and more farmers in developing countries started adopting the use of external inputs – improved crop varieties, chemical fertilizer and pesticides. De Wit (1986) showed that in the rich Western world, the adoption of Green Revolution technology caused a sharp increase in crop yields. Without the external inputs, under the pressure of increasing demand, the average annual cereal yield increases with about 7 kg/ha. The general adoption of external inputs, like in North America and Europe, resulted into an average annual cereal yield increase of about 75 kg/ha/year. An increase in nitrogen fertilizer use per ha directly results in more protein output (Lassaletta et al., 2014). In Africa, however, countries which have adopted fertilizer use are rare, and consequently the average annual yield increase on the continent as a whole has been barely 10 kg/ha/year from the 1950s to the end of the 1990s (Breman, 1998). Latin America and Asia had annual yield increments of almost 30 kg/ha/year; here the score remained in the intermediate range, due to large differences between countries in the extent to which external inputs are being used (De Wit, 1986; Grassini et al., 2013).

Bad transport conditions in many African countries have hampered agricultural development. In a world with liberalized markets, high input prices prevent African agricultural products from being competitive.

1.3 Ineffective policies

Agricultural development analyses show that past and present national policies as well as those of governmental and non-governmental development partners were not effective in pulling the African population out of poverty and assuring food security. The lack of food security is the result of both low productivity and of limited socio-economic development (e.g. Pieri, 1989; Breman & Debrah, 2003; Nin-Pratt et al., 2011; Rakotoarisoa et al. 2011; Mutsaers & Kleene, 2015; Benin, 2016; Koning, 2017; Ciceri & Allanore, 2018). Examples of mistakes and problems mentioned are: a general neglect of agriculture by policy makers who privilege industrialization, the importation of cheap food outcompeting local farmers, the replacing of manure by fertilizer instead of combining them, the neglect of poor soils, and counterproductive policies. Other more general problems include corruption or, what Koning (2017) calls “rivalling ethnic-clientelist networks”, weak institutions, poor infrastructure, unequal trade agreements, market failure, credit constraints, and inappropriate development projects.

An effort to effect change, from the side of African leaders, has been the creation of the African Union in 2002, which has led to structured collaboration among African countries. Through the Comprehensive Africa Agricultural Development Program (CAADP; https://au.int/en/caadp), the countries aim for acceleration of agricultural growth and transformation. Analyzing the effects of the program, IFPRI observes that the funding and implementation of Africa’s agricultural development strategy leave much to be desired, and points to large differences between the member states (Benin, 2016). The governmental partners in particular are increasingly eager to make their support more effective, spurred on by the fear of a growing problem of refugees and migrants.

African soils are amongst the poorest in the world. It is strange, therefore, that governments and donors concentrate almost exclusively on investing in irrigated agriculture. The average African fertilizer use is only one-tenth of the world average; therefore crop yields are very low.

1.4 Highly heterogeneous conditions

Benin (2016) attributes the limited policy effects in Africa to the large variation in socio-demographic, agro-ecological, economic and market factors. He distinguishes 17 unique farming systems, and 543 agricultural productivity zones. And he suggests that the opportunities for a Green Revolution similar to the Asian one[4] are limited; only in Ethiopia, Kenya, Uganda and Malawi such an approach would have a good chance of succeeding. Elsewhere, region-specific Green Revolution technologies will have to be developed, requiring significant investments in research and development, and the opening up of new output markets. Giller et al. (2011) and Dixon et al. (2018) have come to a similar conclusion: African farming systems are highly heterogeneous and single solutions for improving farm productivity do not exist.

Besides an agro-ecological heterogeneity, in Africa we find a socio-economic heterogeneity, resulting from differences in history and geographical position (Acemoglu & Robinson, 2012; Collier, 2008). Collier (2008) stresses the differences between countries with ports on the coast and land-locked ones, and distinguishes among the latter those with good and with bad neighbors. An example of a bad neighbor is one not offering significant market access for the land-locked country.

Africa is indeed a very heterogeneous continent.

[4] Having cereal yield increase through fertilizer as a key component.

1.5 Questionable recommendations

Surveying the numerous failed policies mentioned in section 1.3, and the variety of agro-ecological zones and socio-economic conditions mentioned in section 1.4, one may be tempted to conclude that no silver bullet solution exists. This conclusion is discouraging for African farmers and decision makers. It will take a lot of time to develop a multitude of solutions, tailored to the need of regions and specific groups of farmers. At the same time, there are pressing reasons for making haste:

- The African population is growing fast; unless soil nutrient losses are compensated, the already poor production potential will be impaired by soil nutrient mining; food insecurity and rural poverty threaten to increase (Buresh et al., 1997; Henao & Baanante, 2006).
- As Tittonell & Giller (2013) have shown, the large yield gaps in African agriculture can become poverty traps: further yield declines and soil nutrient mining need to be halted urgently.
- In many countries, it becomes increasingly difficult to expand the land area used for agriculture (Chamberlain et al., 2014), and the land still available has a lower production potential than land already under exploitation (Ciceri & Allanore, 2018).
- Exhausted and degraded tropical soils are difficult to restore (Morris et al., 2007), requiring large amounts of nutrients and soil amendments to rebuild soil reserves.

These reasons for urgent action in the meantime offer a hint for an alternative approach. Instead of developing a multitude of tailored solutions, national governments, donor countries and organizations could jointly[5] focus on a step-by-step elimination of key bottlenecks. The first thing to focus on would be soil fertility improvement, for the following reasons:

- Many of the numerous African agro-ecosystems are alike in that their natural production potential (NPP)[6] is (very) low, and generally determined to a higher degree by poor soils than by low rainfall (Buringh & van Heemst, 1977; Breman, 2015), while parts of the regions with high soil fertility are heavily populated and have depleted soils due to insufficient fertilizer use[7].
- It is mainly because of Africa’s low production potential that the Green Revolution bypassed the continent (Breman & Debrah, 2003).
- McArthur & McCord (2017) predict “strong potential yield and growth effects resulting from policy efforts to support adoption of a Green Revolution-type package of complementary inputs in economies with low agricultural productivity and a large share of the labor force still in agriculture”.

[5] E.g. in the framework of CAADP
[6] Production without external inputs or irrigation.
[7] A good illustration is the Western Rift, with Uganda, Rwanda, Burundi, Eastern Tanzania and Malawi. See, for example King & Yi Wang, 2017. Almost all countries with fertile soils but without high population pressure, are found in the zone of the tropical rainforest, where most of the land has not yet been converted into cropland.

- Fertilizer use is the best means for improving poor soils and tackling the problem of natural low production potential (e.g. Nin-Pratt et al., 2011; Rakotoarisoa, M.A., et al., 2011; Benin, 2016; McArthur & McCord, 2017; Ciceri & Allanore, 2018).
- Carr (2017) and Ricker-Gilbert et al (2014) observed in Malawi that the size of the vulnerable population is inversely correlated with the amount of fertilizer used per capita.

1.6 Fertilizer for triggering agricultural development acceleration

Thus, there is a good case to be made for using fertilizer as a means for triggering accelerated agricultural development in Africa. This study provides extra arguments supporting the decision of the African heads of state to declare fertilizer a strategic commodity for an African Green Revolution (African Union, 2007). The environmental risks of using fertilizers are recognized (Alberda et al., 1992; Breman, 2002; Nosengo 2003; Bouwman et al., 2017), but at the same time the warning voiced by Smaling et al. (2006) is heeded that, in the face of the African population density, not using fertilizer will destroy the environment by overexploitation of natural resources. Besides, the risks related to fertilizer use can be well controlled by avoiding misuse and by providing a context of integrated soil fertility management (ISFM[8]; Breman, 2002; IFDC, 2005; Wopereis et al., 2008; Bationo et al., 2011b; Bationo et al., 2012).

Some economists maintain that Africa should focus on developing alternative sources of income as the basis for socio-economic development, if the natural resources seem too poor to sustain an economy based on agriculture. However, for many countries it has been impossible to industrialize without agricultural development as an intermediate step (Vlasblom, 2013). More importantly, without agricultural development, insufficient numbers of people are expected to find decent work and an income high enough to become food-secure (Koning, 2017). The World Bank (2007) stressed that GDP (gross domestic product) growth originating in agriculture is at least twice as effective in reducing poverty as GDP growth originating outside agriculture. Besides, “Agriculture, including agribusiness, is projected to be a US$1 trillion USD industry in sub-Saharan Africa by 2030 (World Bank 2013)” stated van Rooyen (2014), at the start of an article in which he mentions that more than 5 million ha of African land is being leased by foreign investors. The fact that foreign and local land grabbing is rife, shows that land use is rewarding (Batterbury & Ndi, 2018; Jayne & Muyanga, 2018).

One may even question if the large heterogeneity of African agro-ecosystems is a real impediment for an African Green Revolution if soil fertility improvement is chosen as the main line of approach. Even in fields widely varying in terms of soil fertility (Kihara et al., 2016; Njoroge et al., 2017), balanced fertilizer use

[8] Integrated soil fertility management (ISFM) combines the care of crops with soil care, using fertilizer to nourish the crops and soil amendments to improve and maintain soil health.

provides options to maintain crop yields at high levels (Njoroge et al. 2019). Some of the scientists who stress the need to develop a multitude of regionally tailored solutions (Giller et al., 2011) have developed an approach which, they believe, can contribute to the design of a "uniquely African green revolution" (Tittonell et al., 2011; Vanlauwe et al., 2014). The mapping of African soils is making rapid progress (e.g. Hengl et al., 2017), and the effects of fertilizer use on many crops have already been studied, including the use in an ISFM context. The proceedings of a symposium about Africa's Green Revolution treat more than 200 agronomic experiments, regarding more than 50 crop species (Bationo et al., 2011a). Cereals receive by far the most attention (45%), followed by legumes (30%) and vegetables (10%). Chauvin et al. (2012), describing the consumption pattern in sub-Saharan Africa, found that roughly 45, 35 and 10 percent of African plant foods were cereals, vegetables plus fruit and legumes; and they mention that the consumption of cereals is still increasing. That is why, in this study, cereal yields will be used as the main indicator for an African "agriculture for development" (World Bank, 2007) triggered by increased fertilizer use. This, of course, by no means implies that the productivity of other crops should not be improved as well.

Maize without and with fertilizer during a drought (respectively in the foreground and background). The growing season rainfall was only 220 mm, instead of the normal 400 mm.

2. APPROACH

2.1 Goal

The objective of this study is to determine what can be done to accelerate agricultural development in Africa, and thereby to further food security and socio-economic development. Increasing crop yield is proposed as the key step to be made, and (balanced) fertilizer use as the required means.

For measuring agricultural development, cereal yield growth and fertilizer use are chosen as indicators. Fertilizer – the *primus inter pares* among external inputs – is critically important in Africa, where soils are generally poor. This is borne out by analyses showing a clear relation between yield and fertilizer doses, taking into account rainfall and its variability. African countries will be classified on the basis of the degree of yield growth, in order to identify other key agro-ecological and socio-economic parameters differentiating the classes. These characteristics are then viewed in relation to bottlenecks for change and present policies, in order to identify conditions and policies for yield growth acceleration. It will be shown that significant increase of fertilizer use is a *conditio sine qua non* for improved food security and for making agriculture contribute to socio-economic development.

2.2 Countries studied

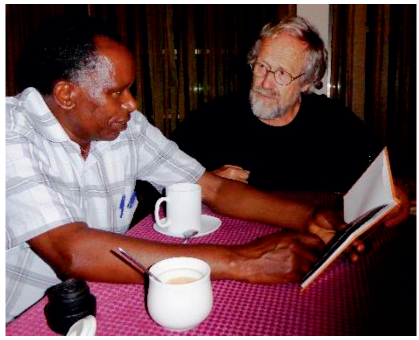
Data regarding 18 Western[1] African countries (Table 1) and 9 countries from Southern Africa (Table 2) have been employed to improve insight in the role of soil and climate, rainfall in particular, as sources of food insecurity and as bottlenecks for development (sections 3.1.1, 3.1.2 and 3.3.1). The selected 18 countries are on three dry–wet transects, two in West and one in Central Africa: from the Sahara desert to Liberia and Sierra Leone, countries with very high and very intensive rainfall; and from the Sahara to the Central African Republic (CAR) and Cameroon, countries with very high rainfall. The Southern African countries cover a transect from the dry Namibian coast to humid Malawi and Mozambique.

In the other sections of chapter 3, treating linkages between yield growth rates on the one hand and demographic, socio-economic and policy conditions on the other, data from as many countries as possible have been used. However, with the exception of Madagascar, islands have been neglected in view of their peculiarities. For 49 countries in total the yield growth rate from 1961 till 2014 has been calculated, but, because of a lack of accessible data, in most cases it was impossible to study the relation with all the variables mentioned above. For the analyses presented in chapter 3, data from a varying number of countries were used; in each case the countries included will be mentioned.

[1] Western Africa: West Africa plus Chad, Cameroon and Central Africa.

2.3 Data use and sources

Given the huge amount of literature about African agriculture, it is rather difficult to make objective choices regarding the information to be used. The difficulty is compounded by the poor quality of many of the data, such as national-level statistics, which reflects the limited capacity and weak institutions of poor countries (Jerven, 2013). Open-access data from renowned institutes have been used as much as possible.



The authors at work in the field. First, second and third row, respectively Henk Breman, Tom Schut, and No’am Seligman.

The evolution of the total cereal production has been studied for all mainland countries and Madagascar for the period 1961–2014. Where production increased, it was determined to which extent the increase was the result of area expansion and/or productivity increase. Data on fertilizer use and annual rainfall were added for the 27 countries mentioned at the start of section 2.2, for the period 1981–2014. The total fertilizer use per hectare was explored; cereals turned out to receive just above 60% of it (FAO, 2006). With the exception of rainfall data, open-access data of the World Bank (https://data.worldbank.org/) and FAO (www.fao.org/statistics) were used. Economic data, such as the gross domestic product (GDP), gross national income (GNI) and agricultural contribution to the GDP, the trade logistics index (TLI), as well as data on the degree of urbanization and the CO_2 emission per capita, are from the World Bank as well. Figures relating to land use (arable land; rangeland; irrigated land) are FAO data, but data on the availability of arable land per country per capita are again from the World Bank.

Rainfall data have been obtained from CHIRPS 2.0 (Funk et al., 2015). The average annual rainfall for agricultural zones was calculated for each country, excluding zones with < 300 mm/year. This isohyet has been chosen in view of the fact that in the Sahel, the region with the most extreme potential evaporation, it separates the zone where water is the most limiting factor for plant growth (< 300 mm/year) from the zone where nutrients are more limiting (> 300 mm; Penning de Vries & Djitéye, 1983).

Relationships between rainfall and yields were evaluated for the countries on the three dry–wet transects described in section 2.2, and further differentiated according to fertilizer use. Linear, or, when significant, segmented regression lines were fitted, using the standard and the segmented regression toolbox in R (v 3.5) and R studio (https://cran.r-project.org). A mixed linear regression model was used to evaluate average yield responses to annual rainfall in interaction with fertilizer application and region, with a year as random factor (figures 1 and 2). The intensity and frequency of droughts per climate zone (tables 1 and 2) have been calculated by using 33 years of rainfall data from 27 countries.

Supplementary climate data, on potential evapotranspiration and aridity, that are used together with average rainfall in subsection 3.3.1 and its tables 1 and 2, were obtained from CGIAR's consortium for special indicators (https://cgiarcsi.community/data/global-aridity-and-pet-database/).

Soil data were derived from ISRIC's soil property maps for Africa (Hengl. et al 2015;2017; http://www.isric.org/content/new-generation-soilproperty-maps-Africa). Buringh and van Heemst (1977) have been consulted for the estimation of the natural production potential (NPP) per country. They estimated it for all continents, distinguishing four series of broad land units. Each series has its own natural production potential, the average yield obtained without manure, fertilizer, or irrigation, expressed in cereal yield. A transparent layover of Africa's map with country borders allowed an estimation of the NPP per country.

Soil and climate data were used to characterize the agro-ecological conditions of countries (tables 1 and 2). They determine if special attention and/or investments are required to ensure that fertilizer use is effective (enough). The climate factors considered are rainfall and the risk of droughts and extreme aridity, due to very high potential evapotranspiration in relation to rainfall. The soil factors considered are extreme pH values (pH $\geq$ 8 for certain soils in countries with low rainfall, or pH $\leq$ 4 in countries with very high and very intensive rainfall), and low storage capacity for water and/or nutrients.

As mentioned above, the World Bank has been the main source of data regarding socio-economic conditions (used in section 3.2, subsection 3.3.3, and in tables in the annex). However, the food security index (FSI) of countries, indicating food availability as well as accessibility, was obtained from The Economist Intelligence Unit Limited (https://foodsecurityindex.eiu.com); and the human development index (HDI)[2] was obtained from UNDP (hdr.undp.org/en/content/human-development-index-hdi). As stated above, both agro-ecological and socio-economic parameters help identifying (combinations of) conditions which are positively or negatively linked with yield growth classes (subsections 3.3.1 and 3.3.3). There is a risk that the interaction between variables results in co-variation without real causality. However, the study of McArthur & McCord (2017) about agricultural inputs and their effects in economic development shows that this risk is limited.

Special attention is paid to population density and the derived availability of arable land per capita (section 3.2), as a factor that is known to be positively correlated with fertilizer use adoption (Breman & Debrah, 2003; Ricker-Gilbert, 2014; Nin-Pratt, 2016). Also the financial benefits of fertilizer use receive particular consideration (subsection 3.3.2), as a factor that can be influenced by the efficiency of farmers (e.g. Snapp et al., 2010) and policies (prices). The fertilizer prices were derived from AfricaFertilizer.org (https://africafertilizer.org/national/) and the cereal prices were derived from USDA World Markets and Trade reports (https://www.fas.usda.gov/data/grain-world-markets-and-trade). For estimations of farm-gate prices we relied on agricultural economy experts from the different countries.

[2] "The Human Development Index is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living. The HDI was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone. The HDI can be used to question national policy choices." (UNDP)

3. Results

In spite of the overall negative image of African agriculture, it is worthwhile to realize that crop production is increasing and that food security is improving on the continent. In 2014, the African population of more than 1.1 billion people is almost 3.9 times the population of the early sixties of the last century. In the same period, the cereal production increased 4.1 times. And indeed, fertilizer use per hectare, now at 12% of the world average, is increasing too: two decades ago it was only 10%. This two percent increase represents a yearly extra use of 60,000 MT of fertilizer for the continent. Below, the increasing fertilizer use is analyzed, and ways to accelerate its adoption are explored.

3.1 Increasing fertilizer use and yields

3.1.1 Soil fertility more limiting than rainfall

Figures 1 and 2 present national annual data regarding cereal yields during the period 1981–2014 for the 18 continental Western and the 9 continental Southern African countries. Figures 1a and 1b present these yields in relation to the average annual rainfall per country and per year, distinguishing in Figure 1a the two regions, and in Figure 1b very limited and moderate fertilizer use. In several countries the annual rainfall was below the critical 300 mm limit (Penning de Vries & Djitéye, 1983) in some years due to droughts.

Figure 1 shows an extreme variation as far as the yield-rainfall relationship is concerned. Only at about 250 mm of annual rainfall yields above 1,000 kg/ha can be obtained, and at 500 mm/year yields of 4,000 kg/ha are possible. However, below 1,500 mm/year much more high yields were reported than above 1,500 mm/year; the average yield with high rainfall is only about 1,250 kg/ha.

Maize during a drought (220 mm of rain during the growing season, instead of the normal 400 mm). a) Unfertilized poor soil. b) A high dose of fertilizer on that poor soil. c) Fertilizer use in an ISFM context on that poor soil. The maize developed equally well in cases b) and c), thanks to fertilizer use. However, in case b) the crop ran out of water and died. In case c), thanks to ISFM, the soil organic matter content was high enough to keep the rainwater in the root zone of the crop.

Chapter 3

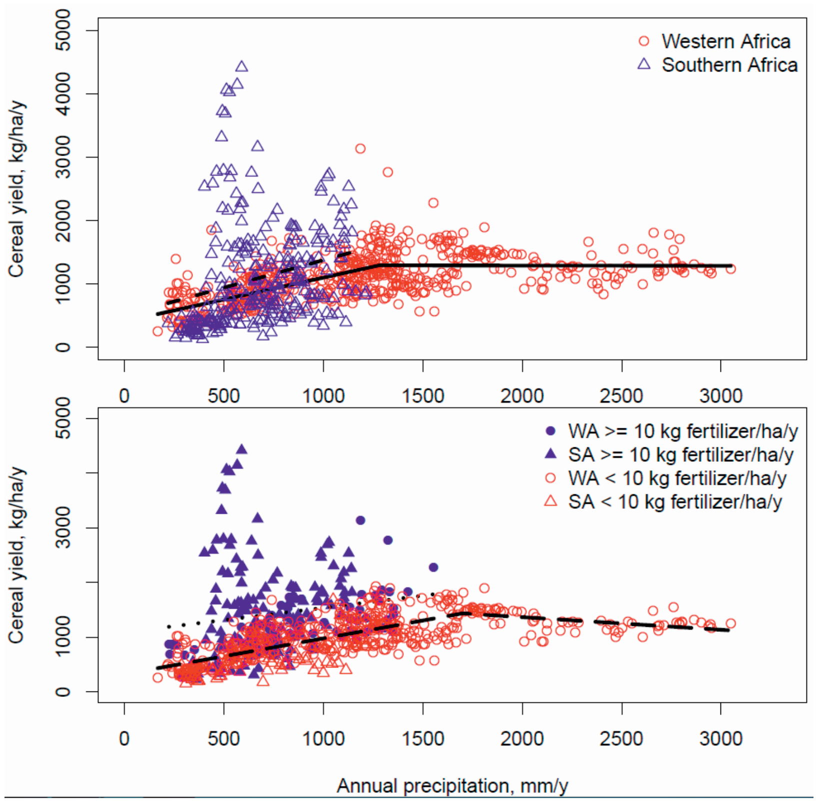


Figure 1 Panel A. Average national annual cereal yields in relation to average national annual rainfall of all continental Western African (WA) and Southern African (SA) countries for the period 1981–2014 with fitted regression lines for SA (dashed) and WA (solid).

Panel B. Average national annual cereal yields in relation to average national annual rainfall of continental Western and Southern African countries for the period 1981–2014 with fitted regression lines, distinguishing absent or very low fertilizer use (dashed line) and moderate use (dotted line).

A first explanation for the extreme variation presents itself when figures 1a and 1b are compared: the similarity in distribution of blue and red colored points illustrates that moderate fertilizer use is common in Southern Africa, whereas it is not in Western Africa. The curves representing the average relationship between yield and rainfall for the two regions (Figure 1a) or the two dose groups (Figure 1b), make clear that the relation between yield and rainfall is rather weak and exists only for rainfall below about 1,250 mm/year, increasing in this range with 69 kg (WA) or 87 (SA) kg yield per 100 mm of rainfall.

Figure 2, presenting the average national annual cereal yields in relation to the fertilizer doses applied, illustrates again that moderate fertilizer use is mainly limited to Southern Africa. Years with more than a national average of 15 kg/ha of fertilizer use on cropland are rare in Western Africa.

In both regions, yields increase by 21–22 kg/ha with every extra kg of fertilizer applied. Onwards from a fertilizer dose of 100 kg/ha, the yield still increases proportionally with the amount of fertilizer used. When considering the average trends shown in figures 1 and 2 for yield-rainfall and yield-fertilizer relationships, it becomes clear that poor soils limit African agricultural development much more than limited rainfall. Average yields in high-rainfall countries are about 1,250 kg/ha. Yields up to 4,000 kg/ha were reported at a maximum dose of only 100 kg/ha of fertilizer, of which only a part was used on cereals (FAO, 2006). The part of the national fertilizer use which benefits cereals also varies; it is on average 60% (section 2.3). This partly explains the variation of the yields as well. Using enough fertilizer enables much higher yields; van Ittersum et al. (2016) identify large yield gaps for current rainfed cereals in Africa, up to 10,000 kg/ha/year and higher in specific high-potential regions.

Food supply is not assured by sufficiently high yields alone; the stability of these yields is also important. Climate does play a role here, as variability in rainfall affects the yields. This variability is less in Western Africa than in Southern Africa. In Southern Africa, the average annual rainfall increases from 300 to 1,100 mm, and its coefficient of variation (CV) decreases from 0.25 to 0.13, from the driest part of the transect (Namibia and the Western part of South Africa) to the wettest part (Malawi and Mozambique), indicating that rainfall not only increases but also becomes more reliable and less variable from year to year. On a comparable rainfall transect in Western Africa[1] the CV decreases from 0.17 to 0.09; and when continuing to regions with 2,700 mm of annual rainfall, it decreases further to 0.07.

In fact, the yield effects of rainfall variability are limited as long as nutrient limitations are more important. This is generally the case, except in the driest part of the transects where yields fail completely in the driest years, with the growing season becoming too short for crops to reach full maturity.

The effects of rainfall variability on yields partly depend on the depth of soil wetting by rain. The thicker the humidified soil layer, the more nutrients are dissolved and can be absorbed by the crop. The effect is, however, far from proportional to the rainfall variability, as the soil nutrient content decreases rapidly with soil depth. Therefore, the effect of rainfall variability on yield variability increases with soil fertility and is presumably further amplified by

[1] Many of the Sahelian countries in Western Africa went through a drought of long duration in the study period. Most years between 1970 and 2000 had rainfall below the 100-year average (L'Hôte et al., 2002); the average rainfall without this drought would have been about 100 mm/y higher than the observed average of the study period.

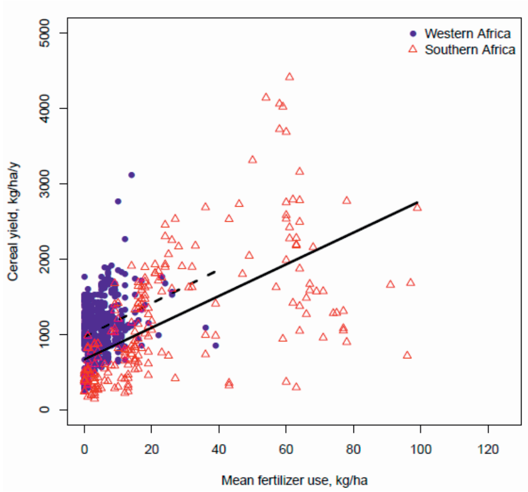


Figure 2 Average national annual cereal yields in relation to average national annual fertilizer use of all continental Western and Southern African countries for the period 1981–2014.

fertilizer use. This is a third factor explaining the extreme variation observed in figures 1 and 2. The two countries with negligible fertilizer use in Southern Africa, Namibia and Mozambique, have CV values for yields of respectively 0.27 and 0.32. The average rainfall of the two countries is 427 and 957 mm/y and the NPP < 0.5 and 1.0-1.25 t/ha respectively. For the eight Western African countries with negligible fertilizer use, CAR, Chad, Guinea, Guinea Bissau, Liberia, Niger, Sierra Leone and Togo, falling into the NPP classes of < 0.5, 0.75-1.0, 1.0-1.25 and 1.25-1.5 t/ha, the yield CV per class are 0.16, 0.20, 0.22 and 0.26 respectively. On average, yield variability decreases with increasing rainfall, as shown above, but this effect is here disturbed by the higher natural soil fertility in countries with a high NPP.

Thus, yield variability is also increased by fertilizer use. The yield CV for the Western African region is with 0.22 lower than the 0.32 for Southern Africa. The average fertilizer use over the entire 33 years period has been respectively 4 and 24 kg/ha/year. South Africa, the country with the highest fertilizer use of all 27 countries (65 kg/ha), has also the highest yield CV: 0.38!

The yield CV will also vary with fertilizer use efficiency. The latter is often low and very variable, because of the recent fertilizer adoption in many countries. Besides the limited knowledge and experience of farmers, the natural poorness of soils and/or soil depletion explain the low initial fertilizer use efficiency. Poor soils require a balanced supply of a number of nutrients, while fertilizer, at least during introduction and early adoption, typically provides N (nitrogen) , or N with P (phosphorus), but seldom a balanced mixture of all required nutrients. The supplied nutrients will partly go to exhausted soil pools of in particular N, P and potassium (K), strongly delaying their availability to the crop. Further, the competition between crops and soil organisms for fertilizer nutrients is presumably stronger on depleted soils. These factors together are causing low fertilizer recovery and use efficiency. In time, when soil pools are restored (Wolf et al 1987; Janssen et al. 1987) and the nutrient content of the soil organic matter is improved, the efficiency increases (Fofana et al., 2008).

3.1.2 The evolution of fertilizer use and cereal yield

Both of our agricultural development indicators, fertilizer use and cereal yield, increase over the period 1981–2014. Fertilizer use increased only slightly, from an average of 3 to 6 kg/ha and from 25 to 29 kg/ha from the first 5 years (1981-1985) to the last 5 years (2010-2014) in Western Africa and Southern Africa respectively. The cereal yields, over the same period, increased from 900 to 1,350 kg/ha in Western Africa and from 980 to 1,410 kg/ha in Southern Africa.

Fertlizer use and cereal yield not only increased; the increase accelerated. The difference between the average of the first 5 years and the overall 33 years average for each region was significantly lower than the difference between the overall average and the average of the last 5 years. During the latter period, many countries seemed to have transitioned from agriculture based on internal inputs to more intensive production, using external inputs.

In Figure 3, the cereal yield increases in the USA, Asia and Africa, as presented by De Wit (1986), are combined with yield data from Western and Southern Africa. For Asia, the data up to 1980 from the Wit (1986) have been combined with World Bank data from 1980 onwards. Around 1950, when in the United States external inputs such as fertilizers, improved seeds and pesticides started to be generally adopted, the average annual yield increase of cereals went from 3 to 50 kg/ha. Better control over production factors doubled this average annual growth rate after 1980 to 100 kg/ha/year. Local adoption of Green Revolution technology in Asia resulted in a growth rate of 25 kg/ha/year from 1955 to 1980, while the growth rates in Africa at 10 kg/ha remained very close to the growth rate that can be achieved without external inputs. Only South Africa and Egypt adopted external inputs at a significant scale.

In Asia the use of external inputs became more general in the early 1980s, and a cereal yield growth rate of 60 kg/ha/year was reached. In Western and Southern Africa, the average growth rate doubled from 10 to 20 kg/ha/year in the second half of the 1990s. These growth rates are still far below their potential; in numerous countries fertilizer use has remained insignificant.

Positive exceptions in Western Africa are Ghana, Ivory Coast and Mali. During the second half of the 33-year period, they reached yield growth rates above 30 kg/ha/year. In the last decade, rates above 40 kg/ha/year have been reported. Their fertilizer use during the last five years was with 15 kg/ha/year three times the average of the entire period. Mauritania also shows a relatively rapid and increasing growth rate, but recent data on the use of fertilizers are not available. Other countries showed negative to slightly positive yield growth rates.

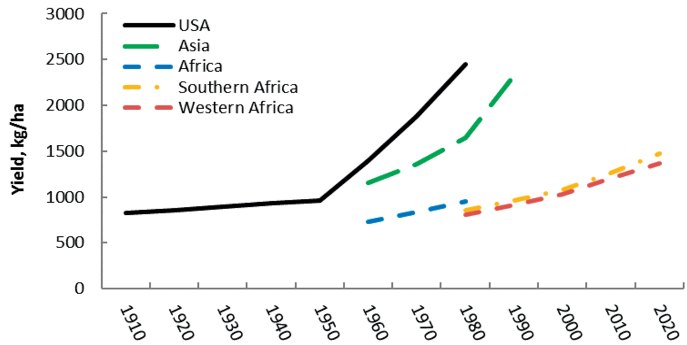


Figure 3 The evolution of African cereal yields compared to those of Asia and the USA. Curves from the USA, Asia and Africa as a whole: De Wit (1986)[2].

In Southern Africa more variation was observed. South African farmers adopted the Green Revolution with external inputs and technologies long ago. The cereal yields are increasing with almost 80 kg/ha/year over the entire period, while fertilizer use is decreasing: input use is becoming more efficient! During the second half of the 33-year period, Zambia and Malawi reached an average growth rate of 50 kg/ha/year, as high as Asian countries between 1960 and 1980 (Figure 3). Their average fertilizer use during the last 5 years reached 35 kg/ha/year. Zimbabwe's yield growth rate, which stood at 35 kg/ha/year in the 1980s, collapsed due to the socio-economic crisis. Fertilizer use became negligible and average yields at the end of the period were more than 500 kg/ha less than at the start, which prompted a rapid conversion of forest into cropland (Chagumaira et al., 2015).

Exceptional is the situation in Botswana, Lesotho and Eswatini[3], where significant amounts of fertilizer were used without clear yield increments (see section 4.1). Yields varied strongly and showed a boost, in Lesotho and Eswatini, during the second half of the 1990s. But the average yield in 2013 was almost 100 kg/ha lower than in 1981.

[2] Recent research show that, indeed, yield growth is often linear. However, the strong yield increases shown in Figure 3 for the United States and Asia, as well as those in Europe and other countries where high doses of external inputs are used, are reaching plateaus, or even start turning into yield decreases (Grassini et al., 2013).
[3] Formerly called Swaziland.

3.1.3 Growth rate of yields per country

Countries were divided in two groups with six subclasses, on the basis of the overall yield growth rate tendencies that were observed in spite of (large) annual yield fluctuations (Figure 4). Group A, covering classes 1, 2, 3 and 4, shows an effective yield growth over the entire period or over the last 15 years, with growth rates becoming more limited going from class 1 to 4. Group B shows for class 5 a stagnating cereal yield growth rate, and for class 6 a yield decrease.

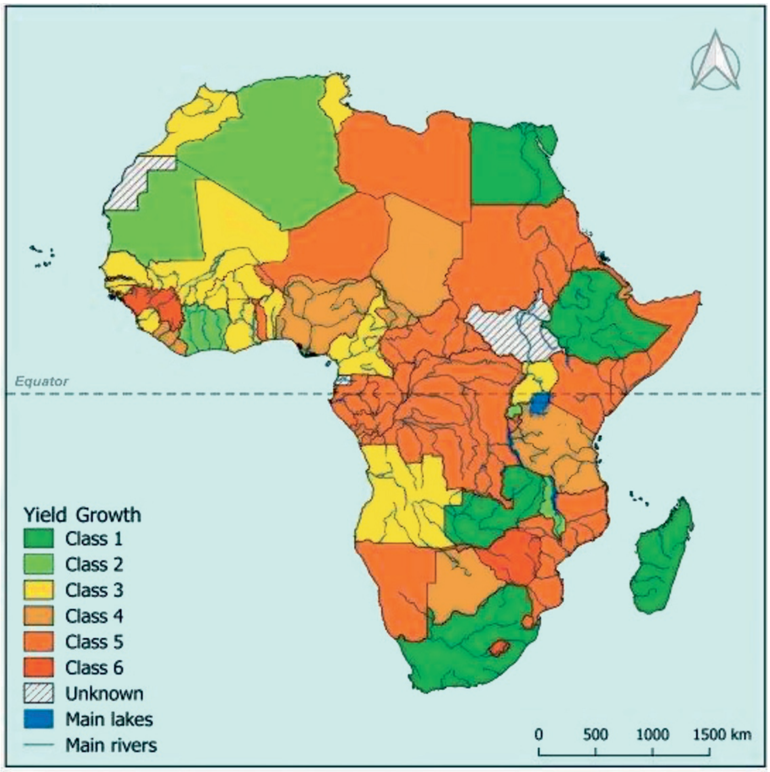


Figure 4 Countries classified in six classes based on the average annual yield change over the entire 1961–2014 period and the last 15 years.

Class 1 countries have an average annual growth rate of cereal yields of at least 70 kg/ha for the entire period, or at least for the last 15 years; Green Revolution technologies appear to have been adopted. Class 2 countries show an increasing rate of growth for cereal yields, at a rate which averages 40 to 70 kg/ha/year for the last 15 year. For class 3 countries, the average growth rate is slower, but reaches values of between 20 and 40 kg/ha/year during the entire period, or over the last 15 years,. Class 4 countries also show a tendency towards yield increases, but the the average growth rate has been slightly more than 10 kg/ha/year only for the last 15 years.

Countries in class 5 have stagnating yields or a slight tendency towards yield growth for certain periods (Eswatini and Togo), but these growth rates are too low to expect more than negligible use of Green Revolution tools, while fertilizer use does not significantly increase. The tendency for class 6 countries is one of yield decrease since 1961, in spite of the fact that the countries may have known (much) higher yields, as Zimbabwe has.

The class 5 countries dominate the map of Africa as far as the total area is concerned, but class 3 countries are the most numerous (Figure 4). Yield growth characteristics of SSA as a whole are also those of class 3. However, more important than the area or number of countries is the population that has to be nourished. The population of countries with decreasing yields represent 3% of the total of 1,135 million people living at the end of the observation period in the countries shown in Figure 4. The populations of the class 5 countries comprise 23% of the total African population. In other words, about one quarter of Africans live in countries with stagnating or decreasing cereal yields, and three quarters live in countries with accelerating yield growth or in countries where agriculture has already reached Green Revolution growth rates.

3.2 Yield growth, population density and fertilizer use

Population density was identified as an important driver for the adoption of fertilizer use, and thereby for yield increase (section 2.3). The annual yield growth per country was plotted against the availability of arable land per capita (Figure 5). This figure illustrates more quantitatively than Figure 3 the acceleration of yield growth that took place in group A countries in contrast to group B countries.

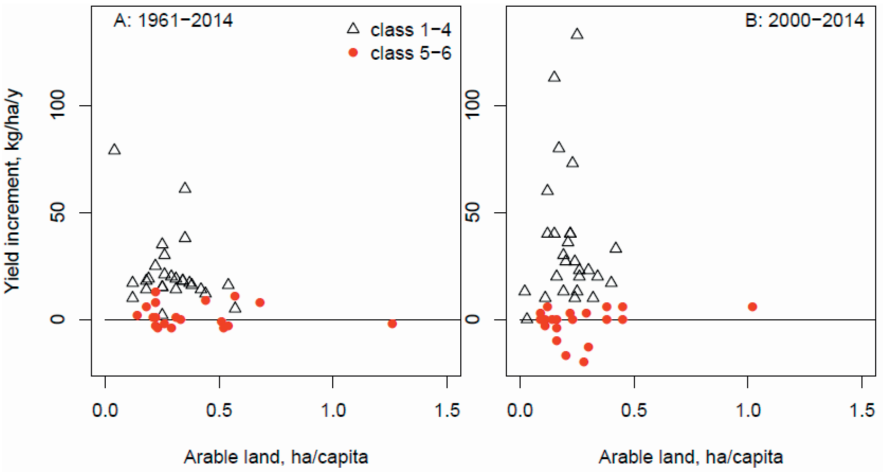


Figure 5 Average annual yield growth per country in relation to the availability of arable land per capita for 1961-2014 (panel A) and 2000-2014 (Panel B), differentiating between countries in yield growth classes 1–4 (group A) and 5–6 (group B).

In spite of the strong decrease of arable land per capita (cap.) for the 19 countries in classes 5 and 6, the yield growth observations for the last 15 years (Fig. 5b) are at the same level as those for the entire period (Fig. 5a), or around zero growth. For the 27 countries in classes 1–4, with decreasing arable land per capita, a clear tendency of yield growth exists, becoming even more marked during the last 15 years of the time series. In other words, yield increments rates accelerated for these countries.

Egypt is an exceptional country in class 1, with a zero growth rate over the last 15 years and an average availability of arable land during that period of only 0.05 ha/cap. It has an average yield growth over the entire period of 79 kg/ha/year. During the last 15 years, yields remained constant at a high level of 7,200 kg/ha/year; the yield potential has been reached (Grassini et al., 2013).

The point of gravity of the class 1–4 countries moved from the average yield growth rate for the entire period of 25 kg/ha/year at 0.35 ha/cap. of arable land, to an average yield growth rate of 41 kg/ha/year at 0.22 ha/cap. over the last 15 years. For class 5 and 6 countries these values are 2 kg/ha/year at 0.54 ha/cap. and 2 kg/ha/year at 0.29 ha/cap. respectively. To indicate what these yield growth rates mean for improving African food security, we use FAO's standard of 250 kg/cap./year of cereals for covering the human energy requirement, and a population growth rate of 2.5%. The average yield growth rate of 41 kg/ha/year for the class 1–4 countries during the 2000–2014 period implies an annual increase of the cereal availability per capita of 41 x 0.22 or 9.0 kg.

The population growth requires an annual increase of 250 x 0.025 or 6.2 kg. In other words, if all arable land is used for producing cereals and all cereals are available for feeding the African population, the yield growth is more than keeping up so far with population growth, at least as far as energy requirements

A positive correlation exists for African countries between their population density and their agricultural development. The average number of births per woman for African countries varies from 6.5 in the poorest countries to 2.5 in the richest. By using agriculture for socio-economic development the population growth can be reduced.

are concerned. In Africa as a whole, the average yield growth rate is 30 kg/ha/year at an availability of arable land of 0.24 ha/cap. This implies an annual increase of the cereal availability per capita of 7.2 kg, more than the 6.2 kg/cap. required by population growth.

However, this calculation presupposes a distribution of the production of surplus countries among the people in countries with insufficient yield growth rates. Without this transfer from surplus countries, the cereal availability per capita is falling in class 4 countries by 2 kg/year, and in class 5 and 6 countries by more than 6 kg/year.

It is crucial to realize that the two groups differ not only in yield growth rates but also in fertilizer use. The average of fertilizer use for the class 1–4 countries over the last period is 43 kg/ha/year, and for the class 5 and 6 counrties 13 kg/ha/year.

3.3 Yield growth and other variables

One technological factor, fertilizer use, and one social factor, population density, *have been invoked to help understand the large yield growth rate differences* among African countries (Figure 4). The scattering of cereal yield and cereal yield growth values in figures 2 and 5 show that these two factors explain only part of the differences. The three following subsections evaluate selected agro-ecological and socio-economic factors that help identifying combinations of parameters which are linked with the yield growth classes.

3.3.1 Yield growth and agro-ecological conditions

Tables 1 and 2 present for countries on the Western and Southern Africa transects for the period 1981-2014 their yield growth class, their NPP group, and a rough indication of the risk that crop growth will be hindered by climate and soil conditions. The rainfall column indicates the risk of droughts hampering crop growth: single or double minus signs behind the rainfall number indicate high and extremely high risk. A minus sign in parentheses indicates that the risk of drought exists in spite of high rainfall, due to the fact that the rain is divided over two rainy seasons. If aridity, extreme soil pH or limited storage capacity for water and nutrients is considered to be a potential bottleneck for a country, this is indicated by an x sign.

The fact that countries with high or increasing yield growth rates (class 1–4) and with stagnating or decreasing yields (respectively class 5 and 6) can be found in all NPP groups, each with their own climate and soil characteristics (tables 1 and 2), suggests that socio-economic factors are more important as constraints for agricultural development than agro-ecological factors.

Tables 1 and 2 do not show, however, that in course of 33 years, the frequency of dry years as well as their severity decreased in both regions. As indicated in section 3.1, yield growth rates started to increase in the second half of the period in particular. Not all countries have equal opportunities for realizing a (strong) yield increase. When developing their agriculture, the West African Sahelian countries have to take drought risks (in the whole of the country or parts of it) into account. The problem is the most serious for Niger, where low rainfall, high aridity and low water storage capacity (due to the prevalence of sandy soils) come together. Even outside the Sahel, droughts are a real risk in certain regions of six countries (Table 1). Therefore, fertilisation may not always produce the expected benefits. In the two Sahelian countries with the lowest rainfall (Mauritania and Niger), the high soil pH can pose a problem. In the two countries combining extremely high and intensive rainfall with strongly weathered soils (Liberia and Sierra Leone), the low soil pH is the inhibiting factor. In areas with aluminum toxicity, the last problem is even greater.

Table 1 Western African countries characterized by their yield growth rate class, their national production potential (NPP), and related potential key climate and soil bottlenecks* to be overcome for strong yield increase.

Country	Climate		Soil bottlenecks			Yield growth rate class
	Rainfall mm/year**	Extremely high aridity	Exceptional pH values	Very limited storage capacity		
				for water	for nutrients	
NPP < 0.5 t/ha/year						
Mauritania	302 --	x	x		x	2
Niger	329 --	x	x	x	x	5
Chad	613 -	x	x		x	4
Mali	665 -	x		x	x	3
Burkina Faso	717 -	x				3
0.5–0.75						
Benin	1,113 (-)			x		3
Nigeria	1,278			x		4
0.75 – 1.00						
Senegal	573 -			x		3
Gambia	803					6
Togo	1,162 (-)					5
Ghana	1,165 (-)			x		3
Liberia	2,240		x			4
Sierra Leone	2,687		x			3
1.00 – 1.25						
Guinea Bissau	1,226			x		3
Ivory Coast	1,278 (-)			x		2
Guinea	1,815					6
1.25 – 1.50						
CAR	1,464					5
Cameroon	1,619					3

* *Indicated by x if not related directly to rainfall.*

*** - and -- behind the rainfall number indicate high and extremely high drought risk;*
(-) indicates drought risk in spite of rather high rainfall, distributed over two growing seasons.

Table 2 As Table 1, for Southern African countries.

Country	Climate		Soil bottlenecks*		Yield growth rate class
	Rainfall mm/year	Extremely high aridity	Very limited storage capacity		
			for water	for nutrients	
NPP < 0.5 t/ha/year					
Botswana	418 --	x	x	x	4
Namibia	427 --	x	x	x	5
0.75–1.00					
South Africa	534 -		x		1
1.00–1.25					
Zimbabwe	602				6
Lesotho	738		x		6
Eswatini	757				5
Mozambique	957 (-)				5
1.25–1.50					
Zambia	997				1
Malawi	1,100				2

** The pH column, present in Table 1, is lacking. None of the countries has agricultural soils with extreme pH values.*

The population density in regions with fertile volcanic soils is much higher than in regions with poor sandy soils. Fertilizers are more effective on fertile soils. Applying fertilizer in an ISFM context is indispensable for significant sustainable effects on poor soils.

Agro-ecological conditions in themselves are not the main obstacle for adopting fertilizer and other inputs, including improved seeds and pesticides; yield growth rate classes are rather arbitrarily distributed over agro-ecological zones (see tables 1 and 2). South Africa, a class 1 country that has reached high levels of productivity, has a low average rainfall and a below-average natural production potential. In spite of soils with a low organic matter content and a related low storage capacity for nutrients and water, all Sahelian countries, except Niger, show increasing yield growth, in different degrees (classes 2–4). Even in Niger, a class 5 country, with only 330 mm average annual rainfall in the period 1981-2013 and a NPP below 0.5 t/ha (Table 1), using fertilizer can lead to 700% millet yield increase: 2.9 instead of 0.4 t/ha (Fofana et al., 2008).

The fact that agro-ecological conditions do not preclude effective fertilizer use and its adoption, does not mean that they do not constitute bottlenecks. Extreme soil pH values and low soil organic content can be overcome. The same counts for drought risks. But these agronomic solutions come with additional costs. Nevertheless, fertilizer use appears economically feasible in drought-prone countries with difficult soils, including South Africa (class 1), Mauritania (class 2), Mali and Senegal (class 3), and Botswana (class 4). The average annual doses used per class by the end of the period of observations is presented in Figure 6B. Data by country can be found in tables III and IV in the annex.

3.3.2 Yield growth and input and output prices

Policy no doubt prevails over agro-ecological factors in determining agricultural development (subsection 3.3.1). It is, however, difficult to distinguish between loose initiatives and implemented and enforced policies in many countries, especially as the measures pertain to a wide range of domains. A shortcut would be to evaluate policies affecting prices (section 2.3; Morris et al., 2007). The results of an evaluation of several other policy factors are presented in the following sections of this chapter.

For less than half of the 49 countries farm-gate prices for certain fertilizers and cereals were obtained; data were lacking for all countries in class 6 (yield decrease). For the highest number of countries, prices were obtained for maize and rice, the cheapest and the most expensive cereals. In the case of fertilizers it concerned urea and NPK (nitrogen, phosphorus and potassium). The results obtained show only a limited correlation between the price levels of fertilizers and cereals and the yield growth rate classes; the fertilizer-cereal price ratio does not improve going from class 4 to 1. But taking all four classes with a positive growth rate together (classes 1–4), average prices for urea and NPK were respectively 0.63 and 0.70 US$/kg around 2014[4], while fertilizer was on average more expensive in class 5 countries: respectively 0.82 and 0.88 US$/kg[5].

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[4] Data from respectively 15 and 10 countries.
[5] Data from 6 countries.

In fact, these prices are only of interest in relation to the prices obtained by farmers for their crops. Therefore, the price of one kg of N has been derived from the urea prices, and has been divided by the price of 1 kg of cereal. An experienced farmer on good soils is able to produce about 25 kg of rainfed maize per kg of N, or 30 kg of irrigated rice (paddy). For the countries of the yield growth rate classes 1–4, the average price of fertilizer-N around 2014 proved to be 5,5 times more expensive than the price obtained for maize, and 3.2 times than the price for paddy (US$/kg : US$/kg). In class 5 countries fertilizer-N was respectively 7.1 and 5.8 times more expensive[6]. Fertilizer and crop prices play a role, but other factors will be at least as important.

3.3.3 Yield growth rate and other socio-economic factors

While no clear relationships were found between degrees of agricultural development and agro-ecological conditions (subsection 3.3.1), those with socio-economic conditions are numerous. The role of arable land per capita and of input and output prices were already considered above. Tables I and II in the annex show, for all 49 countries, nine other socio-economic factors as well as the yield growth class. Table I presents countries in yield growth rate classes 1–4, Table II those in classes 5 and 6. The values are those from the last 5 to 10 years of the observation period (1961–2014) . The human development index (HDI) has been used to differentiate countries; HDI is an index combining health, education and income criteria. The high number of data and their strong variation make it difficult to read these tables. Therefore, the general trends are presented in Figures 6A–6D, while in the tables for each of the socio-economic factors the values for individual countries have been presented. Numbers are given in bold italic if they are on the part of a scale considered as being really unfavorable for agricultural development and food security. High values are not always good: thus, a high agricultural added value (percentage of the GDP) and fragile state ranking are clearly unfavorable.

A factor left out in Tables 1 and 2, because it is so hard to express it in quantitative terms, is the stability of societies. It is hardly a surprise that, as Table II in the annex shows, twelve out of the nineteen countries without agricultural development have been notoriously unstable countries. In general, the stability of the 27 countries in Table I (annex) has been better, at least recently. Maps of Dietz and de Vink (2017), showing the African “no-go areas” and the relative fragility of African states, make clear that a correlation exists between stability and agricultural development expressed by the yield growth classes. It is shown in Figure 6A. Going from yield growth rate class 1 to 6, the average fragility of countries increases, while the corruption perception index is decreasing, which means that corruption increases.[7]

In each of the four panels of Figure 6, two symbols for class 5 countries are shown, one in black and one in red. Some of the countries without (significant)

[6] Data of 12 countries from classes 1–4, and 6 from class 5.
[7] The corruption perception index is going from 100, “very clean”, to 1, “highly corrupt”.

agricultural development did not really fit into the group and were displayed as a separate group. Although these countries shared a lack of annual yield increments, their resemblance in other respects was (very) limited. The countries of class 5a do neither show significant agricultural development nor socio-economic development in general. Importing food seems to be preferred above production in the country. In contrast, the socio-economic characteristics of the countries in class 5b resemble those of class 1 countries, or are even better. These class 5b countries focus on socio-economic development through mining and investing in industrialization while neglecting agriculture. So, although the value added by agriculture is low, they have a (relatively) high FSI, and their CO_2 emission per capita is among the highest in Africa. Most[8] did not score badly in the fragile state ranking and corruption perception index. Figure 6A shows as average fragile state ranking respectively 98 and 77 for 5a and 5b. The 77 ranking is even more favorable than the average of 85 for the class 1 countries. Also, there is less corruption in class 5b than in class 1 countries, while in 5a countries the corruption is very high. By the way, one class 4 country was also reclassified as class 5b, Botswana (see Table I, in the annex, for the list of all other class 5b countries); this strongly improved the homogeneity of class 4.

With just above 40 percent of people living in towns, Africa is the continent with the lowest degree of urbanization.

Choices like these are never entirely objective. We hesitated in the cases of the Kingdom of Eswatini and Lesotho, countries in some respects similar to the class 5b countries: rather stable countries, having a limited contribution of agriculture

[8] Libya is an exception. The end of the observation period coincides with the fall of Qaddafi.

to the GDP but no extremely low FSI (Table I, annex). But their CO_2 emissions, being low, do not suggest important investments in industrialization. They stayed among the 5a countries. The 5a and 5b countries number 11 and 5; the number of countries in the classes 1, 2, 3, 4 and 6 are 5, 5, 12, 4 and 4 respectively.

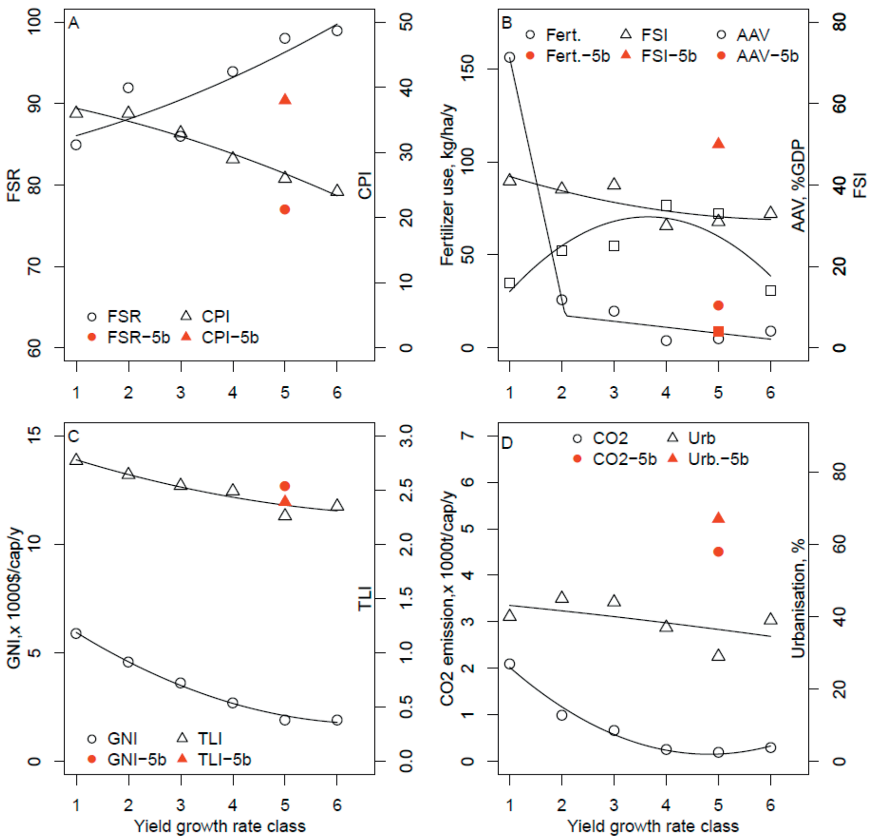

Figure 6 Socio-economic characterization of countries by yield growth rate class at the end of the observation period.

A. Fragile state ranking (FSR, 1–113; from the lowest to the highest fragility) and corruption perception index (CPI, 100–1; very clean to highly corrupt).
B. Annual fertilizer use (kg/ha of arable land), food security index (FSI; 1–100), and the agricultural added value (AAV, percentage of the GDP).
C. Gross national income (GNI/cap. x 10^3 US$/year) and trade logistics index (TLI; 1–5).
D. Annual emission of CO_2 (x 10^3 t/cap.) and degree of urbanization (percentage of the population living in urban environments).

Figure 6B combines information about agriculture (contribution to the GDP), its development (fertilizer use), and food security (FSI). As general trends, going from class 1 to 6, fertilizer use decreases rapidly and the agricultural added value increases strongly. Class 5b countries, however, use as much fertilizer as class 3 countries, but their average agricultural added value is with 4% only a quarter of the average of class 1 countries. Also, the class 6 countries don't follow the general trend as far as the contribution of agriculture to the GDP is concerned; the relative importance of the agricultural added value is almost equal to that of class 1 countries. The class 1 to 3 plus the 5b countries, almost all using fertilizer, have a relatively high FSI; the class 4, 5a and 6 countries, most of which are not using fertilizer, are very food-insecure.

Within the 4 classes with a relatively high FSI and significant fertilizer use (class 1 to 3 and 5b), three out of the twenty-seven countries do not use fertilizer: Congo, a class 5b country, which is importing food, and Madagascar (class 1), and Uganda (class 3), known for the promotion of organic farming. Madagascar in particular does not fit in its class; it is very food-insecure. (In subsection 3.4.7 below, more will be said about organic farming.)

Among the food-insecure class 5a and 6 countries, several use some fertilizer: Kenya, Eswatini (class 5a), Lesotho and Zimbabwe (class 6). Both agricultural development and general socio-economic development seem stagnating. In the class 6 countries, lower cereal yields were observed at the end of the observation period (2010–2014) than at the start (1961–1965). Except for Lesotho, it concerns instable countries (see annex, Table II) which have known better days in terms of agricultural and socio-economic development. This explains why their average agricultural added value is rather low and similar to those of class 1 countries, as indicated above.

Figure 6B helps to understand the well-established inverse correlation between food security and agricultural economic relevance, the contribution of agriculture to the GPD. The correlation is clearly shown in Table 3, which presents information on all 47 African countries from tables I and II (annex): food security in Africa increases with income, but decreases with the share of agricultural added value as percentage of the GDP. *The more farmers the less food!* Upwards from an agricultural added value of about 30%, the average FSI[9] does not decrease much further; it remains about 30%. We are dealing here with typical "agriculture-based countries" as defined[10] by the World Bank (2007), where an "agriculture for development agenda" is badly needed. The ratio of consumers to farmers has to increase strongly, which means that a lot of employment outside agriculture needs to be created.

All countries with an FSI clearly above the average trend of increasing FSI with decreasing GDP share of the agricultural added value are countries with developing agriculture, although the degrees of development differ (Table I,

[9] Taking both food availability and accessibility into account (see section 2.3).
[10] Agriculture accounts for a large share of GDP (32% on average), and most of the poor live in rural areas. More than 80% of the rural sub-Saharan population lives in coutries with an agriculture-based economy.

annex). Most countries with an FSI clearly below the average are countries not showing agricultural development (Table II, annex). However, three countries with agricultural growth from Table I (annex) are having an FSI below the average trend. It concerns Chad, a country heavily relying on agriculture (53% GDP) and showing just the beginning of agricultural development (class 4; Table I, annex), and Angola and Zambia, countries in which the agricultural added value contributes only 6 and 7% to the GDP (Table I, annex). Angola, in yield growth rate class 3, imports huge amounts of food. Zambia, in class 1 (!), exports more than it imports (Rakotoarisoa et al., 2011). A significant part of Zambia's population is too poor to buy enough food; this accounts for serious food insecurity in spite of a relatively high GNI/cap. (Table I, annex). Zambia is among the African countries with a high inequality index (Roser & Ortiz-Ospina, 2018).

In 15 of the 47 countries studied, the food import bills are lower than the agricultural export revenues (Rakotoarisoa et al., 2011). Of these, besides Zambia, seven countries regularly experience serious food insecurity (expressed in a FSI below 35). Only three of them, Eritrea, Gambia and Zimbabwe, do not show agricultural development, as indicated by their respective yield growth rates classes 5, 6 and 6. The other countries are in class 4 (Chad), 3 (Burkina Faso and Guinea Bissau), 2 (Malawi) and 1 (Zambia). (See tables I and II in the annex).

It is not urbanization as such, but rather industrialization that stimulates agricultural development.

Table 3. The food security index of African countries per group of countries following the World Bank's classification of economies and the agricultural added value as percentage of the GDP per group.

WB classification	GNI x 1000 US$/cap	FSI	Agricultural added value (% GDP)	n*
High income	39.3	78	1	1
Upper middle income	7.5	59	5	8
Lower middle income	2.1	42	14	17
Low income	0.7	30	33	24

** n = number of countries*

Figure 6C presents the annual gross national income per capita and the trade logistic index for each of the yield growth rate classes. Figure 6D gives the annual CO_2 emission per capita and the degree of urbanization. Going from class 1 to 6, the GNI/cap., the TLI, and the CO_2 emission decrease. No clear correlation is found, however, with urbanization. But the average degree of urbanization for the classes 1 to 3 plus 5b is with 49% significantly higher than the average of 35% for classes 4, 5a and 6.

The average HDI values of the classes are not presented in Figure 6. The GNI/cap. is a key element of the index and inherently, the pattern of decrease going from class 1 to 6 is very similar to the decrease of the GNI/cap. In general, FSI is positively correlated to both HDI and GNI/cap. However, when comparing countries with and countries without agricultural development (respectively Table I and Table II in the annex), it appears that countries with a similar HDI strongly differ in food security, evidenced by lower FSI values for Table II countries within the same HDI category as those of Table I countries. This agricultural development appears more strongly related to industrialization than to urbanization: the log-converted CO_2 emission (CO_2/capita in tables I and II; Jullien et al., 2017) explained 58%, while the degree of urbanization explained only 29% of FSI variation. It is the urban population that should buy food produced by the rural population, enabling the latter to invest in agricultural development. However, urbanization without industrialization cannot do the job.

Both the degree of urbanization and the carbon emission per capita decrease with larger agricultural added value as percentage of the GDP. At agricultural added values above 20% of the GDP, almost negligible values of carbon emissions are observed, with limited variation. The degree of urbanization, however, is extremely variable. At agricultural added values below 10% of the GDP, values between 20 and 90 percent are observed, while at agricultural added values of 40% of the GDP, urbanization still varies between 10 and 50 percent. The extreme cases of high urbanization without significant carbon emission, read industrialization, are Somalia, Sierra Leone, Guinea Bissau, Liberia and Mauritanian, and to a lesser degree Togo, Mali, DR Congo, and Ivory Coast. Presumably, their cities are concentrations of poverty, and offer few opportunities for labor outside agriculture. Cheap food imports and food aid attracts people to these centers rather than paid jobs. Insufficient urban income, due to limited industrialization, precludes the formation of functioning markets for agricultural products needed to trigger agricultural development. Class 5b countries combine a high degree of urbanization and relatively high CO_2 emission (Figure 6D), but seem to prefer importing food to developing their agriculture.

The TLI, covering the quality of transport (including the needed infrastructure) as well as the administrative burden, shows a clear proportionality with the yield growth rate (Figure 6C). This index appears at least as effective as a policy indicator as prices, treated in subsection 3.3.2, supporting the Breman & Debrah (2003) arguments to explain why the Green Revolution bypassed Africa. Their main argument was that the high costs of external inputs and the limited competitiveness of agriculture on the regional and global market were caused by low road density and a limited and low-quality transport and transport infrastructure. One should note that the TLI is the only factor presented in Figure 6 which shows very similar values for class 5a and 5b countries. The explanation is presumably the very low road density related to a population density of 6 cap./km^2 around 2014, and the high degree of urbanization in class 5b countries (Figure 6D).

3.4 Taking into account bottlenecks for change and present policies

Rakotoarisoa et al. (2011) showed that Africa has become a net food importer, and that the continent has a larger undernourished part of the population than any other. As stressed by Giller et al. (2011), a consensus exists on the need to increase agricultural productivity to eradicate hunger and poverty, an thus to reach the first Sustainable Development Goal. As shown above and in literature (e.g. Nin-Pratt et al., 2011; Bationo et al., 2011.a, Rakotoarisoa, et al., 2011; Lassaletta et al., 2014; McArthur & McCord, 2017; Ciceri & Allanore, 2018) fertilizer use goes hand in hand with yield increase of cereals and other crops, also in Africa. The African Heads of State declared that fertilizer is a strategic good, similar to medicines (African Union, 2007). In one of the background papers for their conference, the Africa Fertilizer Summit (African Region World Bank, 2006), past but failed efforts to promote fertilizer use in Africa have been analyzed. The lessons learned and good practices guidelines developed are still very useful. Nevertheless, African fertilizer use per hectare is still only about one-tenth of the average world dosage, while Africa has an extremely low average NPP, largely due to poor soils (see chapters 1 and 2). In order to identify opportunities for accelerating agricultural development, the findings presented in the preceding sections will here be viewd in relation to bottlenecks for change and present policies.

3.4.1 Low natural production potential

Agro-ecological bottlenecks can be overcome, but the costs for increasing the agricultural productivity may be rather high (subsection 3.3.1). In Africa, Green Revolution technology may be less cost-effective than in more favorable world regions. As stressed in the introduction, the average African NPP is among the lowest in the world; only Australia has a somewhat lower NPP[11]. It is important to realize, however, that traditional low-external-input agriculture is even less efficient; the logistical costs per kg of product on the market are much higher. In Rwanda in 2006, it turned out to be more interesting for milling houses to import Argentinian wheat than to buy local wheat. Going for yield increase using external inputs is worthwhile; the cost per kg of produce decreases significantly (Habimana, 2008).

It is recommended to apply fertilizer in a context of integrated soil fertility management (ISFM), combining soil care with crop care (Breman & Sissoko, 1998; Vanlauwe et al., 2010; Vanlauwe et al., 2015), to make fertilizer as use-efficient and effective as possible. When practiced well, ISFM has many benefits, such as ensuring improvement and maintenance of the soil organic matter status, providing greater buffers against mismanagement, preventing soil acidification, and improving the nutrient and water storage capacity of the soil.

Also harsh environments allow for agricultural development. Livestock thrives where wildlife thrives

[11] According to Buringh & van Heemst (1977), Australia has an average NPP of 520 kg/ha/year, Africa 630 kg/ha/year.

Serious mistakes made in the early days of fertilizer introduction in Africa were imbalanced applications, and the replacement of manure by fertilizer instead of developing optimal combinations (Pieri, 1989). The above-mentioned millet yield obtained thanks to fertilizer use in Niger, that was 7 times higher than the average national yield (Fofana et al., 2008), was realized during an on-farm demonstration of fertilizer use in an ISFM context. The highest yield of 2.9 t/ha was obtained in a year with only 370 mm of rainfall. With improved soil organic matter content, rainwater is better captured, and both water and fertilizer nutrients are well stored in the top soil, making fertilizer use very effective. In a similar on-farm test in the northeast of Rwanda, the combined use of fertilizer and ISFM led to a maize yield of 2.2 t/ha in an extremely dry season with only 220 mm of rain, which caused complete yield failure without the approach (Breman, 2011).

This use of fertilizer in an ISFM context should also become a practice in regions threatened by lower rainfall due to climate change. It stabilizes harvests and leads to a high water-use efficiency (WUE), here measured as kg of cereal grain per ha per 100 mm of extra rainfall. In Western Africa, the average WUE of all year-country combinations without or with minimal fertilizer use (Figure 1a) is the highest in the northern Sahel region (225 kg per ha of

Even in the lowest natural-production-potential class, some countries have a well-developing agriculture.

cereal grain per 100 mm), and decreases going south, becoming only about 75 kg/ha/100 mm in the forest zone. Crops use rainwater less efficiently in Southern Africa. The WUE is 60 kg/ha/100 mm lower in the driest zone and the difference is still 20 kg/ha/100 mm in the humid savanna.

Low WUE is caused by very poor soils, or the low availability of nutrients. The WUE decrease from the dry to the wet ends of the transects is explained by the relative availability for crops of nutrients and water; it decreases with increasing rainfall. Without fertilizer use, most water is lost by evaporation, run-off and leaching. Using fertilizer on soils containing enough organic matter can triple to quintuple the WUE (Penning de Vries & Djiteye, 1982). This is illustrated by the highest yields in Figure 1; more than 4,000 kg/ha were obtained at about 500 mm of rain, with a WUE of about 800 kg/ha for 100 mm of extra rain. Penning de Vries & Djitéye (1982) have shown that a high WUE is easier to obtain on heavy soils than on light sandy soils, as sandy soils with a coarse soil texture and typically low soil organic matter content have a low water-holding capacity. Therefore, ISFM is even more important on sandy soils than on loam and clay. ISFM is not simply the combination of fertilizer and manure or compost: good manure or compost with low C:N ratios[12] degrades easily on sandy soils in Niger (IFDC, 2005; Wopereis et al., 2008). As Suzuki et al. (2016) observed, “This suggested that crop residue with typically high C:N ratio’s) has more potential than cattle manure to enhance the effect of fertilizer.” [13]

3.4.2 Land tenure

Introducing ISFM on poor or exhausted soils implies two phases: soil improvement, and annual maintenance of the improvement. The soil improvement investments are on average about 750 US$/ha (Breman et al., 2003). They will not be easily made as long as land tenure is not well secured. Land registration in Africa is still at low levels; only about 10 percent of the rural land is formally recorded in a public register, leaving 90 percent held under customary law (Byamugisha, 2016).

Whereas in the past customary law has been a satisfactory basis for practicing agriculture, the combined presence of traditional laws and a “modern” land registry makes access to land more unequal. Well-informed and powerful actors enlarge their properties at the expense of smallholder farmers (e.g. for Burkina Faso, Mali and Niger, Bonfiglioli, 1985; for African's Great Lakes Region, Pèlerin, E. et al.; in general, Kasimbazi, 2017). Improving land-use security is increasingly urgent in view of the high African population growth.

[12] C:N ratio = the carbon content of the soil divided by the nitrogen content.
[13] The crop residue referred to is millet straw.

3.4.3 The benefits of increasing population density

At present, the average African population pressure, expressed in the area of arable land per capita, is about a quarter of a hectare. This it already less than in Southeast Asia at the start of the Green Revolution, where the availability of arable land per capita was still more than half a hectare. Now, in Africa, like then in Asia, farmers are more and more focusing on productivity increase by adopting fertilizer use (section 3.2). The OECD-FAO (2016) expects that for maize and other coarse grains, land productivity increase will contribute 2.5 times as much as area increase to the total production in the coming decade in sub-Saharan Africa; for wheat and rice it is 1.1 times.

The class 1 and 2 countries, showing the strongest cereal yield increase, have an average availability of arable land of 0.17 ha/cap. The average of all other countries is 0.27 ha/cap., and is similar for the countries with yield increase (class 3 and 4) and those without it (class 5 and 6). In some of the class 5 and 6 countries, the availability of arable land has fallen far below one quarter of a hectare (Figure 5). These countries include Burundi, DR Congo, Congo, Eritrea, Kenya, Lesotho, Liberia, Somalia and Eswatini. Except for Congo, Kenya and Lesotho, these countries are extremely food-insecure (annex, tables I and II). Policies for triggering agricultural productivity increase are badly needed here.

Such policies may have played a role in Burkina Faso and Mali, countries which show already a relatively high rate of yield growth (class 3), while their availability of arable land is still at least twice as high as the average for class 1 and 2 countries. Only six other countries have similar or higher areas of available arable land (0.4–1.0 ha/cap.): Chad, CAR, Namibia, Niger, Sudan, and Togo. Chad showed only in recent times a slight yield growth rate (class 4), the other countries have stagnating yields (class 5). Except Namibia, all are extremely food-insecure. Chad, Namibia, Niger and Sudan are also among the countries with the lowest NPP (< 0.5 t/ha). Bringing more land under cultivation will be difficult; land not yet in use will be worse in NPP than the already cultivated land. Also here, it seems necessary to introduce policies aimed at increasing land and/or labor productivity.

3.4.4 Gender- related differences

The UNDP’s gender inequality index country ranking (http://hdr.undp.org/en/composite/GII) was compared with the average national maize yields of each country (FAO). Maize yields turned out to increase exponentially with increasing gender equality. While the 10 countries with the highest inequality have an average maize yield of 0.75 t/ha, the 10 countries with the lowest have an average yield of 7.5 t/ha. Most African countries score high on the inequality index: 30 out of the 36 African countries rank above 100 on a list with 160 countries. The average ranking of the 36 African countries is 131, with an average maize yield of 1.3 t/ha. (This is also the average cereal yield derived from the data of section 3.1.). Gender inequality is an impediment for change; agricultural development is difficult to achieve when those doing a lot of agricultural-related work are not involved in decision-making (see KIT et al., 2013, referring to cases from all over the world). At the end of the nineteenth century, the government of the Nethelands, wondering why its agricultural development lagged behind the development elsewhere in Europe, organized a study which identified as a key reason the lack of emancipation and education of rural women. Following the approach of other European countries, the education of rural women of all classes was seriously taken in hand in the first quarter of the twentieth century. This step contributed significantly to the development of Dutch agriculture (Van der Burg, 1988).

Gender inequality goes hand in hand with low crop yields.

3.4.5 Investment in rainfed agriculture or in irrigation

Modern rainfed agriculture is more or less limited below a ratio of in-season rainfall to evaporation of 0.26 (Nidumolu et al., 2012) at around 220 mm in-season rainfall. Mauritania, a country with an agricultural zone receiving only 302 mm rainfall per year in the period 1981–2013 (section 2.3), and with soils combining exceptional pH values with very limited nutrient storage capacity, nevertheless belongs to yield growth rate class 2 (Table 1). It is one of the rare examples where investments in irrigation have played a significant role. Only about 5% of the country has an average rainfall of more than 300 mm/year; about 450,000 ha. is considered being arable land, and the average cereal yield without irrigation is 0.3 t/ha. At present 10% of the arable land is irrigated and has an average yield approaching 4 t/ha. While in a year with average rainfall almost half of the cereal production is from irrigated land, during droughts it can become 70%, like in 2002-2003 (FAO, 2003). Mauritania's agricultural investments focus on irrigation.

The best-known example of a country with mainly irrigated crop production is Egypt, a class 1 country having 70% of its land under irrigation and using 700 kg/ha/year of fertilizer over the last decade. Sudan has the second largest irrigated area, 1.5 million hectares. It is nevertheless a class 5 country. Fertilizer use, mainly for growing cotton, wheat and vegetables, is at a low 4,6 kg/ha. Most of the fertilizer is applied to irrigated crops, which are receiving up to 65 kg/ha. While the rainfed sorghum and millet yield average 0.7 and 0.3 t/ha, irrigated wheat reaches 2–2.5 t/ha. The third country is Madagascar, with more than 40% of its cultivated land irrigated, or 1 million hectares (FAO, Irrigation in Africa in figures: AQUASTAT Survey – 2005; Fethi Lebdi, 2016). Madagascar is a class 1 country, even though it is using even less fertilizer than Sudan (see subsection 3.4.7 below).

Enormous amounts of money are being invested in irrigation.

Except in the countries mentioned, and in Maghreb countries (with 3–4% of cropland under irrigation), irrigation does not play a significant role in Africa. As stressed by Penning de Vries and Djitèye (1982, introduction) and Breman (2015), a low availability of soil nutrients is limiting crop growth much more than low rainfall. Irrigation by itself does not increase yields more than to levels of 1.5 to 2 t/ha where soil fertility is the limiting factor. The additional water affects the yield by mobilizing more soil nutrients through deeper soil wetting, not by direct crop water demand (Penning de Vries and Djitèye, 1982). Irrigation should be accompanied by high fertilizer use, as in Egypt. Egypt's food security is high by African standards. Sudan and Madagascar, with millions of hectares of irrigated land, but without significant amounts of fertilizer being used, are among the countries with the lowest food security (section 3.3.3).

It is useful to take note of the fact that the opportunities for irrigation are rather limited in Africa. At most about 40 million hectares could be irrigated, against 280 million hectares that can be used for rainfed agriculture. In many regions, profitable irrigation is seriously hindered by river water availability, and a limited water storage potential (water for at least two seasons is required for profitable irrigation). Here, again, there is a contrast with Southeast Asia, with its extreme monsoon rainfall.

Nevertheless, large irrigation investments have been made by African countries, by their national and international donors, and by banks such as the African Development Bank and the World Bank. The message that investments in soil improvement are more urgent and more effective does not seem to get through. One does not realize that investments in ISFM are about 750 US$/ha at most[14], against 4,000–8,000 US$/ha for small-scale irrigation, not to speak of the huge investments required for building dams enabling the use of irrigated land for at least two seasons (Breman et al., 2003).

In African rainfed agriculture, crop yield gaps are typically large; close to 80% for water-limited potential yields (Van Ittersum et al., 2016; yieldgap.org). Yields of rainfed agriculture can increase three to five times by using fertilizer in an ISFM context. Without irrigation, cereal yields of 5–7 t/ha can be reached on farms in most regions (e.g. Njoroge et al. 2017), with irrigation plus fertilizer; the maximum yield is about 10 t/ha per season (Breman et al., 2003).

3.4.6 Soil and water conservation

The 300 mm isohyet is used in this study as the lower limit for using fertilizer as a means for increasing land productivity (section 2.3). But water can become a factor more limiting than nutrients where soils are too shallow to absorb and store the rain water, or where run-off causes significant rainwater losses. The latter is a risk that increases with decreasing soil cover and/or increasing slope inclination, in particular on heavier soils (Penning de Vries & Djitèye, 1982). Soil

[14] Only when restoration is needed.

and water conservation, with ISFM, should be seen as essential components of all forms of agriculture. Certain governments of mountainous countries have decided to invest in terracing (e.g. Rwanda). This requires investments still (much) higher than those required by irrigation, in particular when radical backward sloping terraces are constructed.

In so-called “intensive agroforestry”, trees are used for enhancing the effectiveness of fertilizer while controlling its risks. It is an important ISFM technology on mountain slopes, preventing wind and water erosion by increasing soil organic matter content and good soil cover.

Externally accessible positive cost-benefit analyses of the Rwandan investments are in fact ex-ante studies valorizing, besides estimated land-productivity improvement, the supposed on-site and off-site social and environmental benefits (e.g. Maradan, 2017). Preliminary studies limiting themselves to the economics of terracing, are more critical. Iiyama et al. (2012) found that “initial investment costs, provision costs of inputs for yearly crop production, especially opportunity costs of family labour and land” tended to make this form of sustainable land management only marginally profitable or even not viable. Also, Bizoza & de Graaff (2012) conclude on the basis of the calculation of market prices that terraces are hardly profitable, but they insist that the opportunity costs of labor and manure play a key role.

It cannot be stressed enough that the relevance of physical structures for soil and water conservations increases when and where ISFM is neglected. Improving the soil organic matter status helps to decrease water run-off and to increase water infiltration and storage. This is why Fleskens (2007) concludes for Rwanda that the standard priority order should become: agro-forestry > progressive terraces using grass strips and/or contour bunds > radical terraces – unless cost-benefit analyses prove otherwise. The investment costs of agroforestry are less than one tenth of those of radical terraces. Breman (2018) shows the potential of agroforestry as an ISFM technology; it helps to control the risk of fertilizer use on slopes. Roose & Ndayizigiye (1997) had tested it already in practice, and concluded that with agroforestry and liming, together with mineral fertilizer complementation, the erosion hazard was controlled and the productivity of soil and labor was more than three times higher.

3.4.7 Organic farming

Among the 28 countries having (a certain degree of) agricultural development (Table I in the annex), two show contrasting characteristics: a clear yield increase and negligible fertilizer use. Madagascar, a class 1 country, is even at the end of the observation period (2014) using only 3 kg/ha of fertilizer. For Uganda (class 3) it is 2 kg/ha. Both countries are well known for their promotion of organic agriculture.

In Madagascar, a “system of rice intensification” (SRI) has been developed – an organic production system, focusing on healthy soils and using wide plant spacing and special water management. The technology has not led to food security; Madagascar’s FSI (28) is among the lowest of African countries (annex, Table I). In fact, in spite of strong support and intensive promotion, the technology proves disappointing (e.g. Moser and Barrett, 2003; Razafimanantsoa, 2008; Takeshi et al., 2009; see Berkhout et al., 2015 for a meta study). SRI rice covers less than 0.25% of the million hectares of rice in the country (Randriana, 2008). Many reasons are offered; insufficient labor in the face of the very high demand is the one most often mentioned. According to Takeshi et al. (2009), the great demand for organic resources is a key reason for farmers who adopt SRI to use it only on a small plot. The basic limitation of organic agriculture is shown by the fact that it has caused desertification in many parts of the world, before inorganic fertilizer eliminated the bottleneck (Breman et al., 2007). In Madagascar, with only 0.15 ha/cap. of arable land, land degradation and soil erosion are serious threats.

Uganda’s situation, with 0.18 ha/cap., is not much different. The country is nevertheless the largest producer of organic foodstuffs in Africa. Hauser and Lindtner (2017) explain it by pointing to a post-war sense of urgency for the rehabilitation of livelihoods provoked by the degraded environment, food insecurity and economic instability. Local pioneers and NGOs played a crucial role. It could be that up to 2% of cropland in Uganda is under organic farming[15]. Akoyi (2017) shows that it is not an advantage for coffee farmers; coffee farmers under the "Fairtrade-organic" scheme have a lower income than conventional producers. The prices are higher, but the yield is lower.

"Organic-plus-fertilizer": combining the use of organic soil amendments and inorganic fertilizer leads to high, sustainable yields.

In spite of the (very limited) area of land under organic farming, Madagascar and Uganda have an overall positive yield growth rate. In particular the class 1 position of Madagascar needs an explanation. A key factor is presumably the high investment in improvement and extension of the irrigation system, concerning together annually about 50,000 ha, with improved seeds as a second factor[16]. Even without fertilizer use, the two other Green Revolution inputs, improved seeds and pesticides, can have a significant yield effect. This became apparent to the first author during his work in Burundi, DR Congo and Rwanda (2006-2011). The World Bank (2007) uses the past rapid agricultural growth in India[17], which was largely the result of the distribution of high-yielding varieties,

[15] FAO speaks about 122,000 ha or 1% of the cropland; more recent (but promotional) internet information is more optimistic.
[16] Website of the Malagasy Ministry of Agriculture (http://www.mpae.gov.mg/).
[17] Since the seventies, Indian cereal production increased proportionally with increasing fertilizer use, keeping pace with population growth (Prasad, 2009).

as an example illustrating the point that a GDP growth originating in agriculture is much more effective in reducing poverty than a GDP growth originating outside agriculture.

Liu et al. (2015), studying 143 countries, present data on the low use of insecticides, herbicides, fungicides and bactericides in Madagascar. They insist that, in view of the strong correlations between cereal yields and pesticide use, "most countries in Africa… in particularly African countries with low per capita food supplies, need to continue to increase their use of chemicals in order for crop production to feed their increasing populations." In contrast, many other countries in other parts of the world "need to decrease their use of chemical additions in order to protect the environment and human health". The study does not have data about Uganda. Sheahan et al. (2017) do, presenting data on human health and pesticide use in Ethiopia, Nigeria, Tanzania, and Uganda. They show that pesticide use is associated with statistically significant increases in the value of the harvest on a given plot. In Uganda, plots with pesticides have harvest values 38-52 US$/ha higher than plots without pesticides. A similar "cross-country consistency in statistical significance and magnitude" does not exist for organic fertilizer use, nor for irrigation.

In spite of the fact that the contribution of organic farming to the total national agricultural production is very small, the organic mindset in Madagascar and Uganda, reinforced by NGOs and other donors, seems to have a negative impact on fertilizer use. This is risky, given the very low availability of arable land, and unrealistic expectations about yields under organic farming in view of the low availability and quality of organic sources for producing manure or compost (Breman et al., 2007; Breman, 2013). Floret et al. (1993) show that without fertilizer use land has to lay fallow for 3–4 years for every year of cultivation to ensure that the soil organic matter content of the soil does not decrease. Rufino et al. (2011) analyze the competition for organic resources in Zimbabwe and show the consequences for the soil organic matter status, crop yields and animal production. Per hectare of arable land, 4–10 ha of grazing land for livestock is required to produce the manure needed for maintaining crop production. They see increasing fertilizer use as a promising strategy to boost crop and cattle productivity. Giller et al. (2009) and Vanlauwe et al. (2013) show that "conservation agriculture", one of the farming production systems promoted in Africa, is only effective when fertilizer is used.

3.4.8 Crop and/or livestock farming

Current policies encourage the sedentarization of pastoralists, showing a lack of understanding on the part of decision makers (Grandval, 2012). This lack of understanding leads to the disregarding of technological options for productivity increase and fodder quality improvement on drylands. These options require fertilizer use. Even in semi-arid regions poor soils limit production (much) more than low rainfall does (see subsection 3.1.1 and sections 4.1 and 4.3). However, the possibility of droughts increases the financial risk involved in fertilizer use. In the drier parts of Southern Africa, rainfall variability is even higher than at the southern edge of the Sahara (subsection 3.1.1). The drought-related risk associated with fertilizer use may be an argument for investing in irrigation (as in Egypt and Mauritania). Another approach, apart from irrigation, can help decrease the financial risk of using fertilizer in rather dry or even semi-arid regions: mixed farming. Fertilizer use in such regions is less risky for farmers integrating crops and livestock than for those focusing on one of the two (Alberda et al., 1992), especially where grain or other crops are tactically grazed, e.g. in case of droughts (http://www.grainandgraze3.com.au/).

Semi-nomadic livestock serves both pastoralists and crop farmers. Milk can be exchanged against manure.

Sedentary livestock is contributing to the food quality. Milk and cheese are being produced by sedentary livestock keepers in the neighborhood of cities.

Mixed farming is an interesting option for two reasons. One is that both crop and livestock production are seriously limited on poor soils. The limited fodder poor soils produce is of low quality, therefore the milk and meat production are low as well (Ketelaars, 1991). The other is that in arid regions, where rainfall is so low that, even on very poor soils, it becomes more limiting than soil nutrients, the fodder quality is high.This makes arid regions interesting for livestock production, but the amount of fodder is so limited that the density of animals has to be kept (very) low. Pastoralists in the Sahel and elsewhere in dry Africa adapted to this reality by developing (semi)nomadic systems. They fattened animals at the desert borders during the rainy season, and tried to keep dry-season weight losses at a minumum by moving them to flood plains or to the savannah. Levels of protein production per km^2 obtained by these “mobile” livestock systems are not only much higher than those of sedentary livestock raising in Africa, but also up to ten times higher than those obtained by “ranching” systems in comparable regions of the United States and Australia (Breman & de Wit, 1982).

The system became very sensitive to droughts when the dry-season grazing land became increasingly occupied by crop farmers. Consequently, during droughts the pastoralists are obliged to sell their animals for next to nothing to crop farmers in the more humid regions. As long as fertilizer use is negligible, these crop farmers need livestock themselves for transporting nutrients from wastelands to their fields (Breman et al., 2007). It is interesting to note that with an equal average agricultural capital stock of 600 US$/cap., livestock in the class 5 and 6 countries, without significant fertilizer use, contributes 71% to that stock, against 59% in the fertilizer-using class 1–4 countries.

In the introductory phase, the benefits of fertilizer use can generally be reaped much easier in the form of food and cash-crops, than in the form of fodder and livestock. Here mixed farming systems offer an advantage; fertilizer used on crops ensures the availability of higher-quality by-products benefiting the livestock, and a start can be made with mechanizing practices through animal traction (for Sahelian countries, see Breman and Sissoko, 1998; for Central Africa, see Breman et al., 2012). Using fertilizer in mixed farming systems in semi-arid zones decreases the sensitivity to droughts. It does so in two ways, by making the system less sensitive to price fluctuations, and by allowing the use of manure for ISFM. Creating business links between semi-nomadic livestock raisers and crop growers offers the same benefits. From an economic point of view, this is much more interesting than forcing pastoralists to settle. It conserves a production system allowing the exploitation of desert borders (Breman, 2012).

3.4.9 Mechanization

High labor costs are a consequence of the low average African NPP (ACET, 2017). They may account for the fact that African governments choose to encourage mechanization in order to trigger agricultural transformation. Diao et al. (2016) have evaluated such policies and spoken about "…a past littered with poorly-planned programs that failed to assess demand, relative neglect by researchers and policymakers [of the mechanization needs of farmers], and misconceptions about what mechanization is and is not". Failing to develop spare parts supply chains and repair services, was one of the mistakes.

Agricultural development can be accelerated by improving the productivity of land, as is argued in this publication; increasing labor productivity can in principle contribute to development as well (Pardey et al., 1994). Diao et al. (2016) insist that, in order to be successful, approaches aiming to increase labor productivity should vary "both across and within countries, depending on population density, market access, agro-ecology and other factors". This point is well illustrated by Breman & Akonkwa (2012), who compare different regions in Burundi, East DR Congo and Rwanda. Like Diao et al., they consider the distribution of tractors to be an inappropriate government intervention. Mechanization is not the same thing as tractors operating on large commercial farms. In general, tractors don't develop African agriculture; rather, agricultural development creates opportunities for tractors. Tractors may improve labor productivity; they do not by themselves increase the productivity of the land; and their extremely high costs make them inaccessible for all but a few farmers.

Indeed, the mechanization of land preparation, harvesting and threshing can be useful in areas with a high prevalence of HIV/AIDS, for female-headed households, where manual work is too expensive, or where the so-called "window for seeding and planting" is very narrow (Baudron et al., 2015; Baudron et al., 2019). Baudron et al. indicated "that farm power in East and Southern African countries is declining due to the collapse of most tractor hire schemes, the decline in number of draught animals and the growing shortage of human labour" and insist that "a consequence of low levels of farm mechanization is high labour drudgery, which makes farming unattractive to the youth and disproportionally affects women". Sustainable intensification in Africa will require an improvement in access to farm power, but as Breman & Akonkwa (2012) and Baudron et al. (2015) observed, tractors are often too expensive. According to them, increased access to farm power should be "achieved through the use of small, multipurpose and inexpensive power sources such as two-wheel tractors, coupled with the promotion of energy saving technologies". Breman & Akonkwa (2012) show that the use of two-wheel tractors is only financially viable in Burundi, East DR Congo and Rwanda for irrigated high-yielding rice. A cheaper alternative is the use of animal traction. Havard (1999) studied it in 11 francophone African countries. It appears that the introduction has been effective where people were used to working with animals, or in countries where pastoralism is or has been known.

An early and a modern form of mechanization.

3.5 Food availability and food security

The relation between yield growth rates, food availability, and food security is visualized in Figure 7. It shows the average cereal yields per yield growth rate class at the end of the observation period. Besides yields observed in 2014, the differences with the 2000 yields are presented, to provide an impression of change. The yields are presented per capita for the rural and the entire population. This gives a rough indication of the food security and of the possibility to make a living out of farming for each of the yield growth rate classes. The basic data for the individual countries can be found in Table III (classes 1–4) and Table IV (classes 5 & 6) in the annex.

3.5.1 Food availability per person

Figure 7 presents the "cereal yield equivalency", that is, the annual yield per capita if all arable land were covered by cereals and produced the average national cereal yield (kg/ha). It goes without saying that it offers a rough approximation of reality. Cereals occupy somewhat less than half of the arable land. When, for example, roots or tubers are produced, the yield is higher, but with the same nutrient inputs the quality and the price per kilo are lower than for cereals. In contrast, when beans or pulses are produced, the yields are less, but the quality and prices are higher. Also for cash crops the yields will be lower, but the value of the production per hectare will be higher. This makes the use of cereal equivalents a reasonable approximation of reality. Less reasonable is the supposition that the national production is equally distributed over all members of the population.

Figure 7 shows clear trends; the yields per person decrease from class 1 to class 6, while class 5b does not divert much from class 5a, as was the case with of one out of the nine factors in Figure 6, the trade logistics index. The yield per person for the rural population has been derived from the number for the entire population, by dividing the latter by the fraction of the population being rural[18]. The figure shows that the food availability is considerably higher in countries which are developing their agriculture (classes 1–4) than in countries which are not (classes 5a, 5b and 6). It is equally clear that the higher the yield growth rate, connected to the degree of adoption of the Green Revolution tools, the higher the food availability.

The difference between the yields in 2014 and 2000 cannot be derived from the yield growth rates. It is the resultant of yield growth, area expansion and population growth during the last 15 years. The yield differences decreased consistently from class 1 to 6, and are negative for the classes 5 and 6. The highest yield losses are found with the class 5b countries, a clear indication of their neglect of agriculture.

[18] Derived from the degree of urbanization (Figure 6D).

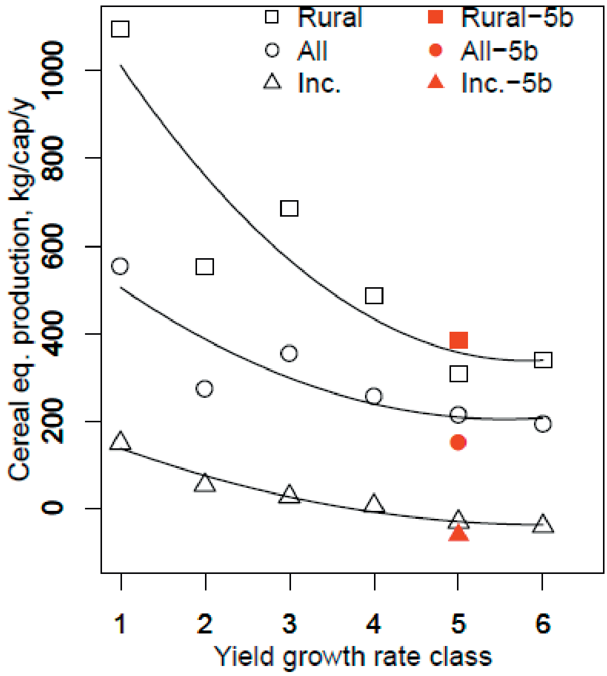

Figure 7. Annual yield in cereal equivalents per capita for the rural (Rural) and entire population (All) in 2014, with the increase for the entire population since 2000 (Inc.), per yield growth class.

3.5.2 Food security

The FAO norm for satisfactory food intake equals 250 kg/cap./year of cereal equivalents. If one keeps this in mind, Figure 7 gives a good impression of the degree of the average food security in the countries per yield growth rate class. Countries of class 1 produce on average more than twice the amount required, class 3 countries produce 1.4 times the minimum requirement and class 2 and 4 countries produce just enough for their populations. The countries in classes 5a, 5b and 6 produce respectively about 15, 40 and 25 percent less than required.

In subsection 3.1.3, is was estimated that 75% of the African population is living in countries with (at least some degree of) agricultural development, that is, countries with a positive yield growth rate (classes 1–4). The classes 5 and 6, without significant agricultural development, are home to 25% of the Africans. The average annual food availability for the first group is 360 kg cereals/cap./year, which is 50 kg/cap./year more than in the year 2000. For the second group, the classes 5 and 6, the average 2014 availability is 195 kg/cap., 40 kg/cap./year less than in 2000. For Africa as a whole, the availability in 2014 is 320 kg/cap./year, about 30 kg/cap./year more than in 2000. This “theoretical” availability is almost 30% higher than the minimum requirement, and is 10%

higher than the 2000 level. The average annual food availability seems growing faster than the population; meanwhile, a quarter of the African population lives in countries where the food availability is insufficient and decreasing.

By calculating the total annual production per person in rural areas, it is possible to estimate the financial benefits of farming. The average production of the countries of classes 1–4 can be compared with that of classes 5 and 6. Using the data of Figure 7, the respective levels of production are 700 and 420 kg per rural capita. To give an impression of what this means for farmers income, these levels of production have been combined with:

- the input and output farm-gate prices of Table 5 below, with Rwanda as an example of a class 2 country and Burundi and DR Congo of class 5 countries;
- data from Habimana (2008) regarding other costs of production involved in “intensive farming” (class 1–4) and in “extensive farming” (class 5 and 6);
- data on the average African family size, being five persons.

On average, a smallholder family of five engaged in intensive farming produces annually 5 x 700 kg = 3,500 kg of cereal equivalents, whereas a family engaged in extensive farming produces 2,100 kg per year. If we subtract their own food requirements of 5 x 250 kg = 1,.250 kg, respectively 2,250 and 850 kg/family remain for sale. The estimated production costs per kg in intensive farming are considerably lower than in intensive farming; respectively 44 and 74% of the gross income (Habiamana, 2008). The estimated annual net income from farming of the two types of families was estimated at 425 and 75 US$ respectively.

The extremely low income of class 5 and 6 farmers is due to the small farm size, combined with very low productivity and high production costs. About 85% of the latter concern the costs of land and labor, expressed in Habimana’s calculations as opportunity costs. Smallholder families are often not in the position to cover these costs; annually they spend about 260 US$ instead of their official 75 US$ net income. Members of the family work for others when possible, while on their own farm labor is constraining production during part of the season. Ongoing use of unproductive land with poor or depleted fertility, resulting in decreasing yields, often obliges farmers finally to sell their land (Tittonell et al., 2013).

Only when food security is realized, significant spending on housing, health, clothes becomes possible.

4. Discussion

4.1 Limited accuracy

The data used may be of poor quality, due to the limited capacity and weak institutions of poor countries (Jerven 2013), even when using data of renowned institutions. Unreliable data may partly account for the scattering of values in the described relations among factors. However, we consider these relations as such to be logical; the outlying values appear to be exceptions which prove the rule. A particular case is the redistribution of imported and subsidized fertilizer by smuggling, mentioned in May 2019 for Ghana[1]. Smuggling could explain the exceptional situation in Botswana, Lesotho and Eswatini mentioned in subsection 3.1.2, where significant amounts of fertilizer were "used" without clear yield increments.

4.2 Agricultural development to increase food security

Technically, it is not a problem to increase African food production and to make Africa food self-sufficient. Fertilizer use is part of the solution (sections 3.1–3.3; e.g. Quifiones et al., 1997). But to make it work, and provide food security, agricultural development has to drive socio-economic development, instead of the other way around, as posited by proponents of other approaches (World Bank, 2007). Here, we strongly argue that agricultural development is necessary not only for increasing food production, but also for increasing access to food and food security. "Agriculture for development" will at least be a must for countries with a large agricultural component in their GDP. The World Bank report stresses the need to recognize key policy dilemmas, and to keep lessons from the past in mind while taking stock of new opportunities. When both rapid production increase and socio-economic development will be realized in Africa, it is well possible that the food requirement – resulting from population growth and demand increase with GDP growth – estimated by van Ittersum et al. (2016) for 2050, will not be reached. When income increases, the population growth will slow down, as happened elsewhere in the world. Koning (2017) insists that the rich and strong countries of the world will have to assist in making this agriculture for socio-economic development possible. It is because of their (partly subsidized) competition on a global liberalized market that agricultural product prices are low, which makes it difficult for poor countries to develop their own agricultural sectors, adopt the use of external inputs for highly productive agriculture and consequently reduce the costs of labor.

Zambia is an example of a relatively rich country where agricultural development is lagging behind socio-economic development; it suffers from food insecurity despite the adoption of fertilizer use and increasing yield trends. For many

[1] https://www.ghanaweb.com/GhanaHomePage/business/Help-government-stamp-out-fertilizer-smuggling-Akufo-Addo-to-farmers-745610#

people the available food is not accessible, due to Zambia's high income inequality (subsection 3.3.3).

The unequal distribution of wealth can become very severe where corruption is rife, and even worse where groups benefit financially by maintaining civil wars. The Sentry, a Washington think-tank, reports about the cases of South Sudan, DR Congo, CAR, and Somalia (https://thesentry.org/). Rich natural resources can become the most serious threat for agricultural and socio-economic development, as in the DR Congo, which belongs to the worst countries in terms of FSI, GNI/cap., CO_2/cap., and trade logistics (annex, Table I).

As expected, corruption appears to be related to food insecurity (https://www.transparency.org/cpi2014/results). The unstable class 5a and 6 countries show more corruption and lower food security than the class 1–4 plus 5b countries (Figure 6A). In both groups, corruption decreases as the HDI increases. It is easier to share wealth than poverty.

Farmer organizations are important links between farmers and the market.

4.3 Agricultural development is taking off

During the last 10 to 20 years, agricultural development starts accelerating, as shown by increasing fertilizer use and cereal yield growth rates (section 3.2), and by their effects on food production and food security (section 3.5). The World Bank (2007) situates the start of growth in sub-Saharan Africa in the mid-nineties of the last century. This acceleration is apparent in countries where three quarters of the African population is living (subsection 3.1.3). Akinyoade et al. (2014) concluded that African food production is already growing faster than the population, while the food quality improves as well. This, however, is not yet the case in a number of countries where one quarter of the African population is living. In these countries the food production per person is decreasing, and smallholder farmers are even not making a living out of their farms (section 3.5). The growth of urban markets is often mentioned as the engine for agricultural development (e.g. Dietz et al., 2012). Figure 6D shows that the relation between food production increase and urbanization is not very strong. There is a stronger correlation between food production increase and the CO_2 emission per person, a measure of the degree of industrialization.

After individual farmers started with it, it took only five years before intensive crop production was generally adopted. One of the early adopters convinced his farmers' organization to construct a panorama platform. At present, it is being used by the authorities to show visiting ministers intensive production up to the horizon.

4.4 The way forward?

The present study aims to indicate conditions and policies that are needed to start agricultural development in class 5–6 countries and to accelerate development in class 2–4 countries. Several authors (e.g. Giller et al., 2011; Benin, 2016) stress that in view of the large number of different agro-

Chapter 4

ecosystems, agriculture development requires many local, specific solutions; according to them, this (partially) explains why Africa lags behind in the adoption of the Green Revolution technologies. This argument is in line with the reasoning of Diamond (1999), who tries to explain why peoples from Europe and Asia have played a dominant role in world history: Eurasia is distinguished by large, rather homogeneous ecosystems, running parallel to the Equator, and does not present many serious obstacles for human movement. Useful inventions easily spread over extended regions and enabled rapid socio-economic development. The Americas and Africa, with mountains and deserts perpendicular to the Equator as barriers, did not have this advantage.

One may wonder to what extent the large diversity of agro-ecosystems is still a serious bottleneck in the digital era. The simple fact that agricultural development in the Americas is far ahead of Africa's, while they show the same diversity of agro-ecosystems (van Warta et al., 2013), should raise doubts. One could also point to the present means of communication and information, and the growing stock of knowledge about obstacles and opportunities for an African Green Revolution (Bationo et al., 2011a).

Nin-Pratt (2016) insists that only Ethiopia, Kenya, Uganda and Malawi are countries where the "fertilizer technology" has a good chance of success.
However, the present study establishes ongoing fertilizer-based productivity increase in 25 African countries, and an intensification of the production of key crops such as maize and rice. The World Bank statistics present two additional

Agricultural inputs are becoming more easily available.

countries, Mauritius and Seychelles, using in 2014 already 285 and 363 kg/ha of fertilizer respectively. When Nin-Pratt (2016) speaks of fertilizer technology, he is referring to the former Asian Green Revolution, with its focus on cereals, while in many African regions other crops dominate the menu. But with urbanization, cereals become a key crop for ensuring food security (Akinyoade et al., 2014; FAO, 2006). Moreover, also for other crops fertilizer use technologies have been developed; IITA, for example, has been working since long on other Africa's primary staple crops, such as banana and plantain, cassava, cowpea, soybean and yam. For crops like these, fertilizer technologies have been developed and their economics have been studied. For example, Nyombi (2014) studies banana, Fermont (2009) cassava, and Wairegi & van Asten (2013) compare banana, beans, cassava and coffee with maize and rice.

4.5 Fertilizer as "silver bullet"

A study of past but failed fertilizer promotion in Africa (Africa Region World Bank, 2006) maintained that it was impossible to design "a universally applicable recipe for success". The study in question nevertheless identified, on the basis of experiences, ten general guiding principles for public interventions. The present study also shows that differences between agro-ecological systems are not the main bottleneck for agricultural development; it is possible to develop fertilizer technologies for many of them. Therefore, instead of focusing on differences between African countries and regions, it appears to be more fruitful to focus on an element that many have in common and that makes Africa different from all other continents, except Oceania (see below): the average low NPP, and, through its effect on population density, high costs of transport, food and labor (subsection 3.4.3).

This suggests that fertilizer use, applied in a context of ISFM, may be the "silver bullet" for African agricultural and rural development. In Africa, as everywhere else, food production increases directly proportional with fertilizer use (Fig. 2). But fertilizer consumption is very low in Africa, compared to the rest of the world (chapter 1). This is a good reason to suppose that food production and agricultural development will benefit from increasing fertilizer use. The World Bank (2007) underlines that low fertilizer use is one of the major constraints for increasing agricultural productivity in sub-Saharan Africa. As stressed by Giller et al. (2011), a consensus exists on the need to increase agricultural productivity to eradicate hunger and poverty, the first Millennium Development Goal. Ciceri & Allanore (2018) stress that fertilizers will play a pivotal role in achieving African food self-sufficiency, "given that ~90% of crop production growth is expected to come from higher yields and increased cropping intensity..." The first step in collaboratively working towards this common goal, the Africa fertilizer summit in Abuja in 2006, badly needs a follow-up. While the African heads of state declared that borders had to be eliminated for fertilizers, as had been decided for medicines before, a lot has still to be done to implement the proposed African Green Revolution (Eilittä, 2006).

The rate of adoption of fertilizer as a component for soil improvement, allowing the intensification of rainfed agriculture, has been very low in most African countries. African agriculture has been vastly underused as a resource for development (World Bank, 2007). This made it difficult to find a solution to the problems of food scarcity, social instability, and the growing numbers of migrants and refugees. The approach has a chance to succeed today where it failed in the past, because the availability of arable land per capita has become so low that increasing the productivity of land has become imperative (Fig. 5; Krautkraemer, 1994). Past failures have as a common element the belief that after the end of colonization, in the early sixties of the last century, Africa and (South East) Asia had an equal start. However, Asian countries adopted Green Revolution technologies, while African countries did not (e.g. Djurfeldt, 2005; Kuyvenhoven, 2008; Rakotoarisoa et al, 2011; Vlasblom, 2013). In fact, a key difference existed and still exists: African natural resources are less abundant and less productive (section 3.2).

Fertilizer as the silver bullet.

Phosphate mining.

4.6 Peculiarities of the African "Green Revolution"

Nevertheless, Africa should draw lessons from the Asian Green Revolution. A key lesson is that "the political reality of the 1960s forced Asian elites to take the interests of peasant farmers seriously"; "the development plans for rural areas served to neutralize the appeal of political radicalism" (Vlasblom, 2013). The food insecurity and poverty of class 4, 5a and 6 countries is such, that uprisings are easily to organize. Investing in fertilizer means increasing the chances of peace in these countries. It is a mistake to assume that peace is a precondition for agricultural development. Improving rural income through higher agricultural productivity will be often the best way to prevent unrest and rebellion, as stressed by Akinwumi Adesina, president of the African Development Bank at the 28th summit of the African Union (Addis Ababa, 2017).

Vlasblom (2013) notes that after independence, the elites in many Asian countries focused on agricultural development, while African governments equated development with rapid industrialization, and saw agriculture as backward. The World Bank (2007) concludes "that GDP growth originating in agriculture is at least twice as effective in reducing poverty as GDP growth originating outside agriculture". This is so, because the former leads to lower costs of food and labor; and low food and labor costs, together with low costs of transport preconditions for developing competitive industries (ACET, 2017). Therefore, it is not astonishing that, in many cases, the effects of investing in industrialization have been disappointing, sometimes even where opportunities were promising (e.g. in DR Congo). CO_2 emission, which can be taken as an indicator for industrialization, is low in most of Africa. It is well correlated with economic development, represented by the GNI/cap., and inversely correlated with the agricultural added value as percentage of the GDP (see Figure 6). With the African NPP being significantly lower than the Asian, the question is how the availability of food can be increased in such a way that the food prices and therefore the salaries go down, and peasant agriculture can turn into market-oriented agriculture. What can be done to improve the competitiveness of African agriculture, which has been hampered by the low NPP and by the high transport, food and labor costs due to the low population density (Breman & Debrah, 2003; Pardey, 2014)?

As shown in chapter 3, today, with the population density increasing, market-oriented agriculture is developing in many African regions under the pressure of urbanization (see also World Bank, 2007; Dietz et al., 2012; Akinyoade et al., 2014). However, urbanization is not automatically a strong engine for agricultural development. It is not, when urbanization is provoked by poverty instead of industrialization. Extreme examples are Liberia, Guinea Bissau, DR Congo, and Gambia, having a degree of urbanization above 40%, negligible CO_2 emission and a very low FSI (annex Table II). Cheap low-quality[2] imported food attracts a lot of people, and urban demand for food doesn't translate into functioning

[2] DR Congo is importing huge quantities of edible offal.

markets, due to the lack of buying power. A key particularity of the African Green Revolution is that it occurs in an era with liberalized global markets; this is a constraining factor as well.

Another lesson to be learned from Asian agricultural development is accentuated by Byamugisha (2016), who points to the cases of two communist countries, China and Vietnam. China initially made the same mistake as the African countries did, that is, to focus on industrialization. Both countries realized that it is necessary to secure land tenure to support long-term investments in agricultural productivity, and to create vibrant land markets that can shift land and labor resources from less to more productive entities. Thanks to land reforms, which led to an increase in investments, agricultural productivity and incomes rose, and agriculture fueled the rest of the economy. This shows that following the agriculture-for-development agenda pays off (World Bank, 2007). In many African countries, land-use security is still a knotty problem (subsection 3.4.2).

The fertilized maize is easily recognized, both from a distance and from up close. For sustainable effects, fertilizer use in the context of ISFM (integrated soil fertility management) is a *conditio sine qua non*.

4.7 A step-by-step approach

The foregoing digression shows that focusing on fertilizer adoption as the first step for accelerating African agricultural development is not a simple matter. Nevertheless, in order to eliminate obstacles to development, one should start with the most important one. This means starting with soil fertility improvement and maintenance, with a view to closing the yield gap in rainfed agriculture, and doing it in a context of ISFM to make it sustainable (section 3.4; Palm et al., 1997; Mando et al., 2005).

Luckily, except in extreme environments (with shallow soils and rocks, or very little rainfall), there are no agro-ecological obstacles for fertilizer use in an ISFM context. As long as run-off and deep infiltration are controlled, 300 mm of rain per season[3] suffices in most cases; which means that fertilizer can be used without too much risk in African climates with the highest potential evapotranspiration, as those of the Sahel (Breman, 1995). The minimum required rainfall can be even below 150 mm where the potential evapotranspiration is low, that is, in mountainous regions and in the Mediterranean climate zones of North and Southern Africa (Alberda et al., 1992; Breman, 2011). The economic risk of fertilizer use is the lowest when applied in a mixed farming system (subsection 3.4.8).

The above is not a plea for starting the introduction of fertilizer everywhere. One should start where the opportunities are best, extending from there into sub-optimal regions. It is pity that certain countries with good agro-ecological conditions, like Nigeria, Gabon, Cameroon and both Congos (Buringh & van Heemst, 1977), choose not to profit from them; instead of using the opportunity to produce for the continent, they prefer to import food from beyond the continent. Within countries, and even locally, one should start on the best soils, which allow for the development of a competitive market-oriented production system. A serious mistake, often made by donor NGOs which are critical of fertilizer use, is to accept the use of fertilizer only on overexploited and depleted land. In fact, fertilizer use effectiveness and profitability increase with soil fertility. Fertilizer is, for example, very effective on Rwanda's volcanic soils (Breman et al., 2011). And in the heart of Niger's Sahel, fertilizer turned out to be much more effective on fields around the farm which are enriched by livestock droppings than on exhausted outfields (Fofana et al., 2008).

Also, it is important to identify the crops and production systems that have the best chance of making fertilizer use remunerative and competitive. As concluded by Wairegi and van Asten (2013) when exploring the scope of fertilizer use in the East African region: "…there is a scope and need for fertilizer use in the East African region, but the choice of crop for intensification and decisions about the amount and type of fertilizer should depend on input/output prices, crop response and crop residue management". Once the fertilizer market, as a component of the external input market, is well developed and farmers have become experienced users, other crops and systems can be made more productive through fertilizer use as well. Also, smallholder farmers will benefit in time from the accessibility of fertilizer due to its use by large farmers, as happened in South Africa and Zambia; and food crops for local consumption will benefit from the input market development and the experience resulting from the production of export crops. Economic and social heterogeneity can be turned to advantage;

[3] Or 600 mm/year where a year has two growing seasons.

this holds true for the diversity within the smallholder population as well. The World Bank (2007) stresses that for effectively accelerating agricultural development, safety nets are required for very poor smallholder farmers and for poor and unfavorable regions. In order for agricultural development to trigger socio-economic development, land grabbing should be combated, in spite of the fact that fertilizer is more profitable on larger farms (Wilson et al., 2018).

4.8 Key policies

Agricultural and economic policies have to be developed that help create or improve the conditions for agricultural development and its acceleration. Table 4 presents an overview which qualifies policies both in a positive and negative sense, derived from the present study (chapter 3). The qualification applies to “agriculture-based countries” as defined by the World Bank (2007). The “agriculture-for-development agenda” aims to transform these countries into “urbanized countries”. The first step is to turn them into “transforming countries”, and this requires specific policies.

The improvement of roads and transport allows for cheaper inputs and more competitive prices of agricultural products.

Possible public support and intervention can take different forms, "promotion" and "investments". "Subsidizing" is one of the ways of promotion; it may be opted for when the available public means are insufficient for general overall support. Before making the choice, one should wonder if it can lead to sustainable change. Improving the conditions for efficient fertilizer use, for example, by investments in ISFM and/or soil and water conservation, may be more effective in the long term than relying on fertilizer subsidies (see also section 4.10).

Table 4 Assessment of the influence of policies* on agricultural development and its acceleration.

Policy: promotion of and investments in	Influence*	
	positive	inhibitor**
Fertilizer & ISFM	+++	
Soil & water conservation	+	+
Improved crop varieties & pesticides	++	
Irrigation		+
Mechanization	+	+
Input & product market plus value chain development	+++	
Favorable cost-benefit ratio inputs	+++	
Transport & trade	+++	
Mixed farming	+++	
Organic farming		+
Land-use security	++	
Gender index improvement	++	
Peace & social stability	+++	
Industrialization	+	+

** The more pluses, the greater the intensity of influence.*

*** A plus sign indicates that capital would be more productive if used for other investments.*

The agenda needs to be focused on increasing agricultural productivity, and fertilizer use in an ISFM context is able to increase both land and labor productivity in a sustainable way. In order to achieve maximum effects and high favorable cost-benefit ratios, improved crop varieties and pesticides should be used (Liu et al., 2015; McArthur & McCord, 2017). Using the latter on their own can only temporarily increase productivity, as resource depletion may harm sustainability (subsection 3.4.7). It goes without saying that for farmers to adopt the use of all three external inputs, input market development is a *conditio sine qua non*. The same counts for access to product markets. Both are necessary for farmers to reach cost-benefit ratios that encourage them to adopt this approach in their search for productivity improvement.

Possibly the most important components of effective input and product market development are road improvement and the improvement of transport logistics in general (subsection 3.3.3). With increasing population density these will be easier to realize (subsection 3.4.3); as a consequence, using fertilizer and other external inputs will become financially feasible for more farmers.

Integrated soil fertility management, the key to sustainable fertilizer use.

After the use of fertilizer and other inputs, mechanization may be the second-best way to improve productivity in Africa. It will, however, have more effect on labor than on land productivity. This is one of the reasons why short-sighted policies to foster agricultural development, by distribution of tractors, for example, can easily become obstacles to development, as they entail an ineffective use of scarce funds. Strategies aiming to reinforce human strength while effectively using the available labor, such as introducing animal traction, two-wheel tractors, or improved threshing methods, have a greater chance of paying off (subsection 3.4.9). Proper mechanization that fits the needs of a country is a welcome complement to fertilizer use, and helps in bringing food prices and wages down, *the* condition for realizing agriculture for development in Africa (Pardey, 2014). African policy makers can profit from lessons learned in India, a typical "transforming country" (World Bank, 2007), in order to make rational choices regarding mechanization and labor use (Basu & Nandi, 2014). They should be warned not to support large-scale industrial agriculture at the expense of smallholder family farming, and not to create a redundancy of agricultural labor before "agriculture for development" has created alternative employment. Zambia's case could serve as a warning example here, with its accent on large-scale industrial agriculture (see subsection 3.3.3).

Two other policies presented in Table 4 distinguished by three plusses in the column of positive influence are starting fertilizer promotion where possible in mixed farming systems, and the promotion of peace and social stability. The justifications are presented in respectively subsections 3.4.8 and 3.3.3. Other essential components of an effective agricultural development policy are the improvement of land-use security and of the position of women – women farmers in particular –; this claim is substantiated in subsections 3.4.2 and 3.4.4. Finally, industrialization should not start prematurely, but should go hand in hand with agricultural development. For example, agro-industries linked to value chains which provide cheap food can help establish the competitive wages required by the factories in urban centers.

Not discussed here, but mentioned by the World Bank (2007), are the factors of health and education. Zambia is mentioned as an example of a country where a high proportion of young men died of AIDS. The scarcity of labor could be a justification for its focus on large-scale industrial agriculture. Also, price and credit policies have not been discussed here. They have remained hidden, as factors influencing market development, and the cost-benefit ratios of inputs and trade. Finally, research and extension services have not been mentioned. Their importance is not denied; on the contrary, good fertilizer use recommendations are indispensable for effective and beneficial fertilizer use. But, too often, policy agendas favor cheap research and extension services, neglecting the conditions that have to be created in order to enable farmers to opt for higher productivity. The knowledge and attitudes of farmers are *not* the main bottlenecks for agricultural development. In some countries, however, Western NGOs convinced farmers that fertilizer would damage their soils. Uganda and Madagascar are the best known examples (see subsection 3.4.7 and section 4.12).

4.9 Fertilizer at the heart of a program

As mentioned before, the outcomes of this study stress the need to correct first what was identified as the most limiting factor: the dominance of poor and infertile soils in Africa. This is why fertilizer, used in an ISFM context, is presented as the silver bullet for change. To become effective, its promotion has to be combined with at least five other policies (each marked by three pluses), and reinforced by the promotion of improved varieties and pesticides, the ensuring of land-use security, and the improvement of gender equality (Table 4). Promoting fertilizer use to counter the low productivity of soils, without paying attention to other yield limiting-factors, will in general be without effect (African Region World Bank, 2006). In order for policies to become effective, policy makers, businessmen and -women, and farmers and their organizations need to collaborate.

The results of the Dutch-funded IFDC CATALIST project, which aimed to trigger agricultural transformation in Burundi, DR Congo and Rwanda (2006–2015), offer a preliminary indication that the package proposed above can work. Table 5 compares fertilizer use and cereal yield, comparing the situation just before the start of the project with that at the end of our observation period. Prices, however, are those from the end of the first project phase (Breman et al., 2011).

Table 5 The differentiated effects of triggering agricultural development in three neighboring African countries, comparing the main indicators for development used in this study.

Indicator of agricultural development	Burundi		DR Congo*		Rwanda	
	2005	2014	2005	2014	2005	2014
Fertilizer use (kg/ha)	3	11	0	3	3	13
Average fertilizer price (US$/kg)**		0.9		1.2		0.7
Average CBR (US$/US$)***		0.21		0,38		0.22
Cereal yield (t/ha)	1.3	1.2	0.8	0.8	1.2	2.0

** Only two provinces, North and South Kivu*

*** Average of DAP (di-ammonium phosphate), KCl (potassium chloride), NPK & urea*

**** Average cost-benefit ratio (CBR) for 3 cereals, maize, rice and wheat, plus beans and potatoes*

A comparison of the data from three countries in Table 5 is of particular interest, as all three have a shared history of colonization, while two of them, Burundi and Rwanda, have an almost similar population and agro-ecology. It was the government of Rwanda who invited the IFDC to support them, and during the entire project period, the government has been focused on agricultural development; the entire package was implemented. In DR Congo, the project has only been active in the two Kivu provinces, bordering on Burundi and Rwanda. Several efforts have been made, however, to get the central government in Kinshasa interested. Four of the policies listed in Table 4 were not developed or effective: input and product market development received no attention; inputs were smuggled into the country, or brought in by the project. The decision taken by the African heads of states in Abuja (African Union, 2007) to eliminate trade barriers for fertilizer had not been put into effect, road networks were in awful condition, and peace and stability were a far cry. Besides, land-use security was (and is) badly lacking, and the countries belonged to the bottom ten on the ranking of countries in terms of the gender-equality. In Burundi, parts of the package were implemented; the country stood closer to Rwanda than to DR Congo. Rwanda supported fertilizer use through subsidies, as is shown in the price difference.

All but one of the numbers in Table 5 reflect this reality; Rwanda shows clear agricultural development, DR Congo does not, and Burundi occupies an intermediary position. Only as far as the CBR value is concerned, Burundi does somewhat better than Rwanda. The difference is caused by one crop, potatoes;

the average farm-gate potato price in Burundi was higher than in Rwanda: 0.24 versus 0.18 US$/kg. Eliminating potatoes from the 5 crops, or considering only the 3 cereals, gives an CBR for Burundi and Rwanda of respectively 0.29 and 0.24. For farmers, fertilizer use was the most attractive in Rwanda, thanks to an effective agricultural policy.

This policy effect on prices is more clear than in subsection 3.3.2. This illustrates the limited accuracy, mentioned in section 4.1. At the basis of the findings mentioned in 3.3.2 are single data obtained from individuals in the countries concerned (section 2.3); Table 5 is based on numerous observations over a longer period.

ISFM not only requires organic soil amendments; lime is also an important input. It is produced on a small scale, mostly, however, for construction purposes.

4.10 Subsidies and competition

One may wonder why fertilizer subsidies are required in Burundi and Rwanda, in view of the fact that their NPP is far above the African average, thanks to fertile volcanic soils and favorable rainfall, and that they have a very high population density. However, the countries are surrounded by large regions with a low NPP and are separated from import harbors by more than a thousand kilometers of low-quality roads, making external inputs expensive.

The package as presented in Table 4 is effective, but ways have to be found to make the effects sustainable. Subsidies for fertilizer are controversial. Carr (2017) and Ricker-Gilbert et al. (2014) observed in Malawi, a country very similar to Burundi and Rwanda, that the fraction of vulnerable people in the population is inversely correlated with the amount of subsidized fertilizer per capita. This is why King and Wang (2015) argue for fertilizer aid. However, this aid would take a big chunk out of the national budget, and the funds could not be used for realizing other required structural changes (Huang et al., 2017). Balu et al. (2011) underlined that "in an environment riddled with inefficiencies that contribute to the high costs of using fertilizers, the introduction of subsidies only adds more fiscal burden". The entire value chain of agricultural inputs has to be improved. Lack of access to cheap credit is, for example, another factor inhibiting fertilizer use (van Manen, 2018).

Huang et al. (2017) view the Rwandan fertilizer subsidy in a (relatively) positive light; they see it as one of the components of a more holistic "crop intensification program". They point out that it used up only an average of about 1% of the national budget. Among the nine countries studied, five Asian and four African, Rwanda spent the lowest percentage of the national budget on fertilizer subsidies and showed the highest cereal yield growth for the 2000–2013 period: 4.6%. In fact, for the nine countries no correlation was found between the funds used, in terms of the percentage of the national budget, and the cereal yield growth observed. For the three other African countries these pairs of numbers are: Malawi 17.0% of the budget and 4.4% yield growth; Nigeria 1.7% and 3.6%; and Tanzania 1.1 and 0.6%. Malawi and Rwanda are class 2, and Nigeria and Tanzania class 4 countries (see Table I in the annex).

Huang et al. (2017) mention that Rwanda stopped its effective fertilizer subsidy program in 2014. In the meantime, Burundi started a so called voucher program, subsidizing fertilizer for a target group of 300,000 farmers. While in 2012 the average cereal yields in Burundi and Rwanda were 1.1 and 2.1 t/ha, after 2014 the Burundian yield started increasing and the Rwandan yield dropped. Both countries had the same yield in 2016: 1.5 t/ha.

Huang et al. (2017) recommend that the Asian countries, typical "transforming countries" in the language of World Bank's Development Report (2007), stop the subsidies. They point to huge public costs, but also see subsidies as a hindrance for private-sector input-market development and as leading to inefficiency in fertilizer use. But in African countries, typical “agriculture-based countries” (World Bank, 2007), where fertilizer use is in its early stages and where soil fertility is being impaired, “fertilizer subsidies will continue to be an inescapable feature of agricultural policy”. An argument for offering support to farmers using fertilizer during the introductory stage is that the use efficiency of fertilizer is low if applications are imbalanced or wrong, especially on poor and/or exhausted soils providing very limited risk-reducing buffers (Njoroge et al., 2019). Further, soil nutrient pools are often exhausted, resulting in a low recovery of P and K, as large amounts of applied nutrients will remain in slowly-releasing pools for many years (Wolf and Janssen, 1989). While experienced farmers after years of regular fertilizer use and soil improvement are able to produce on average 25 kg of extra cereal grain per kg of fertilizer-N, at the start even experienced farmers will not produce much more than half of it on poor soils. This is often due to the strong local variability of soil fertility, an imbalanced supply of nutrients, poor plant emergence and seed set, and strong competition between the crop and soil organisms for both the nutrients already present and for the fertilizer nutrients. In time, thanks to fertilizer use and effective soil fertility management (ISFM), the soil organic matter will become enriched with fertilizer nutrients which will satiate the soil organisms (Mando et al., 2005a; Wopereis et al., 2008).

This low initial fertilizer use efficiency on poor soils, combined with high fertilizer costs, makes it difficult for African farmers to compete with producers from all over the world who benefit from better soils and decades of fertilizer use experience. The global trade liberalization has forced them to compete. One should realize that in a country like Rwanda, the production costs per kilo of product are still significantly higher for the dominant low-external-input agriculture than for farmers who recently adopted the use of fertilizers (e.g. Habimana, 2008). Not using fertilizer is no option. This is why it is tempting for African governments to opt for the quick fix by importing (or allowing the importation of) cheap food from abroad, rather than to provide a long-term solution by investing in national food self-sufficiency and helping farmers to live through the period with low initial fertilizer use efficiency.

Koning (2017) notes that agricultural trade agreements with African countries often benefit the partners more than Africa. One should consider protecting farmers at least during the phase of the introduction of fertilizers and other external inputs. Protective measures are needed most in countries and regions with a low NPP. Few African countries have a NPP above 1.0 t/ha (see tables 1 and 2). Asia as a whole and South East Asia have an average NPP of respectively 1.1 and 1.6 t/ha (derived from Buringh & van Heemst, 1977).

4.11 Mechanization; labor productivity versus land productivity

This provokes the question if productivity increase through fertilizer use ought to be considered at all. Taking stock of the costs of production in counties or regions with extremely low NPP values, should one not say that there is no prospect for

The hoe still plays an important role in African agriculture.

them to be competitive on an open, liberalized market? Again the comparison with another continent is of interest; this time not Asia, but Oceania. Oceania has an even lower average NPP than Africa, about 520 kg/ha against the African 630 kg/ha (Buringh & van Heemst, 1977). If we look closer, Oceania turns out to be heterogeneous; the islands have an NPP far above the average, Australia's is somewhat lower.

We can find a preliminary answer to our question by comparing Africa with Australia and New Zealand, with an average NPP of about 500, and 1,400 kg/ha. In Africa, until recently, production increase was mainly achieved through area expansion; the productivity of land and labor barely increased. From 1961 to 2009, the land productivity increased from 45 to 75 US$/ha, and labor productivity from 430 to 550 US$/cap. In Oceania as a whole, the labor productivity increased from 20,000 to 45,000 US$/cap. This is mainly due to developments in Australia and New Zealand, which are typical urbanized countries (World Bank, 2007), with only 2.6 and 6.2 percent of the population active in agriculture, against 57% in Africa. Australia has 1.93 ha/cap. of arable land, Africa 0.25, and New Zealand 0.13. Per capita employed in agriculture these numbers are respectively 74, 0.44 and 2.1 ha/cap. Australia is an empty country compared to Africa. New Zealand is more densely populated than Africa, having only half the area of arable land per capita (0.13 versus 0.25 ha). New Zealand's farmers are investing heavily in the productivity of their land, using

1,490 kg/ha of fertilizer. Australian farmers are using only 54 kg/ha of fertilizer; they gave invested much more in increasing labor productivity by mechanization. Poor soil fertility combined with high drought risks are forcing farmers to be cautious with respect to the use of expensive inputs; they only apply them when they expect financial returns. The use of fertilizer has gone down in recent years, in response to increased climate variability (www.yieldgap.org). It is possible that Diao et al. (2016) are right when they state that mechanization – or an increase of labor productivity – will have to be part of the approach for transforming African agriculture. In subsection 3.4.9, animal traction was mentioned as an option to be considered. Aune et al. (2017) also mention it as a way to realize a more efficient input use and a higher land and labor productivity.

A factor hindering mechanization in Africa, apart from the very limited availability of land and its low productivity, is the limited availability of capital and credit for rural operators (subsection 3.4.9). This not only affects farmers, it also blocks the development of small- and medium-size enterprises in the entire value chain (van Manen et al., 2018). The unequal access to capital partly explains why it appears to be easier for larger farms to increase agricultural productivity (Wilson et al., 2018). Instead of waiting for public and private action plans, farmers should start organizing themselves and creating economies of scale by collaboration (World Bank, 2007). This has been the approach adopted by Dutch farmers one century ago, and it has been effectively used in the Chinese context as well. One may wonder if John Deer's very recent initiative in Nigeria will also prove effective. "Hello Tractor enables farmers to request affordable tractor services, while providing enhanced security to tractor owners through remote asset tracking and virtual monitoring. This value also extends to banks financing tractors and dealers who service them" (https://www.hellotractor.com/home).

Mechanization may pay off.

A question remains to be answered. Why have low NPP and low population density been a hindrance for agricultural development in Africa, while they did not hinder Australian agricultural development? The answer is that the latter, starting at the end of the eighteenth century, was fostered by a strong and increasing demand for primary products from Great Britain, the occupier of the continent, and that the cheap labor of prisoners was used for crop production (Clarkson, 1971).

There is a parallel with agricultural development South Africa, which also has a low average NPP (see Table 2); the connections with the Dutch and English colonizers account for the anomalous growth. During the First World War, agricultural production in South Africa received a strong boost. The war had reduced the role of competition, as agricultural production in Europe was severely disrupted during the war years
(https://www.sahistory.org.za/article/impact-war-agriculture-and-land).
The second African exception, Egypt, started developing agriculture before hardly any other country had thought about it.

4.12 Environmental risks

When promoting fertilizer use in Africa, its environmental risks need to be recognized. They have to be taken into account by farmers, business people, governments and the general population. Liu et al. (2015) claim that overuse and other improper uses of fertilizer and pesticides are threatening the world's cereal production. But at the same time, they insist that most African countries, in particular those with low per-capita food supplies, need to continue to increase their use of agro-chemicals in order to feed their growing populations. Bindraban et al. (2015) share the view that fertilizer use comes with an environmental cost, and has so far not been effective in lifting African farmers out of poverty.

The main causes of African land degradation are the cutting of trees and the overexploitation of natural resources by extensive agriculture.

Countries should not simply avoid fertilizers for environmental reasons, since soil degradation as a result of fertilizer omission can pose much greater risks for agricultural production (Palm et al., 2004). Soil degradation, caused by overexploitation and exhaustion, is the main cause of desertification in Africa. In an absolute sense, Africa may not yet be heavily populated, but in view of the low NPP, overpopulation is already a significant factor on the continent. Therefore, fertilizer use can be a crucial tool for desertification control; it can trigger intensification in regions with relatively favorable agro-ecological and/or market conditions (Breman, 2002). By doing so, it leaves more land available for nature. Fertilizer can also contribute to the maintenance of biodiversity, as illustrated by the fact that the elephant density is higher in Africa where more fertilizer is being used on cropland (Smaling et al., 2006).

Promoting “agro-ecology” as *the solution* for African’s food insecurity (Schutter, O. de, 2010) entails a more serious environmental risk than the use of fertilizers, for the proponents of this solution ignore the fact that overexploitation by overpopulation is main cause of land degradation and the loss of biodiversity. Organic farming is not a viable alternative to fertilizer use (subsection 3.4.7). It adds on average about 1 t/ha of cereals to the low African yields. But the farmers whose results are summarized in Table 5 doubled or tripled their yields within two to four years after starting to use fertilizers in an ISFM context (Breman, 2013). A minor yield reduction of about 20% is assumed when organic farming is compared to conventional farming (Tittonell., 2014). Three meta-analyses of organic yield gaps (De Ponti et al., 2012; Seufert et al., 2012; Ponisio et al., 2015) rather consistently conclude that the average yield gap varies between 19 and 25 percent. Yet, if these yield differences are adjusted by including the area needed to grow legume crops supplying the required N input into the system, they are typically more than doubled, especially when animals are used to capture N from legume-grass mixtures. There are more examples of improper analyses overestimating the potential of organic farming (e.g. Muller et la., 2017; Van der Ven et al.,2018).

This does not imply that the known risks of agro-chemicals should not be taken seriously, or that components of organic farming should not be considered in the search for technologies and approaches for decreasing these risks, and for the identification of alternatives. The World Bank (2007) suggests the exploitation of biological and ecological processes for input-use decrease. A lot of attention has been devoted to the question whether the potential of leguminous species to fixate biological nitrogen should be utilized before turning to fertilizer nitrogen (e.g. Giller et al., 1997; Bationo et al., 2011b; Breman & van Reuler, 2003). Also, attention could be given to, for example, the potential of mycorrhiza to replace P-fertilizer, and to developing approaches which can help to slow down the replacement of beneficial slow-growing soil micro-organisms by fast-growing ones feeding on fertilizer (Malý et al., 2009). One possible form of follow-up research could aim at identifying better fertilizer and fertilizer use approaches (Bindraban et al., 2015; Breman, 2015; Ciceri & Allanore, 2018).

In the eyes of many, Africa is still “empty”. The basic mistake behind the belief that organic farming can play a key role in solving Africa’s food insecurity problem in a more sustainable way, is the neglect of the low NPP. Africa is overpopulated at a low absolute population density! Many do not realize that, apart from the rapidly shrinking forests, there is land not used for cropping that is nevertheless crucial for cropping. If no fertilizers are used, land has to lay fallow, or grazing land with livestock is required, for maintaining soil fertility. In general it is estimated that that every year of cropping requires four years of fallow for sustainable land use in Africa; this means that 80% of the arable land should lay fallow. Due to population pressure, most of the fallow land in Africa has disappeared. Heady & Jayne (2014), referring to Kenya, Malawi and Nigeria, present average numbers of respectively 25, 15 and 25 percent. But even this land is not “resting”, it is intensively used for grazing. “Empty” land in Africa is rangeland, and the value of the livestock is higher than that of agricultural stocks. For the Western African countries of Table 1, the value of livestock is 63% against 37% for the agricultural stock; for the Southern African countries of Table 2 the numbers are respectively 75% and 25%.

The livestock is badly needed for the maintenance of crop yields on land where no fertilizer is applied. Rufino et al. (2011) found that in Zimbabwe 4–10 ha of rangeland for livestock is required to produce the required manure for maintaining crop production on 1 ha of arable land. In Western Africa, less than 4 hectares of rangeland exist for each hectare of cropland. If the countries bordering the Sahara desert are left out of consideration, only 1.2 ha of rangeland is available per hectare of cropland.

It will be extremely difficult, if not impossible, to stop climate change by the production of biofuel.

For Southern Africa, the numbers seem to be more favorable, but this is mainly due to the fact that parts of Botswana, Namibia and South Africa are occupied by deserts. Desert borders cannot be used for crop production, but they offer good opportunities for raising livestock (Breman & de Wit, 1982). Without this "advantage" of deserts, also in Southern Africa the availability of rangeland is insufficient for maintaining the low present crop yields using manure. In Zimbabwe, for example, 4–10 ha per hectare of cropland are required, with only 2.8 ha of rangeland being available (Rufino et al., 2011). And one has to realize that not only in the Western and Southern African countries with deserts, but also elsewhere most of the livestock is grazing most of the time far away from cropland, which means that most of the manure will never be accessible for crop farmers.

In Africa, the number of elephants rises strongly when more fertilizer is being applied on cropland.

In spite of all this, governments and individuals, inside and outside Africa, justify land grabbing, invoking the belief that Africa is "empty". Land is acquired by outside private investors, companies, governments, and national elites, and it is used for commodity crops, including agrofuels, which are then sold on the overseas market (Kasimbazi, 2017).

To sum up, population density in most of Africa exceeds the natural carrying capacity of the land. The consequences are strong nutrient mining and declining soil fertility (Henao & Baanante, 2006). Improved productivity is badly needed to feed the growing population and to curtail the expansion of agricultural land-use. Expansion will entail the loss of biodiversity. The natural environment is seriously threatened, threatening in turn the socio-economic environment, in particular in those countries where agriculture dominates the GDP. Better crop nutrition will be needed to maintain and improve crop yields on existing farmlands. Balanced fertilizer use can make a difference, while integrated soil fertility management (ISFM) is needed to prevent overdosing and inefficient use. Besides fertilizer to nourish the crop, soil amendments[4] are required to improve and to maintain soil fertility (e.g. Palm et al., 1997; Breman et al., 2011). Without them, the soil will in due time become too acid, and the organic matter stocks will become too low to ensure sufficient nutrient and water storage (Bationo et al., 2012; Mando et al., 2005b). The neglect of these facts largely explains why the promotion of the Green Revolution failed in Africa (Pieri, 1989).

[4] Organic matter and lime in particular.

5. CONCLUDING REMARKS

A hopeful tendency has been identified: African agricultural development is taking off. Whereas very few African countries started their Green Revolution already in the 1960s, many others are following suit in the last two decades: their cereal yields are increasing, and in almost all cases this seems due to the adoption and increase of fertilizer use.

About one quarter of the African population lives in countries where cereal yields have not increased since the early sixties of the last century, or where they have increased only very slowly, owing to a more intensive use of local agricultural inputs. In order to prevent food insecurity in Africa, now and in the future, agricultural development is essential. In view of the importance of agriculture for the economies of many countries, and the concomitant food insecurity, agricultural development needs to become agriculture for socio-economic development. Efforts should focus on the rapid improvement of the productivity of land and labor, with land productivity coming first.

By classifying countries in six classes, characterized by the average annual rate of growth of the national cereal yield, from negative to positive at the highest known rate, policies and conditions favoring or hindering agricultural development have been identified. Agro-ecological conditions or technical aspects seem not to constitute major hindrances for agricultural development; the most serious obstacle are of a socio-economic nature. Meanwhile, the low soil nutrient status is evidently a major cause of low crop yields and low livestock productivity in most of Africa; therefore, the adoption of fertilizer use is to be considered as a precondition for change and development.

In order to be effective, fertilizer use promotion will have to be the central part of an agricultural development program requiring the collaboration of farmers, businesspeople and governments. Problems have to be tackled one by one, starting with the most serious ones. Intensification of rainfed agriculture has been identified as the way to go. To ensure an optimal effect of fertilizer, its use has to be combined with good agronomic practices, including demonstrations, the training of farmers, the use of improved crop varieties, proper crop rotations, and the use of biocides where biological solutions are not available. In order to ensure sustainability, this package needs to be deployed in the context of integrated soil fertility management. The required investments have the best chance to be made if land-use security is assured; and the effective adoption of the technologies depends in part on efforts to reduce gender inequality. Small-scale mechanization may have to be included in the package required to trigger agriculture for development.

Table I Some relevant socio-economic conditions of African countries showing (a certain degree of) agricultural development, characterized by yield growth rate classes 1–4 (cf. Figure 4 and 6). *

Country	FSI (1-100)	GNI/cap x 10^3 ($/year)	CO^2/cap x 10^3 (t/year)	Urbanization (%)	Agricultural added value (% GDPGDP)	TLI (1–5)	Fragile state ranking (1-113)	Corruption perception index (100-1)	Yield growth rate class
HDI > 0.7									
Algeria	47	13.9	3.7	70	11	2.65	79	36	2
Tunisia	56	10.6	2.6	67	10	2.55	77	40	3
HDI > 0.6–0.7									
South Africa	61	12.7	7.6	64	2	3.43	67	44	1
Egypt	49	10.3	2.4	43	4	2.97	***91***	37	1
Morocco	50	7.1	1.7	60	13	2.67	74	39	3
Botswana	61	16.0	3.0	57	2	***2.49***	64	63	4 = 5b
HDI > 0.5–0.6									
Zambia	***33***	3.7	***0.3***	40	7	***2.46***	86	38	1
Madagascar	***28***	***1.4***	***0.1***	***34***	***26***	***2.38***	83	***28***	1
Mauritania	***33***	3.7	***0.7***	59	24	***2.23***	***93***	***30***	2
Ghana	43	3.9	***0.5***	43	22	2.63	71	48	3
Cameroon	38	2.9	***0.5***	54	15	***2.30***	***93***	***27***	3
Angola	***34***	6.3	***0.9***	43	6	2.54	87	***19***	3
Nigeria	36	5.7	***0.5***	47	20	2.81	***100***	***27***	4
Tanzania	***30***	2.5	***0.2***	***31***	***31***	***2.33***	81	***31***	4
HDI > 0.4–0.5									

Ethiopia	36	***1.5***	***0.1***	***19***	***42***	2.59	***98***	***33***	1
Ivory Coast	45	3.1	***0.4***	53	23	2.76	***102***	***32***	2
Malawi	***34***	***0.8***	***0.1***	***16***	***31***	2.81	89	***33***	2
Rwanda	***34***	***1.6***	***0.1***	***28***	***31***	2.76	90	49	2
Uganda	46	***1.7***	***0.1***	***16***	***27***	3.04	***96***	***26***	3
Senegal	38	***2.3***	***0.5***	43	15	2.62	83	43	3
Benin	38	***1.8***	***0.5***	44	24	2.56	78	***31***	3
Sierra Leone	36	***1.8***	***0.2***	40	***54***	***2.03***	90	***31***	3
Mali	***33***	***1.5***	***0.1***	***39***	***42***	2.50	90	***32***	3
Burkina Faso	***32***	***1.6***	***0.1***	***29***	***35***	2.64	89	38	3
Guinea Bissau	***32***	***1.4***	***0.2***	49	***43***	***2.37***	***100***	***19***	3
Liberia	***29***	***0.7***	***0.2***	49	***36***	2.62	***94***	37	4
Chad	***25***	***2.1***	***0.1***	***22***	***53***	2.53	***109***	***22***	4
Djibouti	?	***1.7***	1.7	77	4	***2.15***	87	***34***	-**

* *Numbers given in bold italic indicate really unfavorable conditions for agricultural development and food security.*

** *Area of arable land too small for determination of the yield growth rate.*

Table II Some relevant socio-economic conditions of African countries showing no visible agricultural development, characterized by yield growth rate classes 5 and 6 (cf. Figure 4 and 6). *

Country	FSI (1-100)	GNI/cap x 10* ($/year)	CO^2/cap x 10* (t/year)	Urbanization (%)	Agricultural added value (% GDP)	TLI (1–5)	Fragile state ranking (1-113)	Corruption perception index (100-1)	Yield growth rate class
					HDI > 0.7				
Libya	37	16.2	8.3	78	2	2.50	88	***18***	5 = 5b
					HDI > 0.6–0.7				
Namibia	50	9.6	7.3	46	7	2.66	71	49	5 = 5b
Gabon	60	16.7	2.9	87	4	***2.20***	72	37	5 = 5b
					HDI > 0.5–0.6				
Congo	42	5.2	1.0	65	5	***2.08***	90	***23***	5 = 5b
Eswatini	42	5.9	***0.5***	***21***	10	?	86	43	5
Kenya	40	2.9	***0.3***	***25***	***30***	2.81	***99***	***25***	5
Zimbabwe	***32***	***1.6***	***0.9***	***33***	12	***2.34***	***103***	***21***	6
					HDI > 0.4–0.5				
Sudan	***33***	3.9	***0.4***	***34***	***40***	***2.16***	***110***	***11***	5
Eritrea	***32***	***1.5***	***0.1***	***21***	14	***2.08***	***95***	***18***	5
Mozambique	***31***	***1.1***	***0.2***	***32***	25	***2.23***	86	***31***	5
Burundi	***29***	***0.8***	***0.1***	***12***	***39***	2.57	***97***	***20***	5
Togo	***28***	***1.3***	***0.3***	***39***	***42***	***2.32***	88	***29***	5
DR Congo	***25***	***0.6***	***0.06***	42	21	***1.88***	***110***	***22***	5
Lesotho	37	3.2	***0.1***	***27***	6	***2.37***	79	49	6
Guinea	***32***	***1.1***	***0.2***	***37***	19	***2.46***	***103***	***25***	6
Gambia	***32***	***1.6***	***0.1***	59	18	***2.25***	83	***29***	6

HDI $\leq$ 0.4									
Niger	***30***	***0.9***	***0.1***	***18***	39	***2.39***	***98***	35	5
Somalia	***(24)***	***?***	***0.1***	***39***	65	***1.77***	***113***	***8***	5
CAR	***24***	***0.6***	***0.1***	40	42	***2.36***	***111***	***24***	5

* *Numbers given in bold italic indicate really unfavorable conditions for agricultural development and food security.*

** *Our source for the FSI, The Economist Intelligence Unit Limited (see section 2.3), does not present a value for Somalia. But the country is considered to be comparable to Central African Republic. See https://www.globalhungerindex.org/somalia.html.*

Table III The status of agriculture at the end of the observation period, expressed by fertilizer use, cereal availability, and productivity, for countries in yield growth rate classes 1–4 (cf. Figure 7). *

Country	Fertilizer use (kg/ha)	Availability of cereal equivalents (kg/cap./year)			Production of cereal equivalents (kg/cap. rural population/year	Yield growth rate class
	Last years of observation**	2000	2014	Difference 2014 with 2000	2014	
Algeria	17	250	304	54	1,013	2
Tunisia	29	348	390	42	1,182	3
South Africa	60	675	977	302	2,714	1
Egypt	539	288	216	- 77	***379***	1
Morocco	68	330	372	42	930	3
Botswana	59	***70***	***72***	2	***167***	4 = 5b
Zambia	41	459	672	213	1,120	1
Madagascar	***3***	342	540	198	818	1
Mauritania	***8***	***144***	***154***	10	***376***	2
Ghana	14	273	297	24	632	3
Cameroon	12	585	462	- 123	1,004	3
Angola	***5***	***108***	***162***	64	***284***	3
Nigeria	***6***	362	275	- 87	519	4
Tanzania	***6***	350	403	53	584	4
Ethiopia	17	***165***	368	203	***454***	1
Ivory Coast	41	255	273	18	581	2

Malawi	30	336	440	4	524	2
Rwanda	19	***121***	***200***	69	***278***	2
Uganda	***2***	330	342	12	***407***	3
Senegal	15	272	264	- 8	***463***	3
Benin	14	385	377	- 8	673	3
Sierra Leone	***(1)***	284	385	101	642	3
Mali	29	410	570	160	934	3
Burkina Faso	***8***	306	408	102	574	3
Guinea Bissau	***(7)***	312	255	- 57	500	3
Liberia	***(5)***	***161***	***143***	- 18	***280***	4
Chad	***(5)***	258	306	48	***392***	4
Djibouti	?	***119***	***152***	33	661	4?***

* *Numbers given in bold italic indicate really unfavorable conditions for agricultural development and food security.*

** *In parentheses: as no World Bank data for these years exist, other, less trusted sources were consulted.*

*** *Area of arable land too small for determination of the yield growth rate.*

Table IV The status of agriculture at the end of the observation period, expressed by fertilizer use, cereal availability, and productivity, for countries in yield growth rate classes 5 and 6 (cf. Figure 7). *

Country	Fertilizer use (kg/ha)	Availability of cereal equivalents (kg/cap./year)			Production of cereal equivalents (kg/cap. rural population/year)	Yield growth rate class
	Last years of observation **	2000	2014	Difference 2014 with 2000	2014	
Libya	38	***221***	***196***	25	891	5b
Namibia	12	***150***	***119***	- 31	***220***	5b
Gabon	15	403	272	- 131	2,092	5b
Congo	***1***	***112***	***93***	- 19	***266***	5b
Eswatini	?	***238***	***156***	- 82	***197***	5a
Kenya	28	256	***208***	- 48	***277***	5a
Zimbabwe	29	261	***182***	- 79	***272***	6
Sudan	***4***	258	268	10	***406***	5a
Eritrea	***4***	***72***	***67***	- 5	***85***	5a
Mozambique	***5***	***176***	***168***	- 8	***247***	5a
Burundi	***4***	***187***	***198***	11	***225***	5a
Togo	***4***	500	407	- 93	667	5a

DR Congo	***1***	***112***	***75***	- 37	***129***	5a
Lesotho	(17)	***144***	***84***	- 60	***115***	6
Guinea	2	360	312	- 48	***495***	6
Gambia	***1***	253	***195***	- 58	***476***	6
Niger	***1***	430	396	- 34	***483***	5a
Somalia	***0***	***60***	***48***	- 12	***79***	5a
CAR	***0***	408	360	- 48	600	5a

* *Numbers given in bold italic indicate really unfavorable conditions for agricultural development and food security.*

** *In parentheses: as no World Bank data for these years exist, other, less trusted sources were consulted.*

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Throughout the years Henk Breman and his colleagues have sought to combine in depth agricultural research with operational policy advice. As a policy maker I was impressed by their creativity and thorough knowledge of conditions in the field. In this book they bring together promising results of research and experience in a large group of countries. In a period of accelerated climate change, erratic rainfall, decreasing soil fertility and high population pressure an integrated approach to agricultural development, food security and poverty reduction, as recommended in this book, is crucial.

Jan Pronk

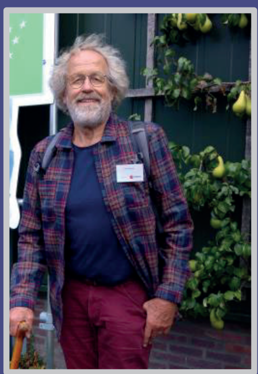
Nowhere in the World is the SDG agenda more relevant and urgent than in Africa. The present analysis is an important contribution to the debate on the future of Africa – and to achieving SDG2. I strongly commend this report to you and encourage you to delve deeper than just the abstract. Read on!

Ken Giller

The book is a tool for policy makers and their advisers, both in and beyond Africa, interested in furthering socio-economic development by investing in agriculture development. It provides a comparative analysis of agricultural development and agricultural policies in almost all African countries since 1960, and identifies socio-economic and agro-ecological determinants for success or failure. The authors claim that fertilizer use is the silver bullet in the quest for greater food security, welfare and economic development on the continent.

The book presents reasons for optimism. Agricultural development is taking off; in quite a few countries the increase in food production outstrips the population growth. However, in other countries food security is not or not sufficiently improving. Still one quarter of the African population is living in countries where crop yields have remained the same, or even have decreased, since the 1960s. This emphasizes the need to develop and support effective policies which can help accelerate agricultural development. Promoting sustainable fertilizer use should be a first step. The analysis is interspersed with examples and photographs from a wide range of countries. Almost thirty countries have been visited by at least one of the authors.

Henk Breman & Tom Schut



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