ATLAS OF AFRICAN AGRICULTURE RESEARCH & DEVELOPMENT

REVEALING AGRICULTURE'S PLACE IN AFRICA







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Edited by Kate Sebastian

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ABOUT THE MAPS

Where not otherwise cited, the administrative boundaries and names shown and the designations used on the maps are from Global Administrative Unit Layers 2013 from the Food and Agriculture Organization of the United Nations (www.fao.org/geonetwork/). The use of these data does not imply official endorsement or acceptance by the International Food Policy Research Institute; the CGIAR Consortium; the CGIAR Research Program on Climate Change, Agriculture and Food Security; the Food and Agriculture Organization of the United Nations; the Bill & Melinda Gates Foundation; or any of the contributing authors or institutions.

The 2013 boundaries and names used on the maps for Ruminant Livestock and Map 2 of Statistical Groupings were provided by the World Bank's Map Design Unit.

Where not otherwise cited, a total population figure for Africa of 1.03 billion was used, based on the United Nations's estimate for 2010 from The World Population Prospects: The 2012 Revision (http://esa.un.org/wpp/Excel-Data/population.htm). For mapping and analysis, the Global Population of the World (GPW) population data projected for 2010 from the Center for International Earth Science Information Network and the Centro Internacional de Agricultura Tropical (http://sedac.ciesin.columbia.edu/data/set/gpw-v3-centroids, accessed Feb. 4, 2014) were used.

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Contents

Foreword

Africa is a paradox. This vast continent is home to almost half of the world's uncultivated land fit for growing food crops—an estimated 202 million hectares—but much of it is off limits to farmers because it is difficult to farm or it is used for other purposes. Despite some recent economic successes, nearly a quarter of its population suffers from hunger, and Africa has the highest incidence of poverty in the world.

It has long been recognized that Africa needs to significantly and sustainably intensify its smallholder agriculture. Low-input, low-productivity farming has failed to keep pace with food demands from a rising population. But achieving sustainable increases in smallholders' productivity is not easy. In many areas erratic rainfall, poor soil fertility, and a lack of infrastructure and support services offer limited prospects and few incentives for poor farmers to invest in boosting productivity.

Comparing and contrasting where the challenges to and opportunities for growth in productivity are located, and doing so at multiple scales and over time, can give us powerful insights that can enrich our understanding of the variables that affect agricultural productivity. The *Atlas of African Agriculture Research & Development* presents a broad range of geospatial data that relate to strategic agriculture policy, investment, and planning issues. The maps and analyses will give anyone who wants to learn about the role of agriculture in Africa, or find new ways to boost agricultural performance, a sense of the increasingly diverse geospatial data resources that can inform their work and guide decisionmaking on agricultural development. A better understanding of current and evolving growing conditions and how to increase productivity, despite obstacles, should aid in tailoring more pragmatic solutions for poor smallholder farmers.

Shenggen Fan
Director General
International Food Policy Research Institute

Acknowledgments

This atlas was supported by funding from the Bill & Melinda Gates Foundation (BMGF), HarvestChoice, the CGIAR Consortium for Spatial Information (CGIAR-CSI), and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

An atlas covering such a broad set of topical issues on agricultural research and development in Africa required the expertise of many people who generously offered their time and insights. The editor, Kate Sebastian, and publisher, the International Food Policy Research Institute (IFPRI), wish to thank the following participating authors for their contributions and work as we created, refined, and finalized the content of the atlas: Christopher Auricht at Auricht Properties, Carlo Azzarri at HarvestChoice/IFPRI, Jason Beddow at the University of Minnesota (UMN), Nienke Beintema at Agricultural Science and Technology Indicators (ASTI)/IFPRI, Chandrashekhar Biradar at the International Center for Agricultural Research in Dry Areas (ICARDA), Jean-Marc Boffa at the World Agroforestry Centre (ICRAF), Giullano Cecchi at the Food and Agriculture Organization of the United Nations (FAO), Yuan Chai at UMN, Guiseppina Cinardi at FAO, Lieven Claessens at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Guilia Conchedda at FAO, Cindy Cox at HarvestChoice/IFPRI, John Dixon at the Australian Centre for International Agricultural Research (ACIAR), Petra Döll at Goethe University, Kathleen Flaherty at ASTI/IFPRI, Karen Frenken at FAO, Heidi Fritschel at IFPRI, Dennis Garrity at ICRAF, Marius Gilbert at Université Libre de Bruxelles, Zhe Guo at HarvestChoice/IFPRI, Jawoo Koo at HarvestChoice/IFPRI, Raffaele Mattioli at FAO, Tolulope Olofinbiyi at IFPRI, Felix Portmann at Senckenberg Research Institute, Navin Ramankutty at McGill University, Timothy Robinson at the International Livestock Research Institute (ILRI), Alexandra Shaw (consultant), Stefan Siebert at the University of Bonn, Gert-Jan Stads at ASTI/IFPRI, Philip Thornton at CCAFS/ILRI, Antonio Trabucco at Euro-Mediterranean Center on Climate Change (CCMC), Justin Van Wart at the University of Nebraska, Klaus von Grebmer at IFPRI, Doris Wiesmann (consultant), William Wint at the Environmental Research Group Oxford, Stanley Wood at BMGF, Ulrike Wood-Sichra at HarvestChoice/IFPRI, Sandra Yin at IFPRI, Yisehac Yohannes at IFPRI, and Robert Zomer at ICRAF-China.

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- Michael Morris and Raffaello Cervigni of the World Bank's Agriculture and Rural Development, Africa Region group, who collaborated on the Ruminant Livestock analysis, which was partially funded by the World Bank as part of a study on vulnerability and resilience in African drylands; and
- Jeffrey Lecksell and Bruno Bonansea of the World Bank's Map Design Unit, who provided the country, lake, and continent boundaries used in the Ruminant Livestock and World Bank income group maps.

The development of this atlas has been enriched by the support and advice of Deanna Olney and the main reviewer, Gershon Feder. It also benefited from the copyediting of IFPRI's Patricia Fowlkes and John Whitehead and proofreading by Heidi Fritschel and Andrew Marble. The atlas would not be the product it is without the valuable input of IFPRI editor, Sandra Yin; designer, David Popham; and head of publications, Andrea Pedolsky.

Abbreviations and Acronyms

ACIAR	Australian Centre for International Agricultural Research
AEZ	agroecological zone
AgGDP	agricultural gross domestic product
ASTI	Agricultural Science and Technology Indicators
CAADP	Comprehensive Africa Agriculture Development Program
CCAFS	Climate Change, Agriculture and Food Security
CERES	Crop Environment Resource Synthesis
CGIAR-CSI	CGIAR Consortium for Spatial Information
CIESIN	Center for International Earth Science Information Network
CIMMYT	International Maize and Wheat Improvement Center
CMCC	Euro-Mediterranean Center on Climate Change
CRU-TS	data from the University of East Anglia's Climate Research Unit Time Series
CV	coefficient of variation
DHS	Demographic and Health Surveys
DSSAT	Decision Support System for Agrotechnology Transfer
ERGO	Environmental Research Group Oxford
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Statistics Division of the FAO and FAO's primary portal for its statistical database
FCC	Soil Functional Capacity Classification System
FTE	full-time equivalent (refers to researchers)
GADM	Global Administrative Boundaries
GAUL	Global Administrative Unit Layers
GCWM	Global Crop Water Model
GDD	growing degree days
GHI	Global Hunger Index
GIS	Geographic Information Systems
GLC2000	Global Land Cover for the year 2000
GMTS	data from the University of Delaware's Gridded Monthly Time Series
GNI	average national income
GRUMP	Global Rural-Urban Mapping Project
GYGA-ED	Global Yield Gap Atlas Extrapolation Domain
ha	hectares
ICARDA	International Center for Agricultural Research in Dry Areas
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDO	intermediate development outcome
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
ILRI	International Livestock Research Institute
ISRIC	World Soil Information
kg	kilograms
km	kilometers
LGP	length of growing period
MIRCA	monthly irrigated and rainfed crop areas
mm	millimeters
MODIS	Moderate Resolution Imaging Spectroradiometer

MSc	master of science degree
NEPAD	New Partnership for Africa's Development
PET	potential evapotranspiration
pH	measure of acidity
PhD	doctoral degree
PPP	purchasing power parity
R&D	research and development
RS	remote sensing
RUE	rain-use efficiency
SPAM	Spatial Production Allocation Model
SSA	Africa south of the Sahara
UMN	University of Minnesota
UN	United Nations
UNSALB	United Nations Second Administrative Level Boundaries
US$	United States dollars
VoP	value of production
WASP	Weighted Anomaly of Standardized Precipitation
WDI	World Development Indicators
WHO	World Health Organization
WorldClim	global climate data layers

Introduction

The *Atlas of African Agriculture Research & Development* is a multifaceted resource that highlights the ubiquitous nature of smallholder agriculture in Africa; the many factors shaping the location, nature, and performance of agricultural enterprises; and the strong interdependencies among farming, natural resource stocks and flows, rural infrastructure, and the well-being of the poor.

Organized around 7 themes, the atlas covers more than 30 topics. Maps illustrate each topic, complemented by supporting text that discusses the content and relevance of the maps, the underlying source data, and where to learn more. The atlas is part of an eAtlas initiative that includes plans for an online, open-access resource of spatial data and tools generated and maintained by a community of research scientists, development analysts, and practitioners working in and for Africa.

The atlas got its start in 2009, when Joachim von Braun, a former director general of IFPRI, was invited to head up the development of the first CGIAR Strategy and Results Framework (SRF). He asked Stanley Wood, then coordinator of the CGIAR Consortium on Spatial Information (CSI), to assemble relevant spatial data and analysis to support the analytical work of the SRF team. Wood first turned to the geographic information system (GIS) specialists at the CGIAR centers to contribute to that effort. Over time researchers at other organizations were invited to contribute.

The many partners and contributors to the atlas share a belief that a better understanding of the spatial patterns and processes of agriculture research and development in Africa can contribute to better-targeted policy and investment decisions and, ultimately, to better livelihoods for the rural poor.

To learn more about the eAtlas initiative, visit http://agatlas.org.

POLITICAL, DEMOGRAPHIC, AND INSTITUTIONAL CLASSIFICATIONS

Administrative Boundaries

Kate Sebastian

WHAT IS THIS MAP TELLING US?

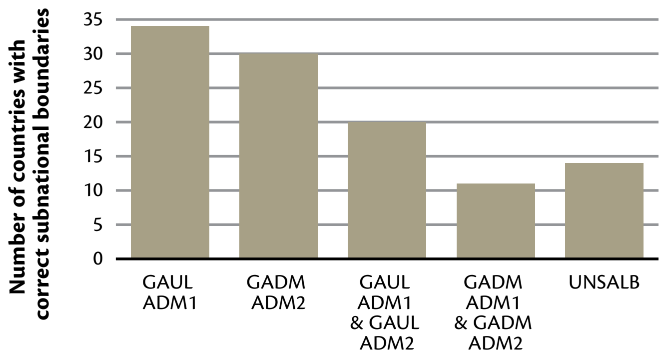
The most common ways to present data for research, demographic, political, and other reporting purposes is by administrative unit or the unit of measure that recognizes the political boundaries and area of a country. The map shows Africa divided into nation equivalent (zero-level) units. The majority of these zero-level units represent countries that are further divided into smaller subnational (first-level) units, such as departments or states, which vary in size and number per country.

Drawing boundary lines is often easier said than done. Discrepancies occasionally occur due to faulty input data or, on occasion, disputed land areas. An example of this is the Hala'ib Triangle, a small area of land over which both Egypt and Sudan claim sovereignty. Most of the reporting in this atlas is done at a regional level and both Egypt and Sudan fall in the northern region so the regional reporting is not affected. Additionally, South Sudan gained its independence as a country in 2011 so it is shown separately on the maps unless the data reported are country-level statistical data that predate 2011. In such cases South Sudan is not separately designated (for example, p. 75).

WHY IS THIS IMPORTANT?

As more aid is dispensed and research decisions are made based on the visualization and mapping of data, it is increasingly important that the boundaries be both accurate and precise. In creating this atlas, for consistency's sake, it was imperative that each map use the same administrative boundaries. There are a number of publicly available worldwide boundary datasets but the Food and Agriculture Organization of the United Nations' (FAO) Global Administrative Unit Layers (GAUL) is the standard used in the atlas, because it constantly revises and updates administrative boundaries to present the most up-to-date data available, and it has the highest boundary accuracy rate for the developing countries of Africa (Figure 1) when compared to the Global Administrative Boundaries (GADM) and the UN's Second Administrative Level Boundaries. Using consistent boundaries allows users to easily compare data by region and even identify patterns. For example, a quick look at cropland area by region (p. 16) and the average value of staple food crop production by region (p. 30) shows that southern Africa not only has the smallest share of total area devoted to cropland but also the lowest productivity.

FIGURE 1 **Accuracy of different administrative boundary datasets**



Source: Adapted from Brigham, Gilbert, and Xu 2013.

Note: GADM=Global Administrative Boundaries; GAUL=Global Administrative Unit Layers (FAO); UNSALB=UN Second Administrative Level Boundaries; ADM1=First-level administrative boundaries; ADM2=Second-level administrative boundaries.

Knowing that the same boundaries were used across the maps gives the reader confidence that these values are based on the same area totals and thus can be analyzed together.

WHAT ABOUT THE UNDERLYING DATA?

GAUL country boundaries and disputed areas are from the UN Cartographic Section (FAO 2013). The secondary boundaries are based on information gathered from both international and national sources. Data are continuously being updated and corrected and are released yearly. The data are licensed strictly for noncommercial use by FAO, which cannot be held accountable for the accuracy, reliability, or content of the information provided. This is important to note due to the political nature of the data. Thus, by presenting these boundaries, FAO, and subsequently the organizations involved in this atlas, are not expressing an opinion concerning the legal status of any area or its authorities or concerning the delimitation of its boundaries.

WHERE CAN I LEARN MORE?

GAUL 2013 boundaries: www.fao.org/geonetwork/

GADM boundaries: www.gadm.org

UNSALB boundaries: http://bit.ly/RJ12kD

MAP 1 Country and first-level administrative boundaries

Data source: FAO 2013.

Statistical Groupings

Stanley Wood and Kate Sebastian

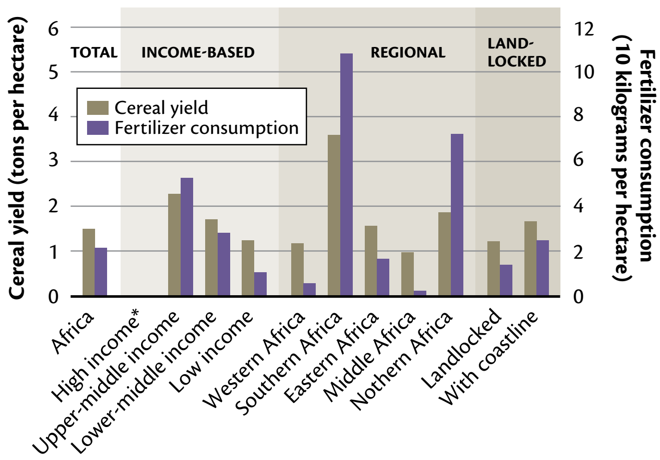
WHAT ARE THESE MAPS TELLING US?

The agriculture research and development community makes extensive use of two primary sources of national statistics: those compiled by the Food and Agriculture Organization of the United Nations (FAO), and those compiled by the World Bank. When presenting summary statistics across countries in Africa, however, the two organizations use different regional aggregation approaches. FAO data, accessible through its FAOSTAT portal, are summarized by five geographically contiguous, subregional country groupings: northern Africa, western Africa, middle Africa, eastern Africa, and southern Africa (Map 1). The World Bank on the other hand uses an income-based grouping schema for data accessible through its World Development Indicators (WDI) portal. Map 2 reflects the World Bank's four categories of average national income per person (GNI per capita in US dollars): low (<$1,025), lower middle ($1,026–$4,035), upper middle ($4,036–$12,475), and high ($12,475<) income (World Bank 2013a).

WHY IS THIS IMPORTANT?

FAO regional aggregates better reflect similarities in agroecology, language and culture, and market integration opportunities across contiguous constituent countries. World Bank aggregates reflect similarity in the narrowly defined status of economic development across geographically dispersed countries (although the sources of economic growth—such as minerals or agriculture or the exploitation of other natural resources such as timber—can vary widely among countries in the same economic development category). As shown in the graphical comparison of different aggregates in Figure 1, including, for further contrast, total Africa and a split between landlocked and nonlandlocked country groupings (Map 3), different regional aggregation schema provide significantly different insights into the variation of key agricultural performance indicators. Not shown in the maps for reasons of scale are small African island nations, such as Cape Verde in western Africa and Reunion in southern Africa. While geographically dispersed, they often face common development challenges and opportunities (for instance, limited food production potential, sea level rise, and large tourist populations). The different logical groupings of nations often translate into formal country associations that represent and promote their specific common interests. The Convention on Transit Trade of Land-locked States and the Small Island Developing States is one example.

FIGURE 1 Comparing different aggregates, cereal yields and fertilizer use, 2010



Data source: FAO 2012a; FAO 2012b; World Bank 2013b.

Note: Because the figure is based on values from 2010, statistics do not include South Sudan (independent since 2011), in the landlocked countries total. Cereal crops include barley, buckwheat, canary seed, fonio, maize, millet, oats, quinoa, rice, rye, sorghum, triticale, and wheat. Fertilizer consumption is based on fertilizer application for all crops.

*Data unavailable.

WHAT ABOUT THE UNDERLYING DATA?

FAO compiles and disseminates agricultural production, consumption, price, input, land use, and related food and nutrition indicators from country-reported data, while the World Bank primarily compiles and harmonizes a broader range of cross-sectoral and macroeconomic data from FAO, the International Monetary Fund, the International Labour Organization, the World Health Organization, and other primary sources. Of particular note, however, are the global responsibilities of FAO and the World Bank to derive, track, and report on the Millennium Development Goal indicators of hunger and poverty respectively.

WHERE CAN I LEARN MORE?

FAO's primary data portal, FAOSTAT, including extensive metadata descriptions: http://faostat3.fao.org

Other FAO reports and data sets: http://www.fao.org/publications/

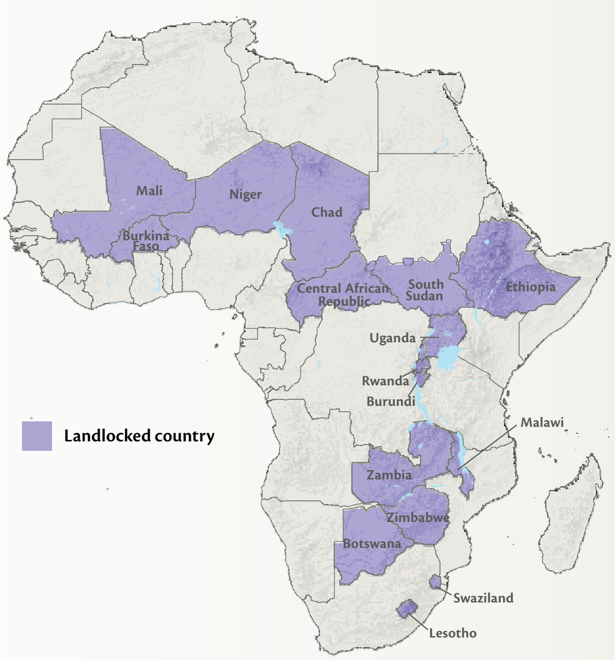
The World Bank's WDI data portal: http://bit.ly./1aS5CmL

Extensive WDI poverty-specific datasets: http://bit.ly/1d7kk9U

MAP 1 FAO regional groups

MAP 2 World Bank income groups

MAP 3 Landlocked countries



Data source: Map 1—FAO 2012a; Map 2—World Bank 2013b and Lecksell/World Bank 2013; Map 3—Authors.

Public Agriculture R&D Investments

Gert-Jan Stads, Nienke Beintema, and Kathleen Flaherty

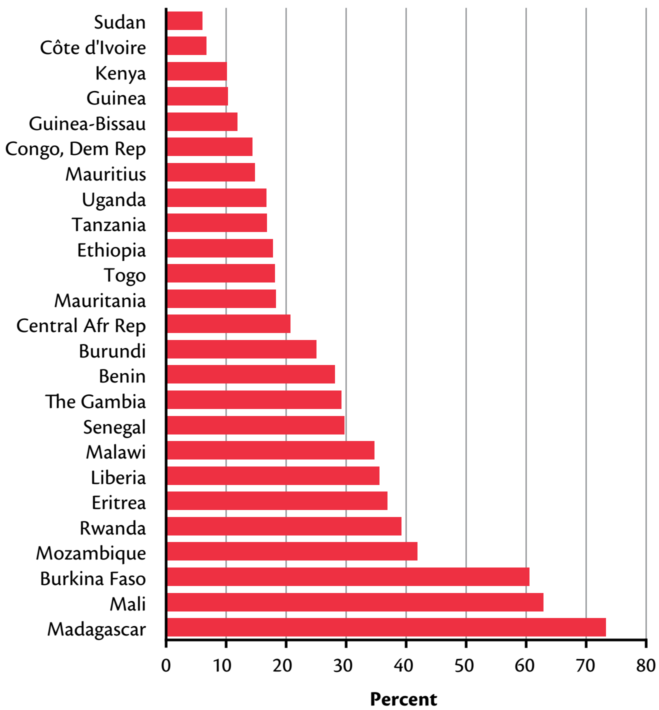
WHAT ARE THESE MAPS TELLING US?

Growth in public agriculture research and development (R&D) spending levels in Africa south of the Sahara (SSA) varied widely from 2008 to 2011 (Map 1). Continent-wide growth was driven by a handful of larger countries. However, 13 of the 39 countries for which Agricultural Science and Technology Indicators (ASTI) data are available experienced negative annual growth in public agricultural R&D spending during 2008/09–2011.[1] Another way of comparing commitment to public agricultural R&D investment across countries is to measure intensity (Map 2)—that is, total public agricultural R&D spending as a percentage of agricultural output (AgGDP). Overall investment levels in most countries are still well below the levels required to sustain agricultural R&D needs. In 2011, SSA as a whole invested 0.51 percent of AgGDP on average. Just 10 of the 39 countries met the investment target of one percent of AgGDP set by the African Union's New Partnership for Africa's Development (NEPAD). Some of the smallest countries in Africa, such as Lesotho, Swaziland, Burundi, Eritrea, and Sierra Leone, have such low and declining levels of investment that the effectiveness of their national agricultural R&D is questionable. In addition, compared with other developing regions, agricultural R&D is highly dependent on funding from donor organizations and development banks such as the World Bank (Figure 1). This type of funding has been highly volatile over time, leaving research programs vulnerable and making long-term planning difficult.

WHY IS THIS IMPORTANT?

A closer look at growth in public agricultural R&D investment levels over time reveals important cross-country differences and challenges. While the intensity ratio of investment (measured as a share of AgGDP) provides a relative measure of a country's commitment to agricultural R&D, monitoring investments is also key to understanding agriculture R&D's contribution to agricultural growth. Research managers and policymakers can use agricultural R&D spending information to formulate policies and make decisions about strategic planning, priority setting, monitoring, and evaluation. The data are also needed to assess the progress of the Comprehensive Africa Agriculture Development Program (CAADP), which is designed to boost investments in agricultural growth through research, extension, education, and training.

FIGURE 1 Donor funding as a share of total agriculture R&D funding, 2011



Source: ASTI 2013.

Note: Donor funding includes loans from development banks and funding from subregional organizations. Figure excludes countries with donor shares of less than 5 percent.

WHAT ABOUT THE UNDERLYING DATA?

The data are from primary surveys of 39 countries in SSA conducted during 2012–2013 by ASTI and national partners. ASTI provides comprehensive datasets on agricultural R&D investment and capacity trends and institutional changes in low- and middle-income countries. The datasets are updated at regular intervals and accessible online.

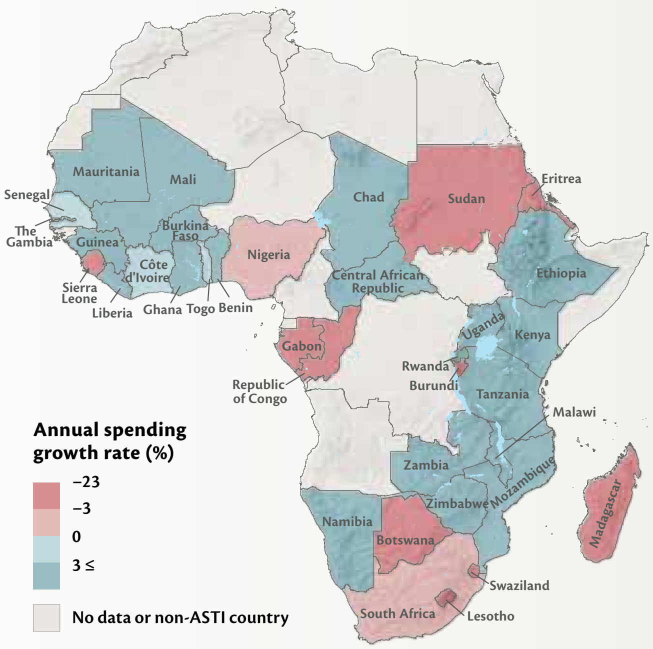
WHERE CAN I LEARN MORE?

ASTI datasets, publications, and other outputs by country: www.asti.cgiar.org/countries

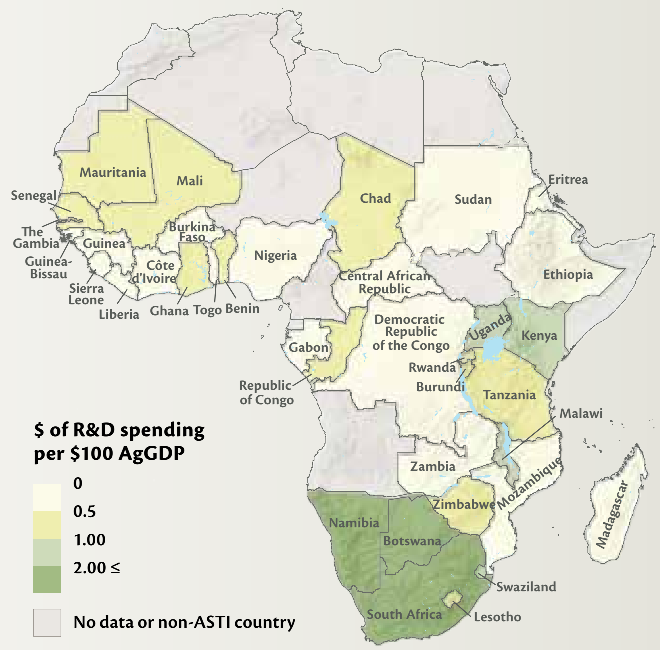
ASTI methodology and data collection procedures: www.asti.cgiar.org/methodology

1 Due to scale, not all ASTI countries are visible on the maps.

MAP 1 Change in public agriculture R&D spending levels, 2008–2011



MAP 2 Intensity of agriculture R&D spending, 2011



Data source: ASTI 2013.

Notes: AgGDP=agricultural output. Intensity of agricultural R&D spending=public agricultural R&D spending per $100 of agricultural output.

Africa's Agricultural Research Pool

Nienke Beintema, Gert-Jan Stads, and Kathleen Flaherty

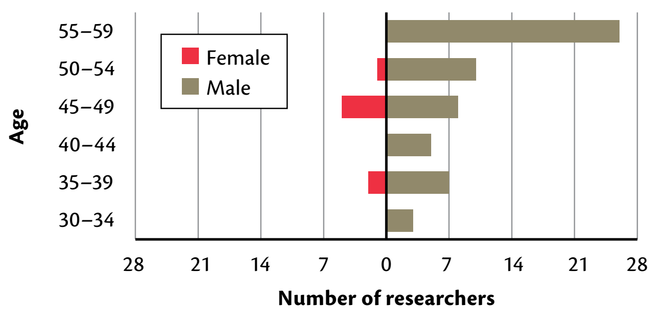
WHAT ARE THESE MAPS TELLING US?

Absolute levels of staffing in public agriculture research and development (R&D) vary considerably across the 39 countries in Africa south of the Sahara participating in the Agricultural Science and Technology Indicator (ASTI) survey (Map 1). In 2011, Ethiopia, Ghana, Kenya, Nigeria, South Africa, Sudan, and Tanzania each employed more than 500 full-time equivalent (FTE) researchers. In contrast, 11 countries employed fewer than 100 FTE researchers each.[1] Despite recent challenges, many western African countries have maintained relatively large pools of well-qualified researchers (those holding PhD and MSc degrees) (Map 2). In contrast, less than half of researchers in Botswana, the Democratic Republic of the Congo, Eritrea, Ethiopia, Guinea, Guinea-Bissau, Lesotho, Liberia, Mozambique, and Zimbabwe hold graduate degrees. Map 3 shows the number of FTE researchers per 100,000 people who are economically active in agriculture. While the overall average for ASTI countries is 7 FTE researchers per 100,000, only Botswana, Cape Verde, Gabon, Mauritius, Namibia, Nigeria, and South Africa each employ more than 20 FTEs per 100,000 agriculture sector workers.

WHY IS THIS IMPORTANT?

There is growing concern about the ability of African agriculture research and development (R&D) systems to respond to current and emerging development challenges. Some of Africa's smallest countries have such low, and in a few instances, declining levels of researcher numbers that the effectiveness of their national agricultural R&D systems is questionable. Structural problems also persist in the age and sex composition of R&D personnel (Figure 1 provides a national example), where the limitations of an aging research workforce and knowledge base are exacerbated by the low participation of female researchers (especially when compared to their much broader participation in the sector as farmers, farm workers, and traders). Furthermore, despite stable growth in the number of agricultural researchers, many research agencies experienced high staff turnover as a consequence, in part, of researchers retiring from the workforce (Beintema and Stads 2011). Aging scientist populations and the deterioration of average degree levels in many countries imply a chronic erosion of domestic innovation capacity. Ongoing monitoring of national agriculture research capacity can contribute to the formulation of appropriate responses.

FIGURE 1 Age and sex structure of agricultural R&D staff: Senegalese Agricultural Research Institute, 2008



Source: Sène et al. 2012.

WHAT ABOUT THE UNDERLYING DATA?

Underlying primary data are from 39 national surveys conducted during 2012–2013 by the ASTI initiative and national partners. ASTI generates and curates comprehensive and comparable agriculture R&D institutional, investment, and capacity data for low- and middle-income countries. The datasets are periodically updated and are accessible online.

WHERE CAN I LEARN MORE?

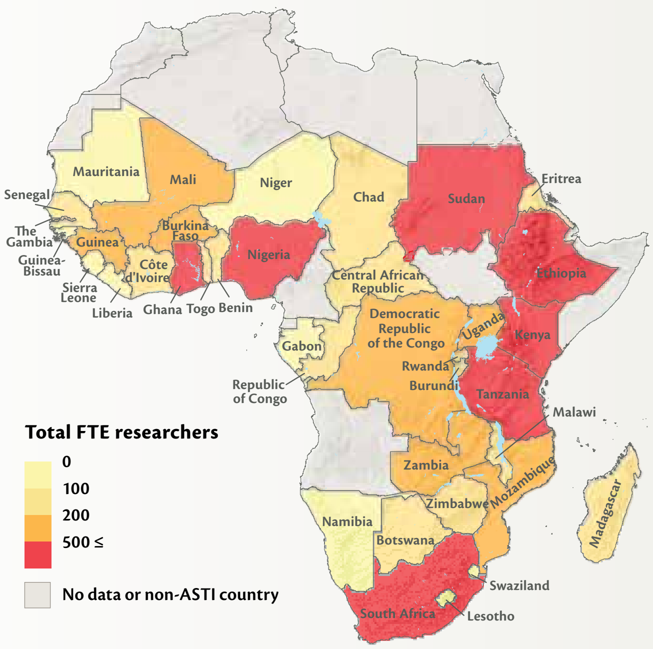
ASTI datasets, publications, and other outputs by country: www.asti.cgiar.org/countries

ASTI methodology and data collection procedures: www.asti.cgiar.org/methodology

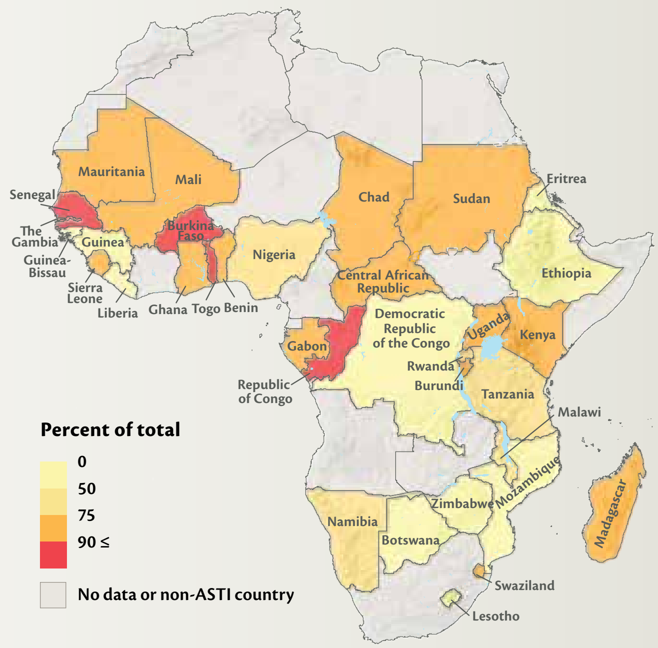
Other ASTI resources: www.asti.cgiar.org/about

1 Due to scale, not all ASTI countries are visible on the maps.

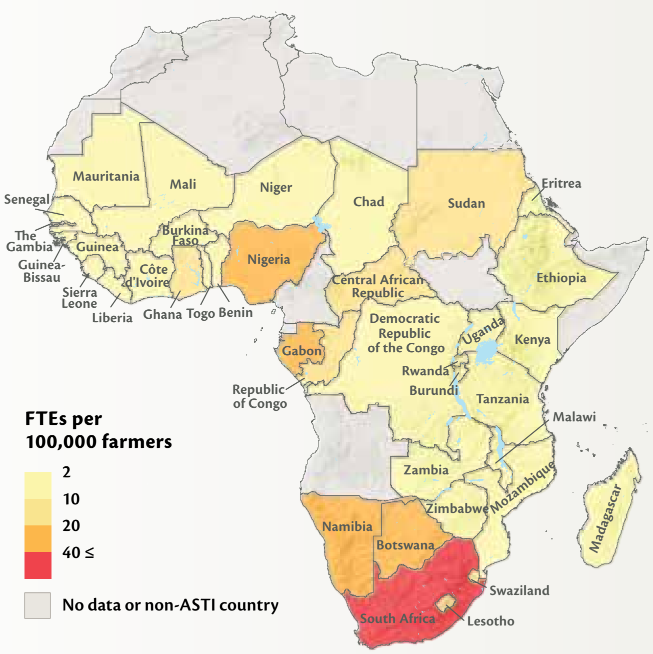
MAP 1 Number of agricultural researchers, 2011



MAP 2 Share of agricultural researchers with postgraduate degrees, 2011



MAP 3 Concentration of agricultural researchers, 2011



Data source: Maps 1 and 2—ASTI 2013; Map 3— ASTI 2013 and FAO 2013.

Notes: Maps 1 and 3—FTE=full-time equivalent. FTE values take into account only the proportion of time spent on research and development; Map 2—Researchers with postgraduate degrees earned PhDs or MScs; Map 3—Farmers include all agricultural sector workers.

ASTI
Agricultural Science & Technology Indicators

IFPRI
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

CGIAR Research Program on Dryland Systems

Chandrashekhar Biradar

WHAT IS THIS MAP TELLING US?

The map shows the distribution of dryland agricultural production systems (also known as the CGIAR Research Program on Dryland Systems) in Africa. Dryland systems are characterized by low and erratic precipitation, persistent water scarcity, extreme climatic variability, high susceptibility to land degradation, including desertification, and higher than average loss rates for natural resources, such as biodiversity. The lack of water is the main factor that limits profitable agricultural production. Dryland systems consist of combinations of plant and animal species and management practices farmers use to pursue livelihood goals based on several factors including climate, soils, markets, capital, and tradition. Dryland Systems is a multidisciplinary research program that aligns the research of CGIAR research centers and partners. It aims to tackle complex development issues in two key strategic research themes known as intermediate development outcomes (IDOs). The first IDO focuses on low-potential and marginal drylands and developing strategies and tools to minimize risk and reduce vulnerability. The second IDO focuses on higher-potential dryland regions and supporting sustainable intensification of agricultural production systems. Within each large target area, a number of representative action sites and complementary satellite sites serve as test sites where most of the research will be conducted. These sites—which include the Kano-Katsina-Maradi Transect in Nigeria and Niger; Wa-Bobo-Sikasso Transect in Ghana, Burkina Faso, and Mali; Tolon-K and Cinzana along West African Sahel and dryland savannas in Ghana and Mali; the Nile Delta in Egypt; Béni Khedache-Sidi Bouzid inTunisia; the Ethiopian Highlands; and Chinyanja Triangle in Malawi, Zambia, and Mozambique—were identified based on criteria relating to aridity index, length of growing period, market access, hunger and malnutrition, poverty, environmental risk, land degradation, and demography.

TABLE 1 Dryland Systems sites in Africa, 2013

Action Sites	IDO1	IDO2
Area (ha)	32,861,151	60,865,568
Population	924,092	18,621,053
Households	184,818	3,724,211

Source: Author.
Note: IDO=intermediate development outcomes.

WHY IS THIS IMPORTANT?

The goal of the Dryland Systems research program is to identify and develop resilient, diversified, and more productive combinations of crop, livestock, rangeland, aquatic, and agroforestry systems that increase productivity, reduce hunger and malnutrition, and improve quality of life for the rural poor. The research program aims to reduce the vulnerability of rural communities and entire regions across the world's dry areas by sustainably improving agricultural productivity. The map provides a starting point for implementing interventions for intermediate development outcomes. It also can help researchers extrapolate from the research outcomes at action sites to target areas and scale up better interventions to target regions over time.

WHAT ABOUT THE UNDERLYING DATA?

The Remote Sensing (RS)/Geographic Information Systems (GIS) Units of the participating CGIAR centers characterized dryland systems to delineate target areas, action sites, and complementary satellite sites, using various spatial layers, such as aridity index (p. 55), length of growing period (p. 57), access to markets (p. 66), environmental risk, land degradation, and additional criteria from regional and representative target region perspectives (CGIAR 2012).

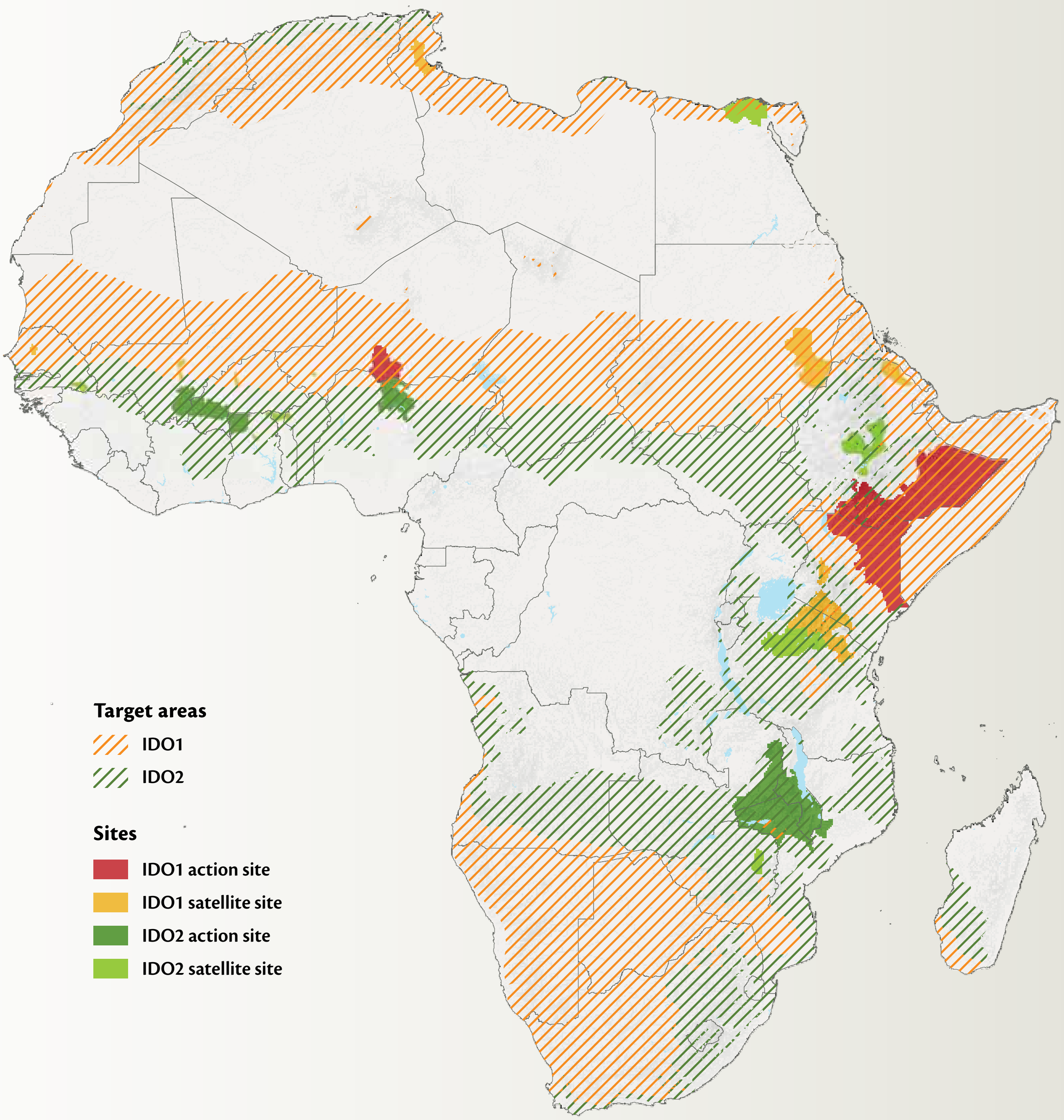
WHERE CAN I LEARN MORE?

Dryland Systems: http://drylandsystems.cgiar.org

ICARDA Geoinformatics: http://gu.icarda.org

Dryland Systems and Other CGIAR Research Programs: http://bit.ly/1eQnJdC

MAP 1 Dryland Systems action sites and target research areas



Data source: GeoInformatics Unit/ICARDA 2013.

Note: IDO=intermediate development outcomes. Action sites are representative areas of major widespread agroecosystems where initial intervention takes place to identify best approaches and top priorities for scaling out to large areas (target regions). Satellite sites are complementary (back-up) action sites.

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FOOTPRINT OF AGRICULTURE

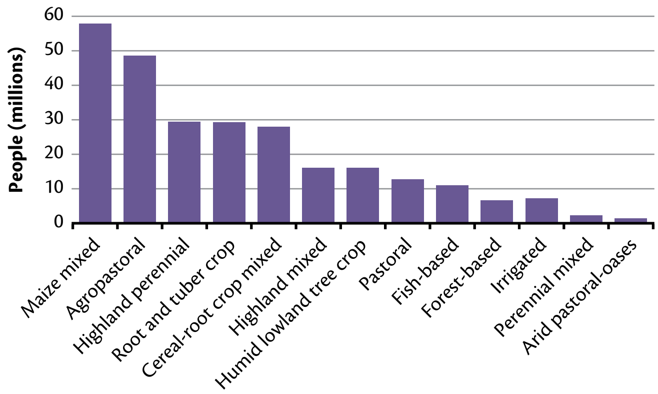
Farming Systems of Africa

Christopher Auricht, John Dixon, Jean-Marc Boffa, and Dennis Garrity

WHAT IS THIS MAP TELLING US?

Populations within the same farming system share similar farming practices and livelihood strategies. As the map shows, many farming systems in Africa exhibit a strong geographical pattern, extending across northern Africa and Africa south of the Sahara (SSA), reflecting a mix of factors, including climate, soils, and markets. In SSA, 16 percent of land area is dominated by the maize mixed farming system, mostly in the eastern, central, and southern regions. This farming system is home to nearly 100 million rural people, of whom 58 million live on less than $1.25 a day (Figure 1), representing 23 percent of the total rural poor in SSA. The highland areas of eastern and southern Africa feature smaller fragmented systems, such as the highland perennial and highland mixed systems that cover just 2 percent of the area, but are home to 11 and 6 percent, respectively, of SSA rural poor. A large share of the rural poor live in the agropastoral farming system (18 percent), root and tuber crop system (11 percent), and cereal-root crop mixed system (10 percent), which combined cover more than one-third of SSA's area.

FIGURE 1 **Rural poor living on ≤ $1.25/day by farming system, Africa south of the Sahara, 2010**



Data source: Dixon, Boffa, and Garrity 2014; Azzarri et al. 2012; UN 2013.

Note: See glossary for definitions of specific farming systems. Poverty data calibrated to 2010.

WHY IS THIS IMPORTANT?

Broadly similar farming systems share recognizable livelihood patterns and similar development pathways, infrastructure, and policy needs. Delineating major farming systems provides a framework to guide the development and targeting of strategic agricultural policies and interventions to reduce poverty and promote the adoption of more sustainable land use practices. This classification can help policymakers and scientists target institutional innovations and technologies to specific farming systems, thereby focusing planning, policies, and research. In this respect, high potential farming systems with good market access might benefit most from improved maize, cowpeas, and dairy, while drier areas might benefit from improved sorghum, millet, and livestock, because these contrasting farming systems offer different ways to improve livelihoods. Similarly, fertilizer policies should take into account the different nutrient requirements and markets of various crops in different farming systems.

WHAT ABOUT THE UNDERLYING DATA?

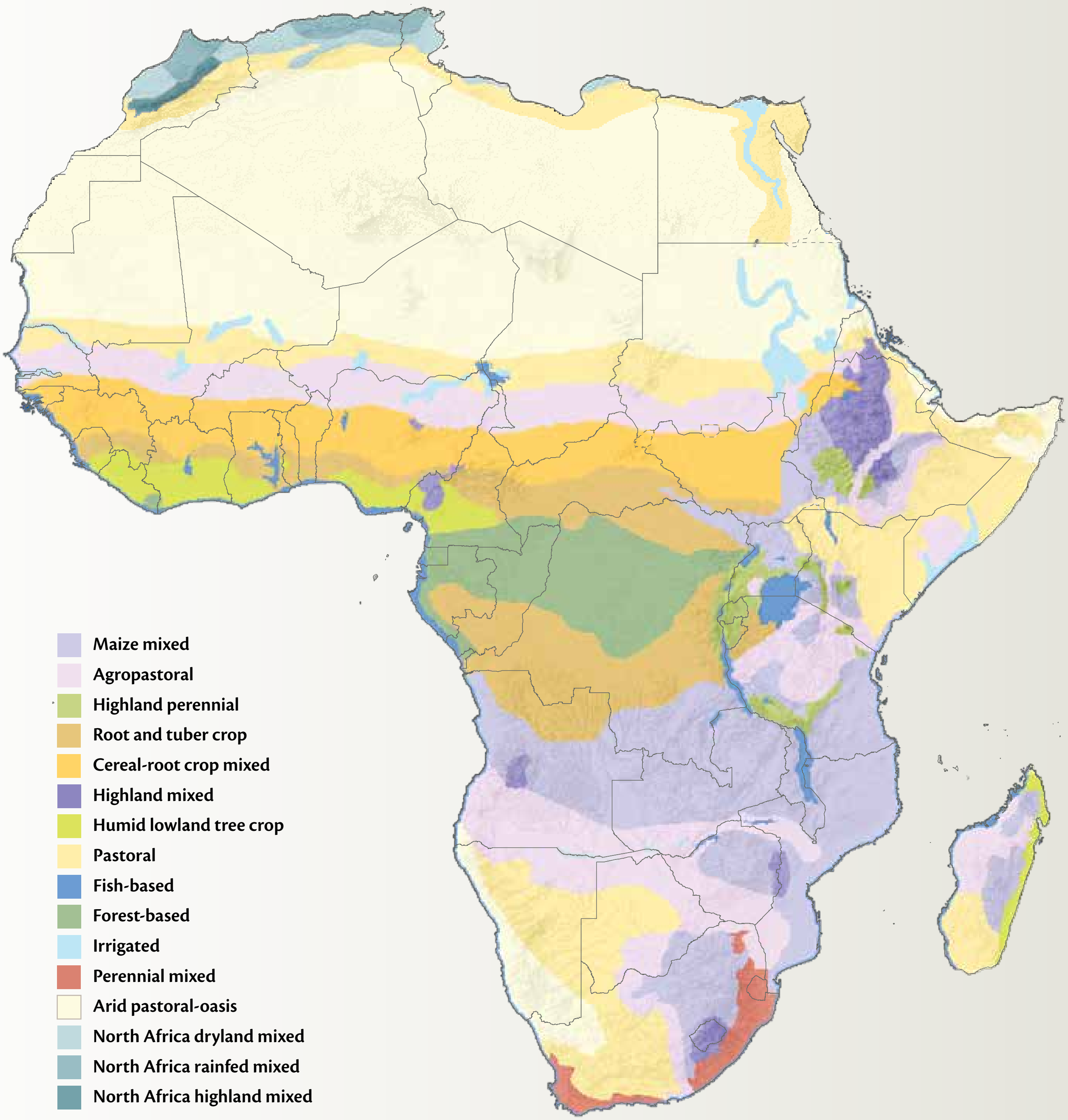
Farming systems are defined based on: available natural resources (including water, land area, soils, elevation, and length of growing period); population; cropping and pasture extent; the dominant pattern of farm activities and household livelihoods; and access to markets. The spatial characterization of African farming systems used data on agroecological and socioeconomic variables. The two main spatial variables were length of growing period (FAO/IIASA 2012) and distance to markets (HarvestChoice 2011; Map 1, p. 67), supplemented by data on population and poverty, elevation, soils and irrigation, crop and livestock patterns, productivity, and change over time (Dixon et al. 2014; FAO 2013a–e). A multidisciplinary team of experts for each farming system identified system characteristics, emergent properties, drivers of change and trends, and priorities. This work updates and expands the analysis of the African farming systems in the World Bank and FAO farming systems and poverty assessment (Dixon et al. 2001).

WHERE CAN I LEARN MORE?

Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. Dixon et al. 2001. http://bit.ly/1dDekBW

Understanding African Farming Systems: Science and Policy Implications. Food Security in Africa: Bridging Research into Practice. Garrity et al. 2012. http://bit.ly/1h8lmGJ

MAP 1 Farming systems of Africa



Data source: Dixon, Boffa, and Garrity 2014.
Note: See glossary for definitions of specific farming systems.

Australian Government
Australian Centre for International Agricultural Research
Food and Agriculture Organization of the United Nations

Cropland and Pastureland

Navin Ramankutty

WHAT ARE THESE MAPS TELLING US?

Map 1 shows the extent of cropland, and Map 2 shows the extent of pastureland circa 2000. The values are presented as a percentage of each ~100 km² grid cell. Pastureland covers one-quarter of the African continent (Table 1) and dominates the landscape in the Sahel and Sudano-Sahelian regions in the west, the Maghreb, much of eastern and southern Africa, and western Madagascar. The only portions of the continent not grazed are those that are too hot and too dry, such as the Sahara, and the tropical rain forests of the Congo Basin. Cropland covers approximately 7 percent of the continent. Western Africa has the greatest proportion at 39 percent. High concentrations of cropland (60≤ percent) can be found along the Mediterranean coast in the Nile Valley, Nigeria, the Ethiopian highlands, the Rift Valley north and west of Lake Victoria, and South Africa near Cape Town and north of Lesotho. Low-to-moderate cropland intensity (20–60 percent) extends from Nigeria to Senegal and can be found in parts of Sudan, and scattered throughout southeastern Africa.

WHY IS THIS IMPORTANT?

These maps of cropland and pastureland provide critical pieces of information used to analyze food security and agriculture's environmental impact. More accurate assessments of the land under cultivation and areas potentially available for expansion could help improve food security. For instance, in Africa south of the Sahara—one of the only regions in the world where increases in food production have not kept pace with population growth—the land area suitable for cultivation is estimated to be nearly five times what is currently in production. Knowledge of pasturelands is similarly vital to food security because livestock provide not only a source of food but also income, insurance, soil nutrients, employment, traction (for instance, plowing), and clothing (Thornton and Herrero 2010). However, both grazing and planting also contribute to environmental degradation (Foley et al. 2005) and already have modified a large part of the African continent. Overgrazing contributes to land degradation, further diminishing soil health, plant productivity and diversity, and by extension, livestock production. Grazing is also a significant source of methane emissions, a potent greenhouse gas that contributes to climate change.

TABLE 1 Cropland and pastureland by region, c. 2000

Region	Crop Area		Pasture area		Total area	
	(000 sq km)	Share of total (%)	(000 sq km)	Share of total (%)	(000 sq km)	Share of total (%)
Eastern Africa	501	23.4	2,404	31.3	6,172	20.9
Middle Africa	249	11.6	1,144	14.9	6,448	21.8
Northern Africa	374	17.5	1,603	20.9	8,266	27.9
Southern Africa	172	8.0	1,380	18.0	2,683	9.1
Western Africa	842	39.4	1,149	15.0	6,031	20.4
Total	2,138	100.0	7,680	100.0	29,599	100.0

Data source: Ramankutty et al. 2008 and FAO 2012.
Note: sq km=square kilometers.

WHAT ABOUT THE UNDERLYING DATA?

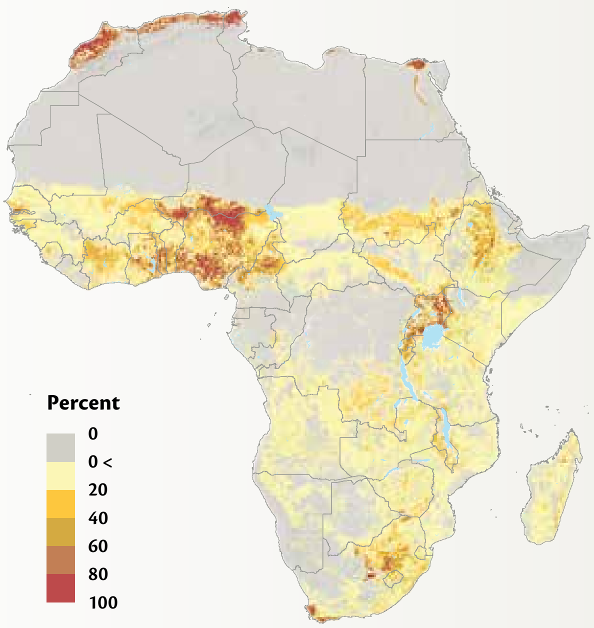
The distribution and intensity of croplands and pastures are expressed as a percentage of the area within each ~100 km² grid cell. The maps represent "arable land and permanent crops" and "permanent meadows and pastures," respectively, as defined by the Food and Agriculture Organization of the United Nations (FAO 2013). Data for both maps derive from integrating administrative-level agricultural statistics with global land cover classification data from satellite remote sensing using a statistical data fusion method (Ramankutty et al. 2008). The agricultural statistics for Africa came mainly from FAO's national statistics (FAOSTAT 2012), supplemented with subnational statistics for Nigeria and South Africa. Two different sources of satellite-based land cover classification data were merged: the MODIS land cover dataset from Boston University (Friedl et al. 2010) and the GLC2000 dataset (Bartholomé and Belward 2005) from the European Commission (both at 1 km spatial resolution).

WHERE CAN I LEARN MORE?

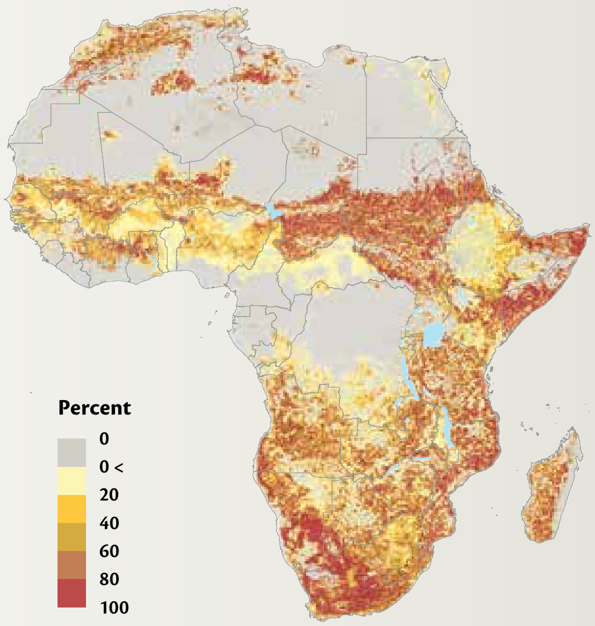
Download crop and pasture data at EarthStat: www.earthstat.org

"Farming the Planet. Part 1: The Geographic Distribution of Global Agricultural Lands in the Year 2000." Ramankutty et al. 2008: http://bit.ly/1ctE7Nf

MAP 1 Cropland, c. 2000



MAP 2 Pastureland, c. 2000



Data source (all maps): Ramankutty et al. 2008.

Notes: All values are expressed as a percentage of the area within each ~100 km² grid cell. Cropland=arable land and permanent crops; pastureland=permanent meadows and pastures, as defined by the Food and Agriculture Organization of the United Nations (FAO 2013).

McGill

Irrigated Areas

Stefan Siebert and Karen Frenken

WHAT IS THIS MAP TELLING US?

Total area equipped for irrigation in Africa is 13.5 million hectares (ha) of which 11.5 million ha are actually under irrigation (Figure 1). The map shows the countries with the largest amount of area equipped for irrigation are Egypt (3.5 million ha), Sudan and South Sudan (1.9 million ha), South Africa (1.5 million ha), and Morocco (1.5 million ha). All of these countries face arid climate conditions. In Madagascar where it is more humid, rice is cultivated on about 1 million ha of irrigated land. These six countries account for almost 60 percent of the area equipped for irrigation in Africa. The regions with the highest density of irrigated land (50 percent or greater of the grid cell)[1] are located mainly in northern Africa in the Nile River Basin (Egypt, Sudan) and in the countries next to the Mediterranean Sea (Morocco, Algeria, Tunisia, Libya).

WHY IS THIS IMPORTANT?

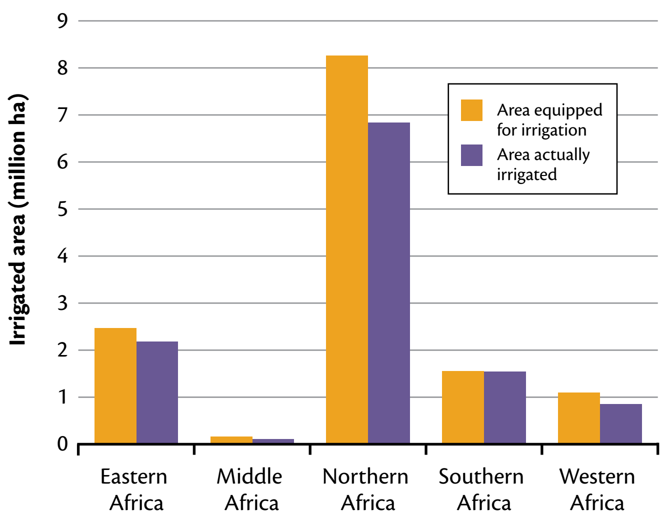
Since the beginning of crop cultivation, irrigation has been used to compensate for the lack of precipitation. In rice cultivation, irrigation also controls the water level in the fields and suppresses weed growth. Crop yields are higher and the risk of crop failures is lower in irrigated agriculture. Because the risk of drought stress is lower on irrigated land, farmers are more likely to spend on other inputs like fertilizers. Irrigation may also increase cropping intensity (p. 28), allowing farmers to cultivate several crops per year on the same field. It is important, therefore, when assessing crop productivity and food security, to consider the availability of irrigation infrastructure.

Irrigation represents the largest use of freshwater in Africa. Many dams were constructed to improve the supply of irrigation water, thereby modifying river discharge and increasing evaporation from artificial lakes. Extraction of groundwater for irrigation is increasingly of concern, because it has lowered groundwater tables in important aquifers. Use of irrigation results in an increase of evapotranspiration and reduces the land's surface temperature. Information on the extent of irrigated land is therefore also important for hydrological studies and regional climate models.

WHAT ABOUT THE UNDERLYING DATA?

The map shows the area equipped for irrigation as a percentage of a 5 arc-minute grid cell. It was derived from version 5 of the Digital Global Map of Irrigation Areas (Siebert et al. 2013a). The map was developed by combining subnational irrigation statistics for 441 administrative units derived from national census surveys and from reports available at the Food and Agriculture Organization of the United Nations and other international organizations with geospatial information on the position and extent of irrigation schemes. Statistics for the year closest to 2005 were used if data for more than one year were available. Geospatial information on position and extent of irrigated areas was derived by digitizing a large number of irrigation maps derived from inventories based on remote sensing (Siebert et al. 2013b).

FIGURE 1 Area equipped for irrigation and area actually irrigated per region, c. 2005



Data source: Siebert et al. 2013a and FAO 2012.

WHERE CAN I LEARN MORE?

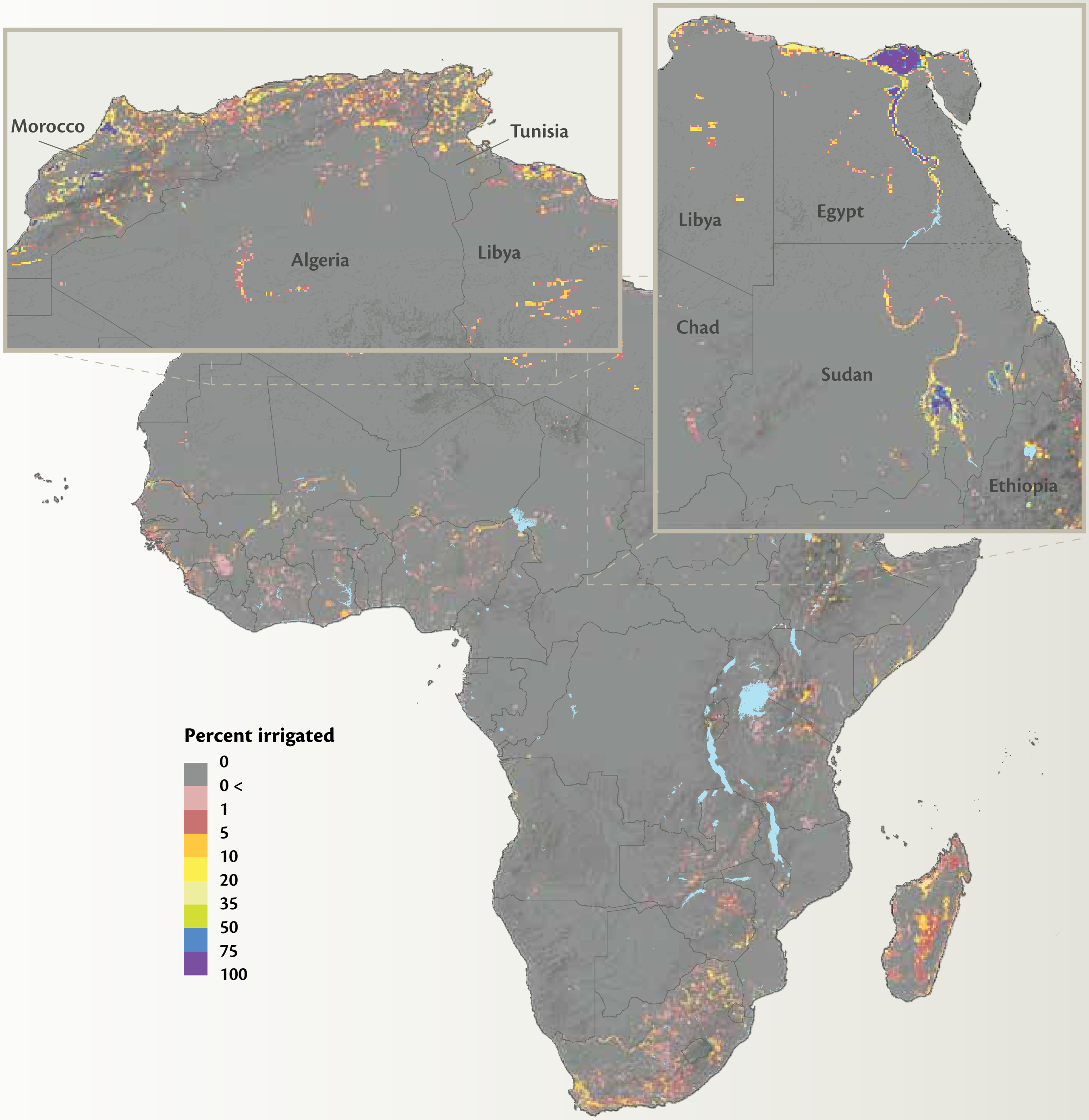
Global Map of Irrigation Areas (Version 5): http://bit.ly/1eHpDex

Update of the Digital Global Map of Irrigation Areas to Version 5. Siebert et al. 2013b: http://bit.ly/1cM6bip

Development and Validation of the Global Map of Irrigation Areas. Siebert et al. 2005.

1 Each cell measures approximately 100 km² or 10,000 hectares at the equator.

MAP 1 Extent of irrigated areas, c. 2005



Data source: Siebert et al. 2013a.

Note: The percent values represent the share of each 100 km² cell that is equipped for irrigation.

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Cereal Crops

Ulrike Wood-Sichra

WHAT ARE THESE MAPS TELLING US?

Cereals are grown in all of Africa except for desert and forested areas. The cereal area is about 30 percent maize, 23 percent sorghum, 21 percent millet, 9 percent wheat (Maps 1–4), and 9 percent rice. Maps 1–3 show that maize is prevalent throughout Africa and the densest areas for sorghum and millet, with more than 3,000 hectares per cell,[1] are just south of the Sahel. Wheat (Map 4) is grown in high concentrations in northern Africa, with sparser areas in eastern and southern Africa. In the last 50 years, the harvested areas of maize, millet, and sorghum each doubled from a base of 10–15 million hectares to 20–30 million hectares (Figure 1). Rice areas have nearly quadrupled, from 2.8 to 9.3 million hectares. Yields have notably climbed for maize and wheat during the same period, rising from 0.7 to 2.3 metric tons per hectare for wheat and doubling from 1.0 to 2.0 for maize (Figure 2). Rice yields have increased by more than half, from about 1.5 to 2.5 metric tons per hectare. Millet and sorghum yields show little change (FAO 2012).

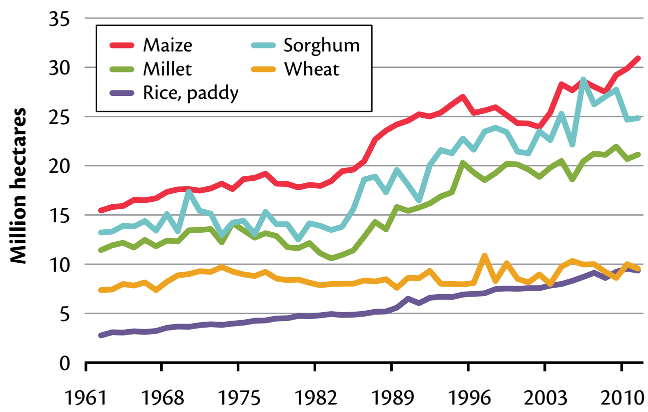
WHY IS THIS IMPORTANT?

Cereals account for 50 percent of the average daily caloric intake in Africa. Wheat and rice are particularly important, accounting for 30 percent and 16 percent of cereal calories consumed, respectively. Cereal production in Africa is substantial, but it is not enough to meet demand; the continent must import about 55 percent of consumed wheat and more than 30 percent of consumed rice (FAO 2012). Understanding where half of the continent's calories (both vegetal and animal) are grown, and how intensively, is vital to increasing productivity and enhancing food security. Identifying areas where new or improved rice- and wheat-growing technologies could have the most impact can also aid in making the continent less dependent on imports.

WHAT ABOUT THE UNDERLYING DATA?

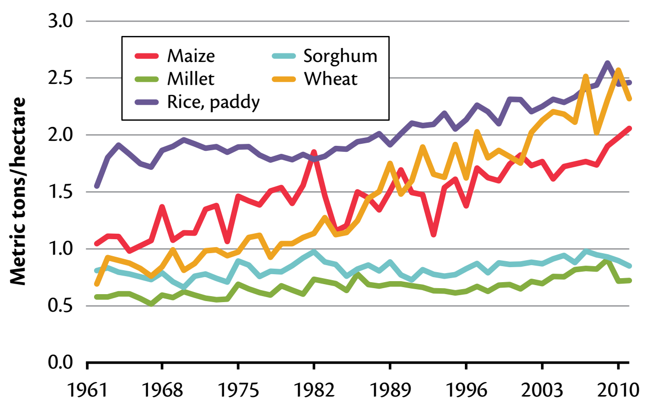
The maps are based on area harvested per cell, calculated using the Spatial Production Allocation Model (SPAM) 2000 (You et al. 2012). The model uses many datasets, including land cover recorded by satellites, crop suitability maps under various water regimes and production systems, irrigation maps (p. 19), subnational crop statistics from each country, country totals from the Food and Agriculture Organization of the United Nations (FAO 2012), and data on production systems within each country.

FIGURE 1 Area harvested of top five cereal crops



Data source: FAO 2012.

FIGURE 2 Yield of top five cereal crops



Data source: FAO 2012.
Note: One metric ton=1,000 kilograms.

WHERE CAN I LEARN MORE?

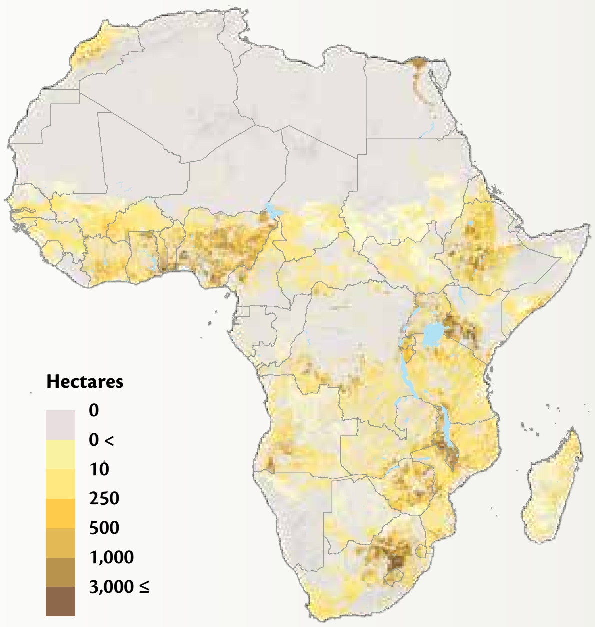
SPAM: The Spatial Production Allocation Model: http://mapspam.info

Food and Agriculture Organization of the United Nations Statistics Division database: http://faostat3.fao.org

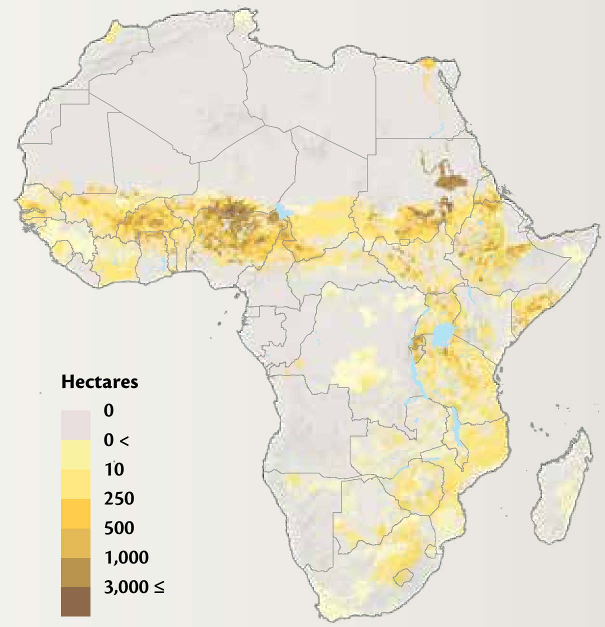
1 Each cell measures approximately 100 km² or 10,000 hectares at the equator.

Cereal crop area harvested, 2000

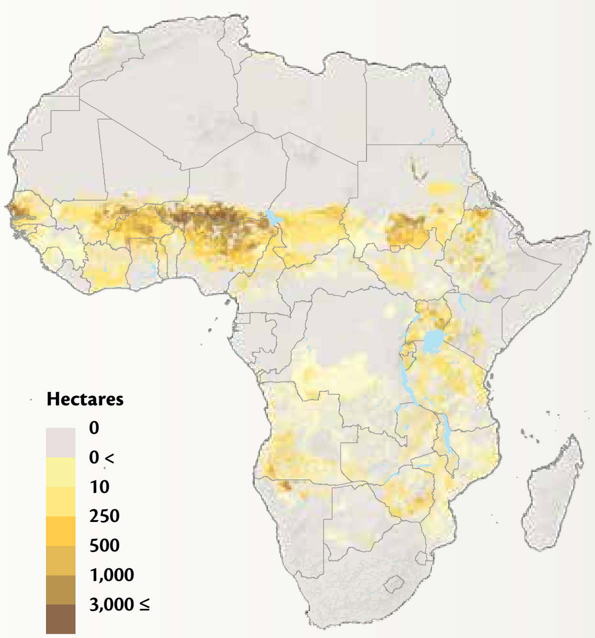
MAP 1 Maize



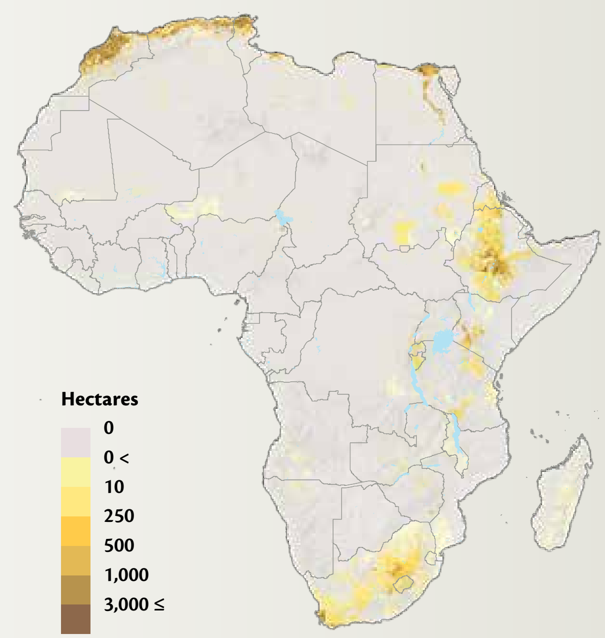
MAP 2 Sorghum



MAP 3 Millet



MAP 4 Wheat



Data source (all maps): You et al. 2012.

Note: The values on the maps represent the number of hectares harvested per 100 km^2 cell.

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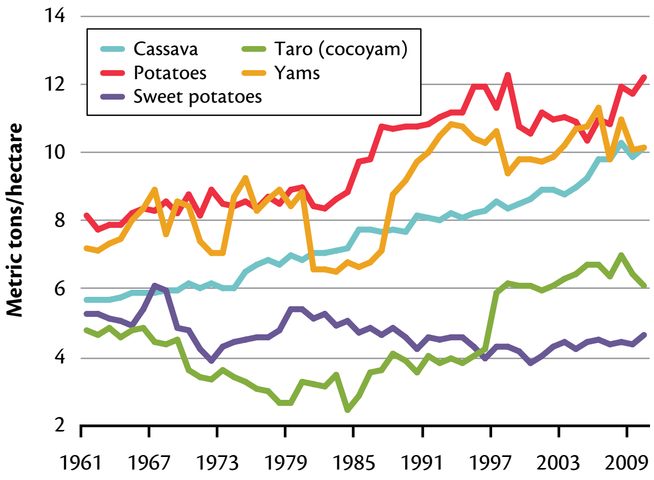
Root Crops

Ulrike Wood-Sichra

WHAT ARE THESE MAPS TELLING US?

The area devoted to harvest root crops in Africa has grown significantly over the last 50 years. Cassava area has more than doubled, from 5.5 million to 12 million hectares (ha); sweet potato area has more than quintupled, from 600,000 to 3.3 million ha; and potato area has grown more than six-fold, from 250,000 to 1.8 million ha. Cassava and sweet potatoes continue to be among the most important root crops in Africa, with cassava occupying about half of the root crops area and sweet potatoes about 14 percent. South of the Sahel, cassava and sweet potatoes are grown in similar areas (Maps 1 and 2). Both are grown intensively, with 1,000 or more ha per cell,[1] in the southeast corner of Nigeria, in the eastern part of Uganda, and in Rwanda and Burundi. Potatoes are becoming a more important part of Africa's crop mix, although they currently account for only 8 percent of the harvested area and are grown in just a few African countries (Map 3). While harvested area of root crops has expanded considerably since 1961, yields per hectare have increased significantly for only some crops (Figure 1). Cassava yields have notably improved by about 80 percent, from less than 6 to roughly 10 metric tons per hectare. Potato yields have also fared well, increasing by about half from about 8 to 12 metric tons per hectare. Taro and yam yields grew more modestly, by 41 percent and 26 percent to 6 and 10 metric tons per hectare, respectively. Sweet potato yields, however, have hovered around 5 metric tons per hectare for decades and even shown a slight downward trend over the past 30 years (FAO 2012).

FIGURE 1 Yield of top five root crops



Data source: FAO 2012.

Note: One metric ton = 1,000 kilograms.

WHY IS THIS IMPORTANT?

Africa needs to improve yields and the share of nutrient-rich roots and tubers in the diet of its growing population. Roots and tubers contribute only about 13 percent of the calories in the average African's diet, which is a smaller portion than other staples. But roots, especially cassava, are "insurance crops" that increase food security because they can be left in the ground until needed. Nearly all the sweet potato crop (85 percent) is destined for human consumption. But cassava is also important as fodder, and more than a third produced goes to animal feed. Most of the roots and tubers consumed are grown locally. Thus, policymakers and agricultural experts can use the maps to identify areas that might benefit from larger harvests of roots and tubers, and by extension, improve nutrition at the local level.

WHAT ABOUT THE UNDERLYING DATA?

The maps are based on area harvested per cell, calculated by the Spatial Production Allocation Model (SPAM) 2000 (You et al. 2012). The model uses many datasets, including land cover recorded by satellites, crop suitability maps under various water regimes and production systems, irrigation maps, subnational crop statistics from each country, Food and Agriculture Organization of the United Nations' country totals (FAO 2012), and data on production systems within each country.

WHERE CAN I LEARN MORE?

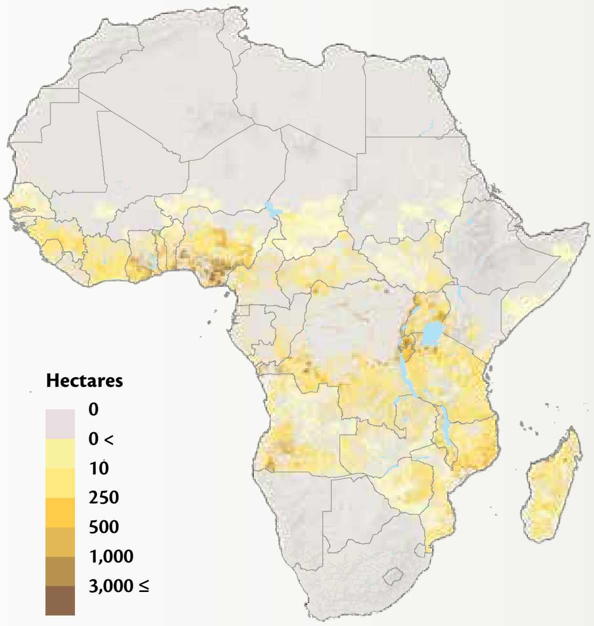
SPAM: The Spatial Production Allocation Model: http://mapspam.info

Food and Agriculture Organization of the United Nations statistical database: http://faostat3.fao.org

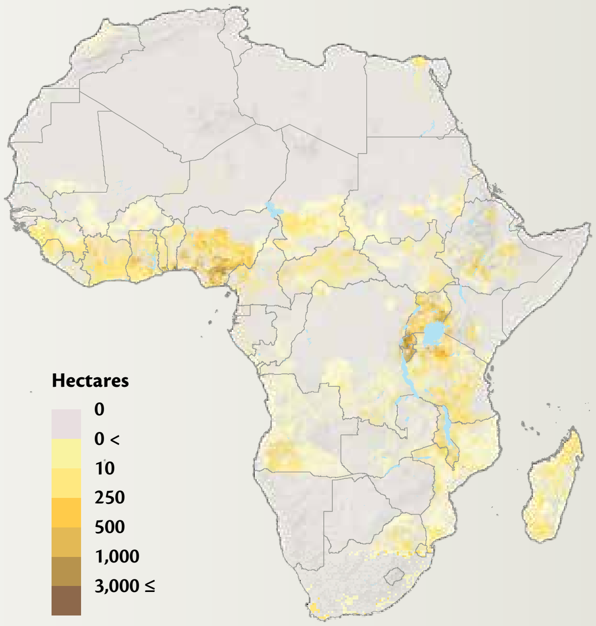
1 Each cell measures approximately 100 km² or 10,000 hectares at the equator.

Root crop area harvested, 2000

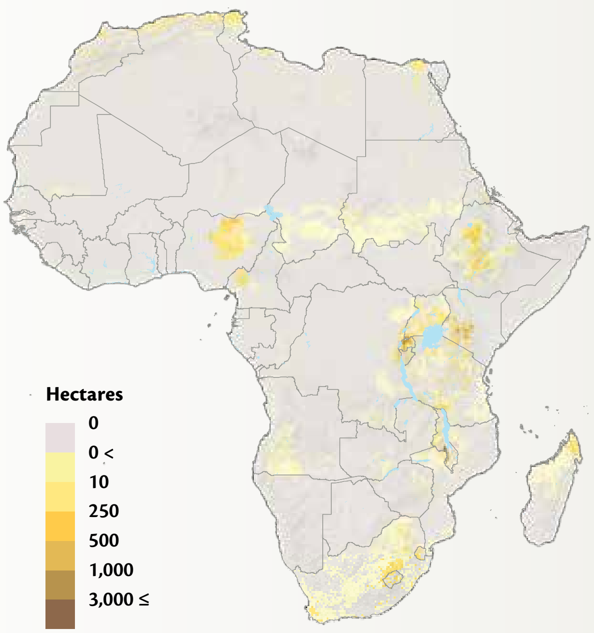
MAP 1 Cassava



MAP 2 Sweet potato



MAP 3 Potato



Data source (all maps): You et al. 2012.

Note: The values on the maps represent the number of hectares harvested per 100 km² cell.

Livestock and Mixed Crop-Livestock Systems

Philip Thornton

WHAT IS THIS MAP TELLING US?

Livestock-producing agricultural systems cover 73 percent of Africa and stretch across several climates (Map 1). To some extent, these climates determine what type of farming is practiced. In Africa, livestock-producing systems are broken into two main categories: livestock and mixed crop-livestock. These systems exist in three common African climates: arid/semiarid, humid/subhumid, and temperate/tropical highlands. Livestock systems are most prevalent on grazing lands in arid climates that cover large swaths of Africa. Mixed crop-livestock farming systems are either rainfed or irrigated. Rainfed systems are much more common (although areas of Sudan and Egypt have important irrigated mixed systems that present different opportunities and constraints). There are many mixed crop-livestock systems throughout western Africa, eastern Africa, and parts of southern Africa. The Congo Basin, in central Africa, is mostly forest, with some savanna and cropland at its outer edges. As a result, the Basin is home to a small number of livestock systems relative to the rest of the continent and only a smattering of mixed crop-livestock systems.

WHY IS THIS IMPORTANT?

Many studies have found the influences of crop and livestock production vary considerably, not only regionally but also according to production system (Robinson et al. 2011). Globally, but particularly in Africa and Asia, crops and livestock are often interdependent and influence farmer households and livelihoods in a number of ways. Detailed knowledge of crop and livestock systems and their distribution allows researchers to measure impacts on everything from the environment to livestock disease risk. For example, viewing the livestock density by type and region helps researchers measure the level of environmental impact (Table 1). Classification of agricultural systems can also provide a framework for predicting the evolution of the agricultural sector in response to changing demography and associated shifts in food demand, land use (for example, competition for land from food, feed, and biofuel production), and climate.

WHAT ABOUT THE UNDERLYING DATA?

The systems classification is based on Seré and Steinfeld (1996). In livestock systems, more than 90 percent of dry matter fed to animals comes from rangelands, pastures, annual forages, and purchased feeds, and less than 10 percent of the total value of production (VoP) comes from nonlivestock farming activities. Mixed crop-livestock farming systems are systems in which more than 10 percent of the dry matter fed to animals comes from crop by-products (for example, stubble) or more than 10 percent of the total VoP comes from nonlivestock farming activities. The systems were mapped using various mapped data sources, including land cover data, irrigated areas, human population density, and length of growing period (LGP). The climate categories are defined as follows: arid/semi-arid has an LGP ≤ 180 days; humid/subhumid has an LGP > 180 days; and the temperate/tropical highlands climate is based on specific LGP, elevation, and temperature criteria. The systems classifications have several weaknesses, including differences in estimates of the amount of Africa's cropland, depending on the data used, thus, there is some uncertainty in identifying the mixed crop-livestock systems. Researchers are now using other data sources to break down the mixed systems of the Seré and Steinfeld classification by dominant food and feed crop categories (Robinson et al. 2011).

TABLE 1 Livestock density by region, 2005

REGION	TYPE OF LIVESTOCK average number/km²		
	Cattle	Sheep	Goat
Northern Africa	5	10	5
Middle Africa	3	1	2
Eastern Africa	14	6	9
Western Africa	6	10	12
Southern Africa	7	11	4
AFRICA	**7**	**7**	**7**

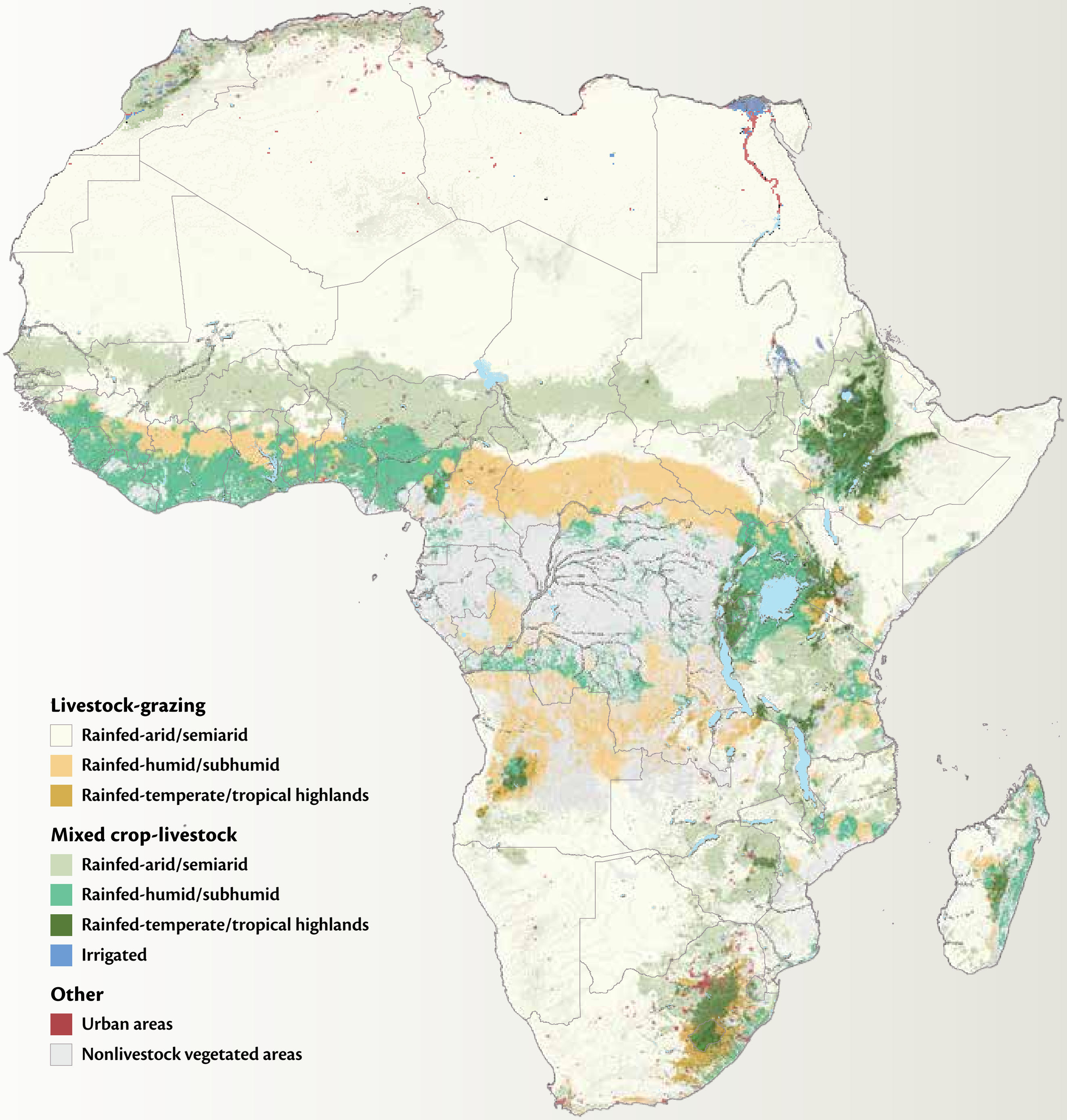
Data source: Robinson et al. 2011 and FAO 2012.

WHERE CAN I LEARN MORE?

Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. Dixon et al. 2001.

Global Livestock Production Systems. Robinson et al. 2011.

MAP 1 Livestock production systems by climate zone



Data source: Robinson et al. 2011.
Note: The mixed categories represent a mix of crop and livestock systems.

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Ruminant Livestock

Timothy Robinson, William Wint, Giulia Conchedda, Guiseppina Cinardi, and Marius Gilbert

WHAT ARE THESE MAPS TELLING US?

Ruminant livestock are raised across large parts of Africa where environmental conditions allow (Maps 1–4). Cattle, sheep, and goats are the most widespread, while camels are restricted to drier areas, particularly in the Horn of Africa and the arid parts of western Africa. These maps of ruminant distribution should, however, be used in conjunction with the livestock production systems map (p. 25) to better understand the systems and climate zones where ruminant livestock are found. The role of livestock varies greatly depending on the production system. The heavily forested areas and hyperarid deserts of Africa have very low densities of livestock. In arid and semiarid regions of Africa, where the potential for crop growth is limited, cattle, sheep, goats, and camels are raised in low productivity, pastoral (extensive livestock grazing) systems in which ambulatory stock can take advantage of seasonal, patchy vegetation growth. In these areas, raising livestock is the only viable form of agriculture. In the more settled humid, subhumid, and tropical highland areas, cattle and small ruminants largely live in the same areas as the human population. In these mixed crop-livestock farming systems, livestock can increase crop production by providing draft power and manure, and by enhancing labor productivity. At the same time, organic material not suited for human consumption can be converted into high-value food and nonfood products, such as traction, manure, leather, and bone.

WHY IS THIS IMPORTANT?

Poverty in Africa remains widespread (p. 77). One quarter of the world's estimated 752 million poor livestock keepers live in Africa south of the Sahara (SSA), where more than 85 percent of them live in extreme poverty (Otte et al. 2012). Agricultural productivity gains and diversification into high-value products such as livestock are essential ways of raising rural incomes and improving food security in such areas. For three reasons—the large share of the rural poor who keep livestock, the important contributions livestock can make to sustainable rural development, and the fast-growing demand for livestock products—diversification into livestock and increased livestock productivity must play an integral role in strategies to reduce poverty and increase agricultural productivity. Progress in poverty reduction will require well-targeted interventions to promote economic growth that the poor can contribute to and from which they can benefit. Livestock maps such as these, along with other information such as poverty and production systems, can contribute significantly to better targeting.

WHAT ABOUT THE UNDERLYING DATA?

The Gridded Livestock of the World database (Wint and Robinson 2007) provided the first modelled livestock densities of the world, adjusted to match official national estimates for the reference year 2005 (FAO 2007), at a spatial resolution of 3 arc-minutes (about 25 km² at the equator). Recent methodological improvements have significantly enhanced these maps. More up-to-date and detailed subnational livestock statistics have been collected; a new, higher resolution set of predictor variables based on multitemporal Moderate Resolution Imaging Spectroradiometer (MODIS) imagery is used; and the analytical procedure has been revised and extended to include a more systematic assessment of the model accuracy. While the observed, subnational statistics vary in date and resolution, the maps are standardized so that the national totals match the official estimates for 2006 (FAO 2013).

WHERE CAN I LEARN MORE?

Download the data from the Livestock-Geo-Wiki Project: http://livestock.geo-wiki.org

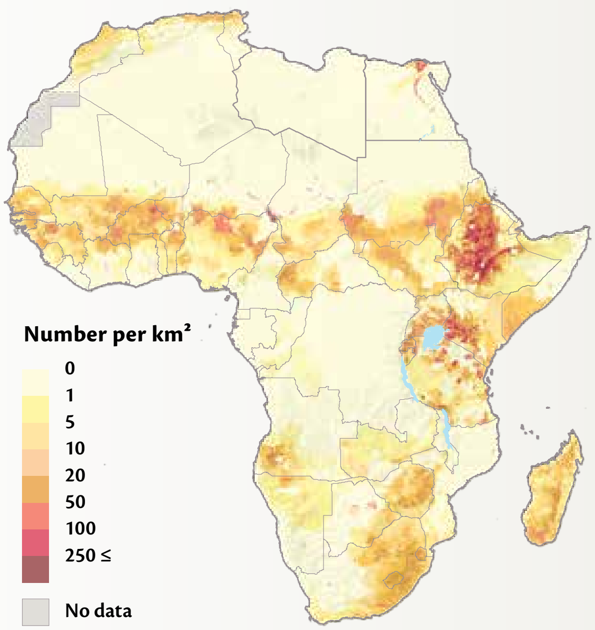
"Mapping the Global Distribution of Livestock." Robinson et al. 2014.

"The Food and Agriculture Organization's Gridded Livestock of the World." Robinson, Franceschini, and Wint 2007.

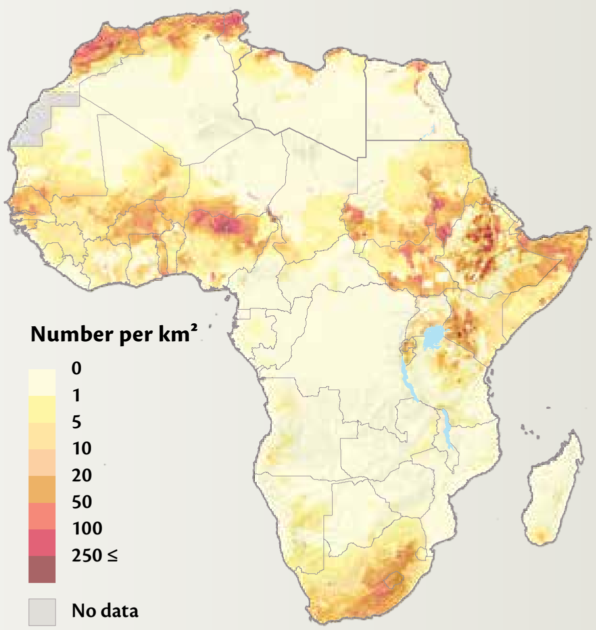
Gridded Livestock of the World, 2007. Wint and Robinson 2007.

Ruminant livestock distribution, 2006

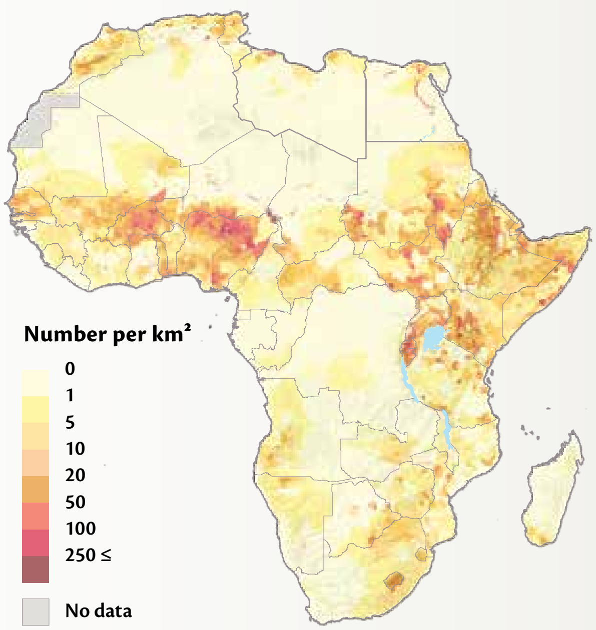
MAP 1 Cattle



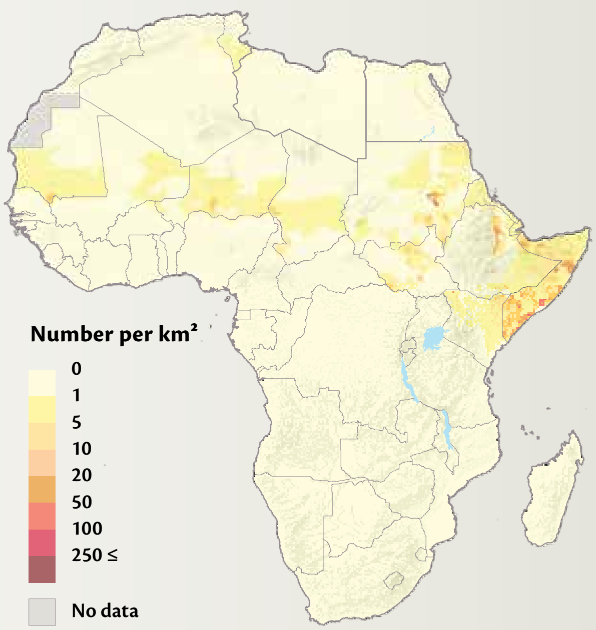
MAP 2 Sheep



MAP 3 Goats



MAP 4 Camels



Data source (all maps): Robinson et al. 2013; Leckell and World Bank 2013.

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Cropping Intensity

Stefan Siebert, Petra Döll, and Felix T. Portmann

WHAT IS THIS MAP TELLING US?

The map shows cropping intensity, which is the number of crop harvests per cell per year.[1] Cropping intensity is highest in irrigated regions, such as the Nile Delta (p. 19), or in wetland rice-growing areas, such as southern Nigeria and Côte d'Ivoire, where more than one crop harvest per year is possible. In contrast, many rainfed areas in Africa see less than one harvest per year due to scarce water or nutrient supplies, particularly in drier regions such as the Sahel, South Sudan, Central African Republic, and much of southern Africa. Additionally, shifting cultivation, in which crops are grown every three to ten years on available cropland with fallow periods in between to allow for nutrient regeneration, is common practice in Africa. These limitations and practices lead to low cropping intensity values on average for most regions of Africa (Figure 1). One also can use the map to identify potential target areas for agricultural intensification by identifying regions with low-cropping intensity and comparing them with areas with fast-growing populations.

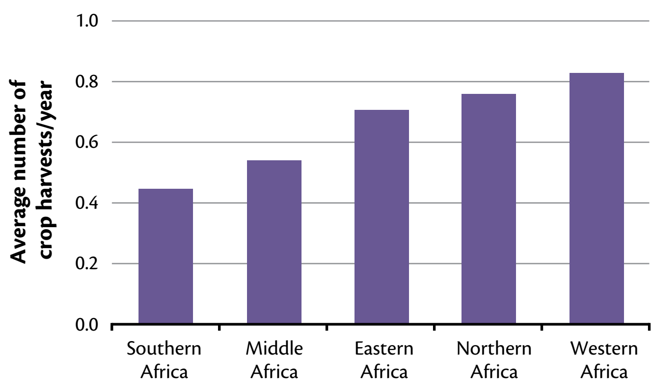
WHY IS THIS IMPORTANT?

The growing demand for agricultural products requires either the cultivation of more land or intensified agricultural land use. It would be difficult to increase cropland area, particularly in regions with high population density, sensitive ecosystems, or poor soil quality. In such regions, intensifying agricultural land use may be the only option. Previous research on crop productivity has focused primarily on crop yields or yield gaps and therefore strictly on the amount of crop yield per harvest. This works for temperate climate regions where only one harvest is possible per year. In contrast, in tropical or subtropical regions, increasing the number of harvests per year can lead to increases in crop production. Increasing cropping intensity by reducing the length of the fallow period is a traditional way to adapt cultivation systems to growing demand for crop products and to shortages in cultivatable land. To be sustainable, increases in cropping intensity must be supplemented with improved water and nutrient management.

WHAT ABOUT THE UNDERLYING DATA?

Cropping intensity was calculated based on the MIRCA2000 dataset (Portmann, Siebert, and Döll 2010) as a ratio of harvested crop area to cropland extent, which included fallow land. This dataset provides, separately for irrigated and rainfed agriculture, monthly growing areas of 26 crops or crop groups at a 5 arc-minute resolution. It refers to the period around 2000 and was developed by combining global inventories on cropland extent (Ramankutty et al. 2008; Map 1, p. 17); the harvested area of 175 distinct crops (Monfreda, Ramankutty, and Foley 2008); the extent of area equipped for irrigation (Siebert, Hoogeveen, and Frenken 2006); and inventories on irrigated area per crop that used crop calendars derived from FAO and other databases.

FIGURE 1 Cropping intensity by region, 2000



Data source: Siebert, Portmann, and Döll 2010 and FAO 2012.
Note: Cropping intensity=the number of crop harvests per year.

WHERE CAN I LEARN MORE?

Current Opinion in Environmental Sustainability: www.sciencedirect.com/science/journal/18773435/5/5

FAO Irrigated Crop Calendars: http://bit.ly/1c9yLH6

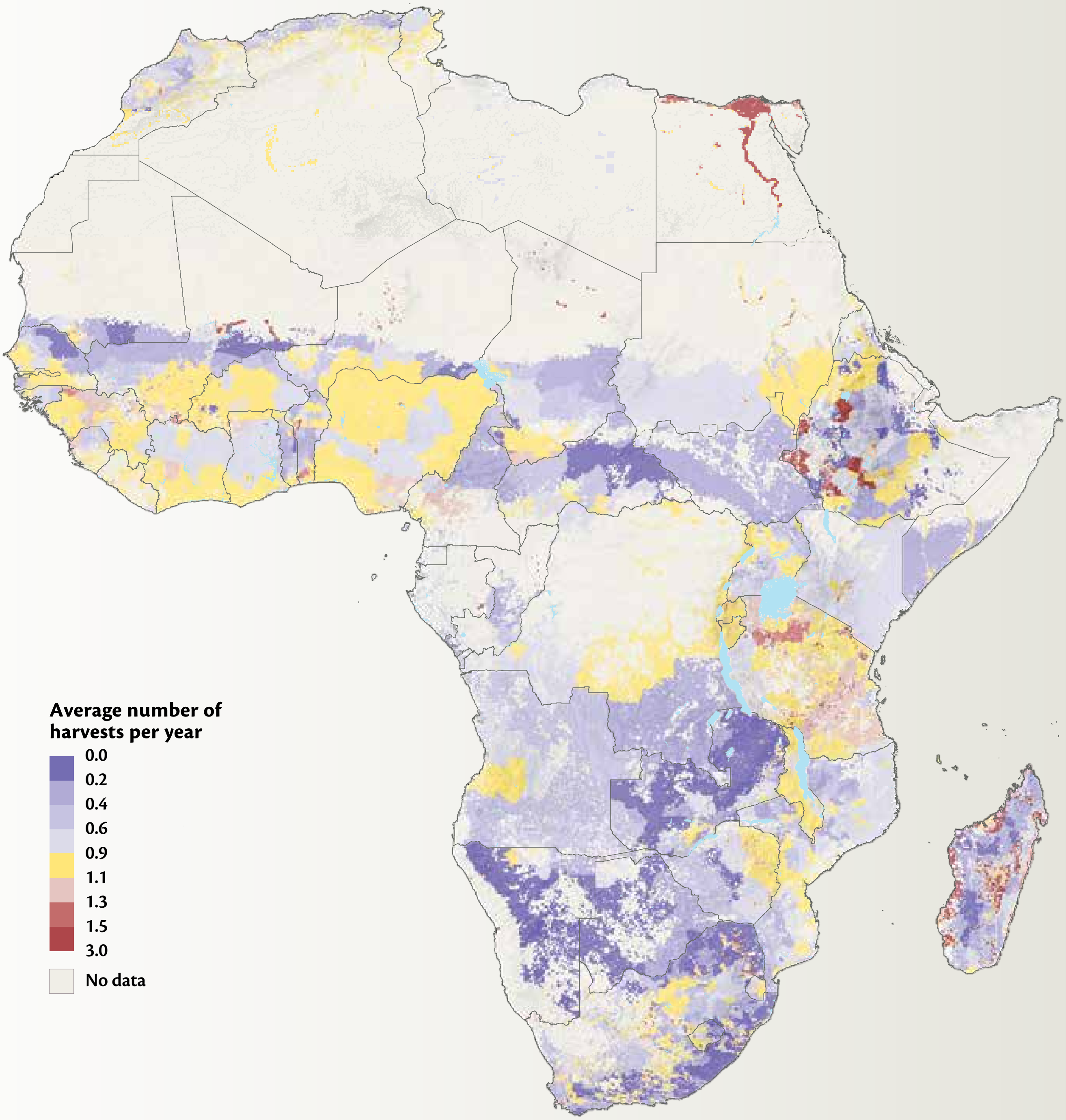
"Global Estimation of Monthly Irrigated and Rainfed Crop Areas": http://bit.ly/1dc6Gz8

"Global Patterns of Cropland Use Intensity." Siebert, Portmann, and Döll 2010: http://bit.ly/1rnJ0RT

"Increasing Global Crop Harvest Frequency: Recent Trends and Future Directions." Ray and Foley 2013: http://bit.ly/1gTax8S

1 Each cell measures approximately 100 km² or 10,000 hectares at the equator.

MAP 1 Cropping intensity



Data source: Siebert, Portmann, and Döll 2010.

Land Productivity for Staple Food Crops

Ulrike Wood-Sichra and Stanley Wood

WHAT IS THIS MAP TELLING US?

Almost three-quarters of Africa's harvested agricultural land is devoted to the production of staple food crops,[1] but only about one-third of that land generates annual output worth more than $500[2] from each cropped hectare. With farmers typically cultivating just a half to three hectares of land to support entire families, rural poverty and food insecurity are pervasive, especially where nonfarm employment options are limited. While some areas can produce food crop outputs worth more than $2,500 per hectare (compared to an average of $517 per hectare across all of Africa), such impressive results are concentrated in less than 1 percent of the total harvested area and are likely boosted by access to irrigation. Map 1 shows the distribution of Africa's average land productivity for staple crops ranging from $250 or less per hectare at the fringes of the Sahel and in parts of eastern Africa to $1,000 or more per hectare in southern Nigeria, parts of Ghana, and along the Nile Valley and Delta. Summarizing values by agroecological zone (p. 34), tropical arid zones, such as on the northern edge of the Sahel and in eastern Africa, have some of the lowest average values of production per hectare; and subtropical arid zones, such as the Nile Delta where irrigation is widely practiced, and subtropical humid zones in southern Africa, have some of the highest average values of production per hectare (Table 1).

WHY IS THIS IMPORTANT?

Land productivity serves as a compact measure of the general status of agricultural and rural development. It is an implicit reflection of the status of local environmental conditions, input use, and farmer know-how. Its spatial variation, furthermore, provides a picture of the likely relative differences in land rental values. Detailed empirical studies of diversity in land productivity point to a range of associated factors including agroecology; farmers' access to knowledge; inputs, credit, infrastructure, and markets; land tenure; and cultural preferences that shape crop and technology choices, production practices, and market engagement.

WHAT ABOUT THE UNDERLYING DATA?

Estimates of land productivity were derived using two core data sources: (1) average annual production (metric tons) and area harvested (hectares) for 14 of the most widely grown food crops during the period 1999–2001 derived for each 5 arc-minute grid cell[3] across Africa using the Spatial Production Allocation Model (SPAM) 2000 (You et al. 2012), and (2) prices and national value of production for each crop over the same period (FAO 2012). The total value of food crop production (VoP) for any grid cell is calculated as the sum of the VoPs for each crop, where VoP is a product of crop price and production. Land productivity is derived by dividing the total VoP of the 14 crops by the total harvested area of those same crops for each grid cell.

TABLE 1 Average value of staple food crop production (US$) per hectare by region in Africa

Agroecological zone	Eastern	Middle	Northern	Southern	Western	AFRICA
Subtropic–arid		781	1448	501		**1355**
Subtropic–semiarid	546	726	295	392		**338**
Subtropic–subhumid			336	532		**349**
Subtropic–humid				837		**837**
Tropic–arid	89	208	186	336	225	**184**
Tropic–semiarid	336	469	100	351	246	**270**
Tropic–subhumid	496	479	161	491	1083	**760**
Tropic–humid	659	661	133	1571	1144	**749**
Average	480	536	433	398	580	**517**

Data source: You et al. 2012; FAO 2012; Sebastian 2009.

Note: All local prices converted to international dollars at 2004–2006 average purchasing power parity exchange rates.

WHERE CAN I LEARN MORE?

More information on the SPAM model: http://mapspam.info

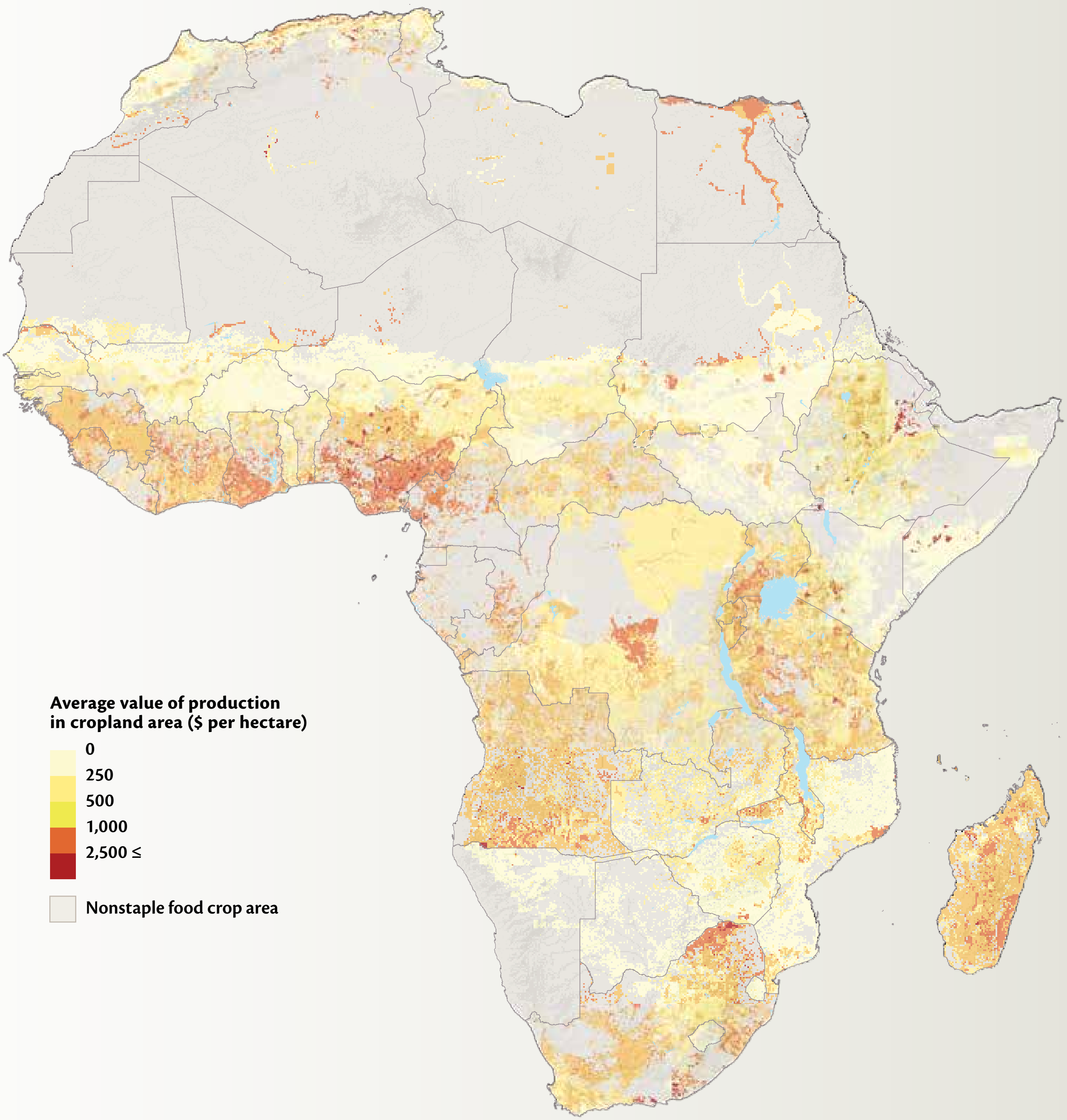
FAOSTAT database: http://faostat3.fao.org/home/index.html

1 Harvested areas and production values include the following staple food crops: maize, sorghum, millet, rice, wheat, barley, cassava, sweet potatoes and yams, bananas and plantains, Irish potatoes, beans, groundnuts, soybeans, and other pulses.

2 All local prices converted to international dollars at 2004–2006 average purchasing power parity exchange rates.

3 Each cell measures approximately 100 km² or 10,000 hectares at the equator.

MAP 1 Land productivity for staple food crops, 2000



Data source: You et al. 2012 and FAO 2012.

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GROWING CONDITIONS

Agroecological Zones

Kate Sebastian

WHAT IS THIS MAP TELLING US?

Agroecological zones (AEZs) are geographical areas exhibiting similar climatic conditions that determine their ability to support rainfed agriculture. At a regional scale, AEZs are influenced by latitude, elevation, and temperature, as well as seasonality, and rainfall amounts and distribution during the growing season. The resulting AEZ classifications for Africa have three dimensions: major climate (tropical or subtropical conditions), elevation (warmer lowland or cooler upland production areas), and water availability (ranging from arid zones with less than 70 growing days per year to humid zones where moisture is usually sufficient to support crop growth for at least nine months per year) (Fischer et al. 2009).

The map shows the broad latitudinal symmetry of major climates and water availability north and south of the equator, disrupted by the influence of highland and lake complexes primarily associated with the East African Rift Valley that extends from Ethiopia to Mozambique. The Sahel—located between the Sahara Desert in the north and the Sudanian Savanna in the south—comprises warm tropical arid and semiarid zones characterized by a strong north-south water availability gradient, while the highlands of East Africa are distinguished by cooler, more humid tropical conditions. The most extensive humid zone is centered on the Congo Basin, stretching from the Rwenzori and Virunga mountains at the borders of Uganda, Rwanda, and the Democratic Republic of the Congo in the east to the Atlantic coast in the west. The continent is primarily tropical, but significant subtropical areas with pronounced seasonality in temperatures and day length are found in northern and southern Africa (beyond the tropical limits of 23.44 degrees north and south of the equator).

WHY IS THIS IMPORTANT?

Most African farmers, particularly in tropical areas, rely on rainfed agriculture with very limited use of inputs such as fertilizers. This means that the land's agricultural production depends almost solely on the agroecological context. The spatial distribution of Africa's dominant farming systems (p. 15) is, therefore, closely aligned with the regional pattern of AEZs. Local agroecological conditions not only influence the range of feasible agricultural enterprise options but also often strongly predict the feasibility and effectiveness of improved technologies and production practices. For this reason agriculture research and development planners are keen to understand the nature and extent of agroecological variation in the areas where they work. Planners who think in terms of AEZ boundaries rather than country or regional boundaries open up the potential for sharing knowledge and tools with people on the opposite side of the continent who work in similar AEZs. There is also growing interest in the potential consequences of agroecological change. Change might be brought about by mitigating local agroecological constraints through, for example, investments in irrigation or improved soil-water management practices. Or external factors such as climate change may drive agroecological change. The likely negative economic and social implications of shifting agroecological patterns in Africa due to climate change are priorities for emerging research and policy research.

WHAT ABOUT THE UNDERLYING DATA?

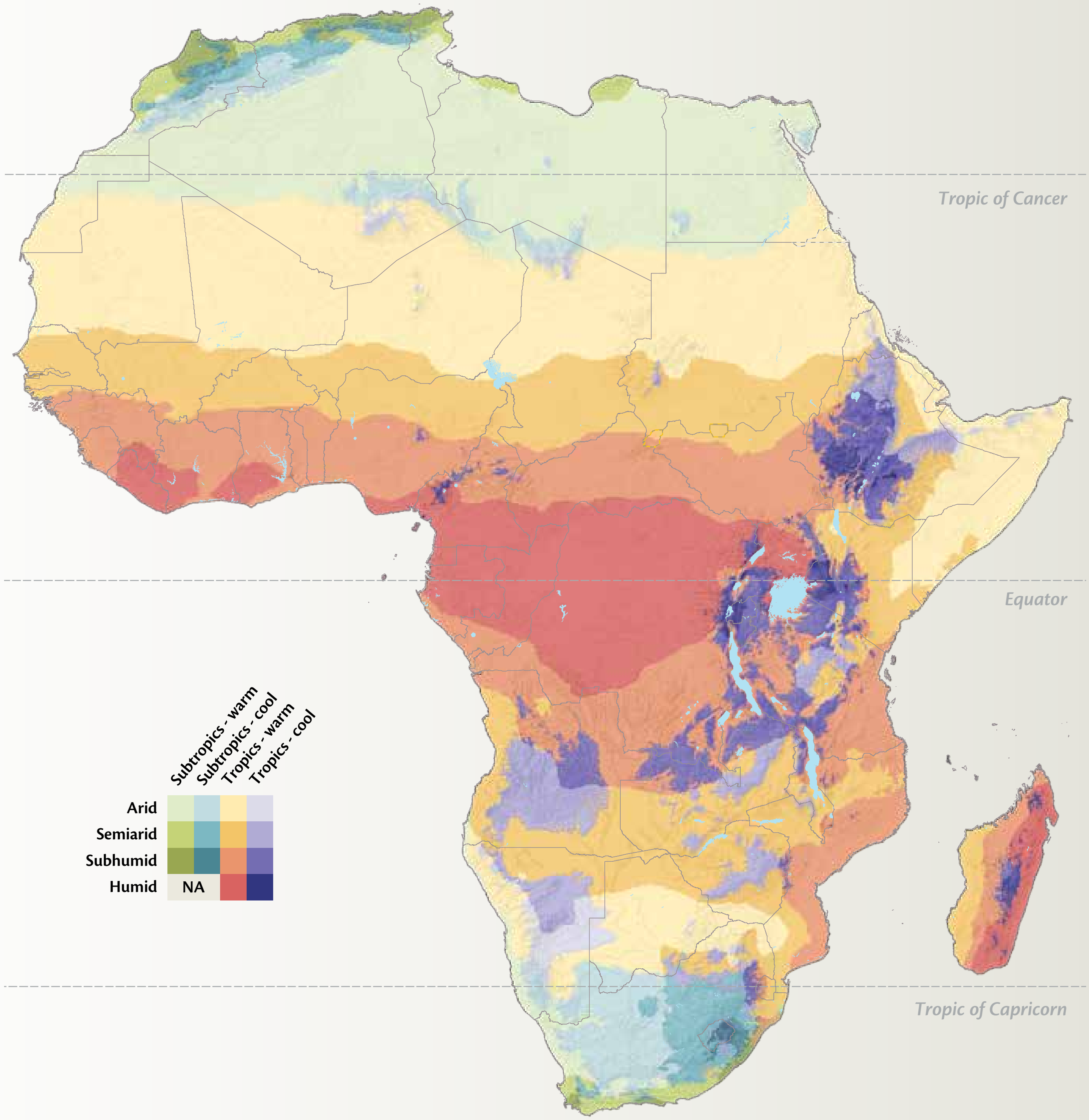
The most common approaches to agroecological zone mapping were originally developed by the Food and Agriculture Organization of the United Nations (FAO) and are still being developed and applied (for example, Fischer et al. 2009 and FAO/IIASA 2012). In Africa, the variable (and in many cases declining) quality and availability of climate-station data needed to generate reliable climatological maps is an ongoing challenge (p. 37), although increased access to satellite-derived weather and land-surface observations could ease the constraints on gathering the data in the future. The map was developed applying the regional AEZ approach using long-term average, spatially interpolated climate data for Africa for the period 1960–1990 (Hijmans et al. 2005; Sebastian 2009).

WHERE CAN I LEARN MORE?

AEZ maps and underlying data can be downloaded at: http://hdl.handle.net/1902.1/22616

The most comprehensive collection of global AEZ-related data can be found at the FAO/International Institute for Applied Systems Analysis Global Agro-Ecological Zones website: www.fao.org/nr/gaez/en/

MAP 1 Agroecological zones



Data source: Sebastian 2009.

Note: Moisture classes are defined as follows: Arid=length of growing period (LGP) of less than 70 days; Semiarid=LGP of 70–180 days; Subhumid=LGP of 180–270 days; and Humid=LGP of greater than 270 days.

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Climate Zones for Crop Management

Lieven Claessens and Justin Van Wart

WHAT IS THIS MAP TELLING US?

Agricultural climate zones represent ecological conditions farmers face based on moisture availability, length of growing period, and seasonality. Zones with little seasonal variation in temperature and in wet conditions are primarily found in central Africa whereas the northernmost and southernmost countries experience high temperature seasonality and arid conditions. This map provides information not only on what growing conditions these agricultural climate zones present, but also on the relative size of each zone. In some countries the climate zones are quite large, such as in Mali or Niger where the weather is homogenous across large areas. In other countries, such as Kenya or Ghana, these zones are much smaller as agricultural systems face more diverse climates across space due to topography, proximity to the coast, and/or rainfall variation. The relative size and extent of these zones offer information on the expected diversity of cropping systems within each country and can be used to understand how effectively research and technology can be extrapolated to other regions. Table 1 provides a general understanding of the density and average harvested area of zones within each region.

TABLE 1 **Agricultural climate zones and harvested area by region of Africa**

Region	Number of agricultural climate zones	Average harvested area per zone (000 ha)
Northern Africa	72	446
Western Africa	39	2,425
Eastern Africa	71	853
Middle Africa	56	370
Southern Africa	77	80
All Africa	126	680

Data source: van Wart et al. 2013 and FAO 2012.
Note: ha=hectares.

WHY IS THIS IMPORTANT?

While agroecological zones (p. 34) help broadly define environments where specific agricultural systems may thrive, an agriculture climate zone seeks to more adequately distinguish between the diversity of practices for similar agricultural systems within the larger agroecological zones, primarily in terms of different climates. A map of agricultural climate zones is a tool that can help scientists, governments, and businesses determine the best areas to boost production or focus investment. These zones help streamline technology adoption and encourage innovative approaches by providing insights into the size, location, and properties of the climates where such technologies and research have improved productivity. The map also helps identify similar zones where new farming methods could be deployed in the future to increase productivity of existing cropland. Knowing the location of specific agricultural climate zones can help stakeholders target new technologies and approaches to the zones where they can make the most difference, and by extension, help meet the growing demand for food in the future. These agricultural climate zones can also be used to scale up or extrapolate and compare site-specific results, such as those obtained through field experiments or crop simulations, to larger regions or even other countries. For example, new rice management systems being developed by the AfricaRice organization for western Africa (Africa Rice Center 2011) would also be useful in south central India and central Thailand, where rice is grown in similar climate zones.

WHAT ABOUT THE UNDERLYING DATA?

These observations are based on the Global Yield Gap Atlas Extrapolation Domain (GYGA-ED) approach. The GYGA-ED is constructed from three variables: (1) growing degree days (GDD) with a base temperature of 0°C; (2) temperature seasonality (quantified as the standard deviation of monthly average temperatures); and (3) an aridity index (annual total precipitation divided by annual total potential evapotranspiration). Each grid cell for weather data is approximately 100 km² at the equator. Growing degree days and temperature seasonality were calculated using climate data from WorldClim (Hijmans et al. 2005); the aridity index values were taken from CGIAR-CSI (Trabucco et al. 2008) (p. 54). A more extensive description and comparison with other zone schemes can be found in van Wart et al. (2013).

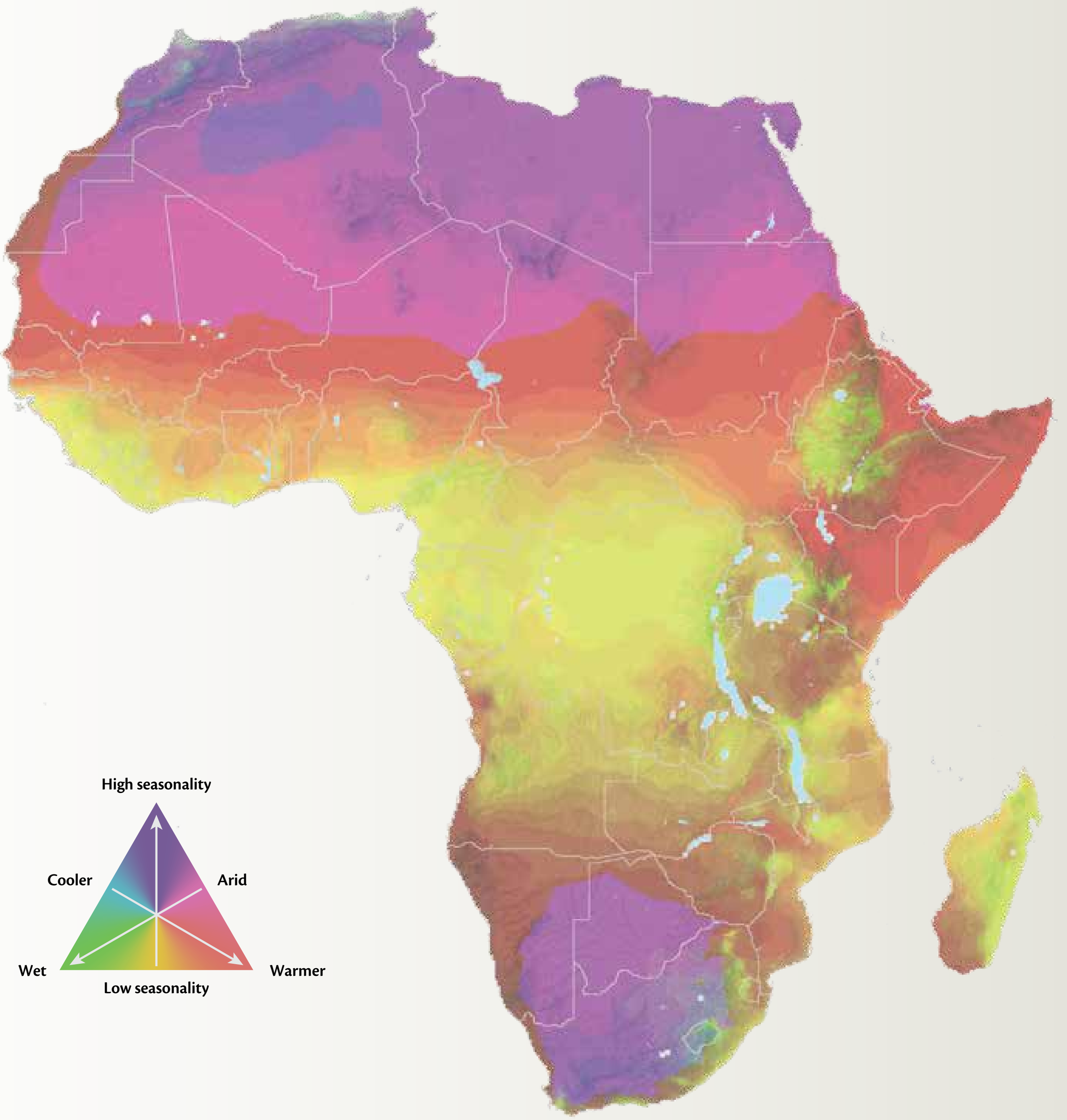
WHERE CAN I LEARN MORE?

Global Yield Gap Atlas: www.yieldgap.org

Zone characterizations: "Use of Agro-Climatic Zones to Upscale Simulated Crop Yield Potential."
van Wart et al. 2013.

Boosting Africa's Rice Sector: http://bit.ly/1kBUWO3

MAP 1 Agricultural climate zones



Data source: van Wart et al. 2013.

Note: The gradient on this map reflects three factors: moisture, temperature, and seasonality. Seasonality is based on variations in temperature and is quantified as the standard deviation of monthly average temperatures.

Global Yield Gap Atlas

Rainfall and Rainfall Variability

Philip Thornton

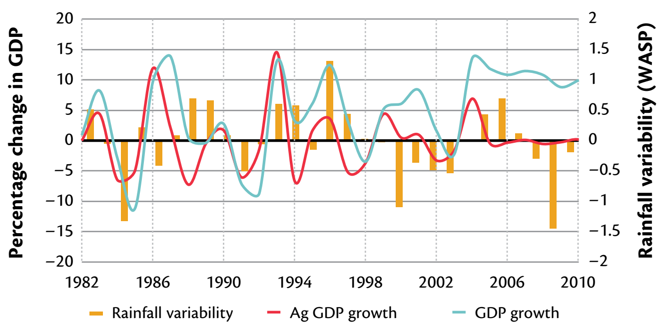
WHAT ARE THESE MAPS TELLING US?

An average of less than 1,000 millimeters of rain falls per year across most of Africa (Map 1). Rainfall tends to decrease with distance from the equator and is negligible in the Sahara (north of about latitude 16°N), in eastern Somalia, and in the southwest of the continent in Namibia and South Africa. Rainfall is most abundant on the eastern seaboard of Madagascar; portions of the highlands in eastern Africa; large areas of the Congo Basin and central Africa; and parts of coastal western Africa including Liberia, Sierra Leone, and Guinea. Northern Africa experiences highly variable rainfall, except along the coasts of Algeria and Morocco (Map 2). This region's coefficient of variation—a measure of how much rainfall varies from the annual average—is greater than 45 percent, reflecting the erratic nature of rainfall in a region that gets little precipitation. The story is similar in the extreme southwest of the continent and in pockets of the Horn of Africa. The amount of rainfall in parts of the Congo Basin is much less variable, with a coefficient of variation around 10–15 percent. For most of the continent where rainfed crops are prevalent, the variability is 15–35 percent.

WHY IS THIS IMPORTANT?

In Africa, where most agriculture is rainfed, crop growth is limited by water availability. Rainfall variability during a growing season generally translates into variability in crop production. While the seasonality of rainfall in the drier rangelands can play a significant role in productivity, rain-use efficiency (RUE)—the amount of biomass produced (in kilograms of dry matter per hectare) per millimeter of rainfall—also drives production. RUE averages about 3.0 kg of dry matter per hectare for every millimeter of rainfall in northern Africa, 2.7 in the Sahel, and 4.0 in eastern Africa, compared with up to 10.0 or so in temperate rangelands (Le Houérou, Bingham, and Sherbek 1988). Estimates of annual rainfall variability in the drier rangeland can offer a rough indication of possible production changes. Figure 1 shows how Ethiopia's gross domestic product echoed rainfall variability (measured as a percentage variation from the long-term average) from the early 1980s to 2010. The close relationship illustrates the importance of rainfed agricultural production to the national accounts of Ethiopia during this time period. Ethiopia is one of many countries in Africa where the economy is closely tied to rainfed agriculture.

FIGURE 1 Economic growth and rainfall variability in Ethiopia, 1982–2010



Source: Thornton, Ericksen, and Herrero 2013; World Bank 2013; IRI/LDEO 2013.
Note: WASP = the 12-month Weighted Anomaly of Standardized Precipitation.

WHAT ABOUT THE UNDERLYING DATA?

Rainfall data are from WorldClim (Hijmans et al. 2005), an interpolated product based on average monthly climate data from weather stations from 1960 to 1990. The data were aggregated to a spatial resolution of 5 arc-minutes (grid cells approximately 100 km² at the equator), and the long-term average monthly rainfall amounts add up to the annual totals (Map 1). To estimate the variability of annual rainfall (Map 2), the weather generator MarkSim (Jones and Thornton 2013) was used to simulate 1,000 years of daily rainfall data for the roughly 420,000 grid cells that make up Africa and the standard deviation of annual rainfall was calculated for each grid cell and converted to the coefficient of variation. MarkSim predicts rainy days and is able to simulate the variation in rainfall observed in both tropical and temperate regions.

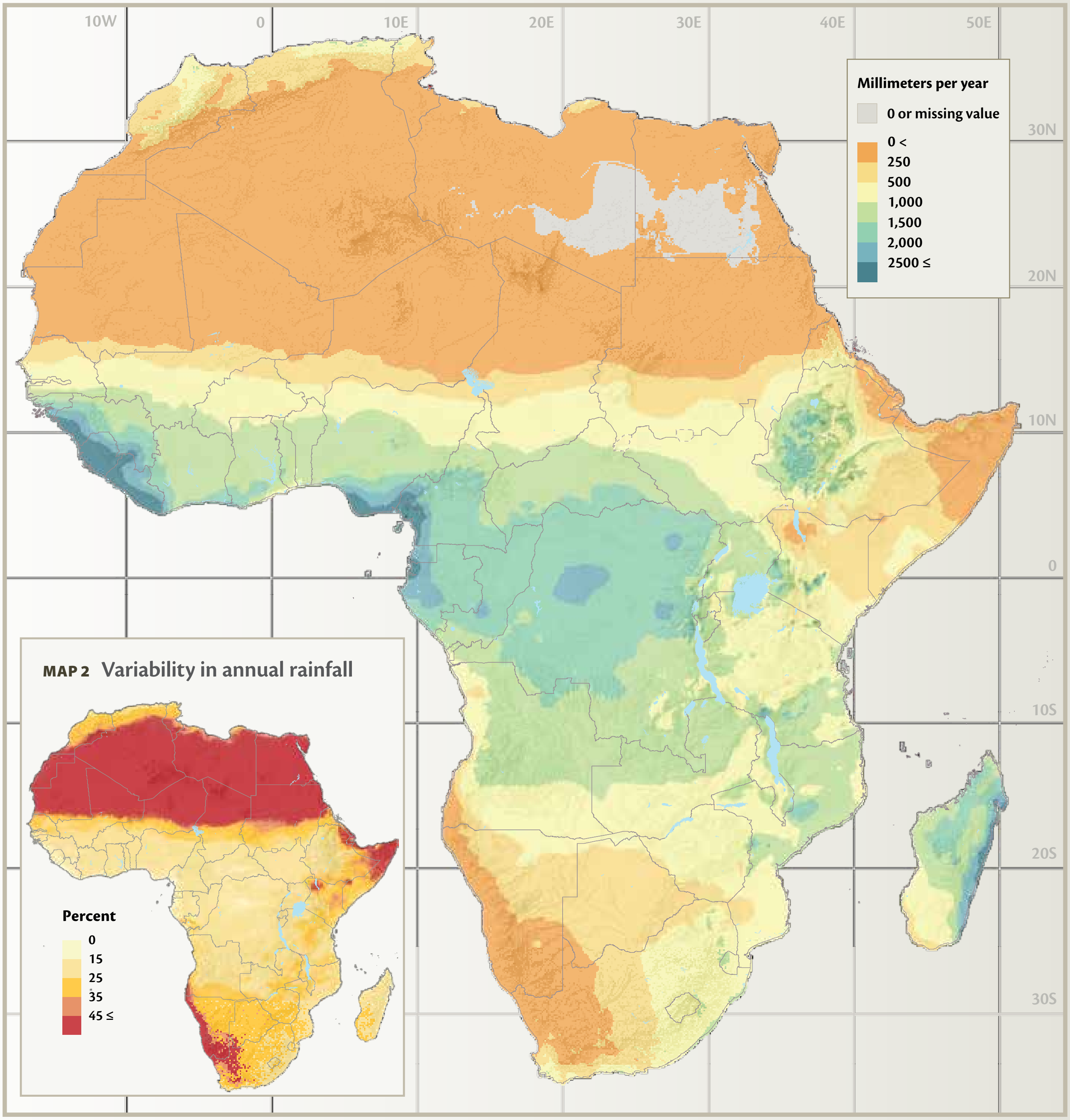
WHERE CAN I LEARN MORE?

WorldClim data. Hijmans et al. 2005: www.worldclim.org/methods

Generating Downscaled Weather Data from a Suite of Climate Models for Agricultural Modelling Applications. Jones and Thornton 2013.

"Evidence from Rain-use Efficiencies Does Not Indicate Extensive Sahelian Desertification." Prince, Brown De Colstoun, and Kravitz 1998.

MAP 1 Average annual rainfall



Data source: Map 1—WorldClim (Hijmans et al. 2005); Map 2—MarkSim (Jones and Thornton 2013).

Note: Rainfall variability is represented by the coefficient of variability (CV), calculated as the standard deviation divided by the mean annual rainfall. It is expressed as a percentage and indicates how much rainfall varies from average annual rainfall.

Soil Fertility

Cindy Cox and Jawoo Koo

WHAT ARE THESE MAPS TELLING US?

Years of weathering have leached nutrients away from many soils in the cropped areas of Africa south of the Sahara (SSA). The resulting highly acidic soils (< 5.5 pH) are vulnerable to aluminum toxicity, an issue across much of Africa (Map 1), which occurs when aluminum becomes soluble and poisons plants. It is the most common soil constraint across major farming systems in SSA (Figure 1), affecting 32 percent of cropland, followed by low nutrient reserves (20 percent) and high leaching potential (12 percent). The worst soils in SSA are concentrated along the eastern coast, throughout central Africa, and scattered throughout the Sahel (Map 2). The Sahel and central Africa suffer primarily from high-leaching potential and low-nutrient reserves. Some soils along eastern Africa's coastal edges and in the Horn of Africa are calcareous, containing high levels of calcium carbonate. Such soils can be highly fertile, but extremely calcareous soils can make crops nutritionally deficient by fixing phosphorus (P), which makes it insoluble and therefore not available to plants. SSA is also home to large expanses of fertile soils that are free of constraints.

WHY IS THIS IMPORTANT?

About 80 percent of SSA's cropland is not considered highly suitable for agriculture, because the extremely weathered soil limits farmers' yields. Low-input farming further degrades soils when farmers fail to replenish nutrient reserves mined by crops. To combat poor soil, liming can increase pH and decrease acidity in soils. Breeder selection for crop varieties, such as beans, sorghum, and fodder crops that resist aluminum toxicity, is another way to deal with toxic soils. Furthermore, the consequences of poor soil fertility can exacerbate other constraints, such as water uptake. Understanding where and how soils are constrained is a primary concern for the farmers and stakeholders who depend on less than ideal soil conditions and those who seek to improve their welfare.

WHAT ABOUT THE UNDERLYING DATA?

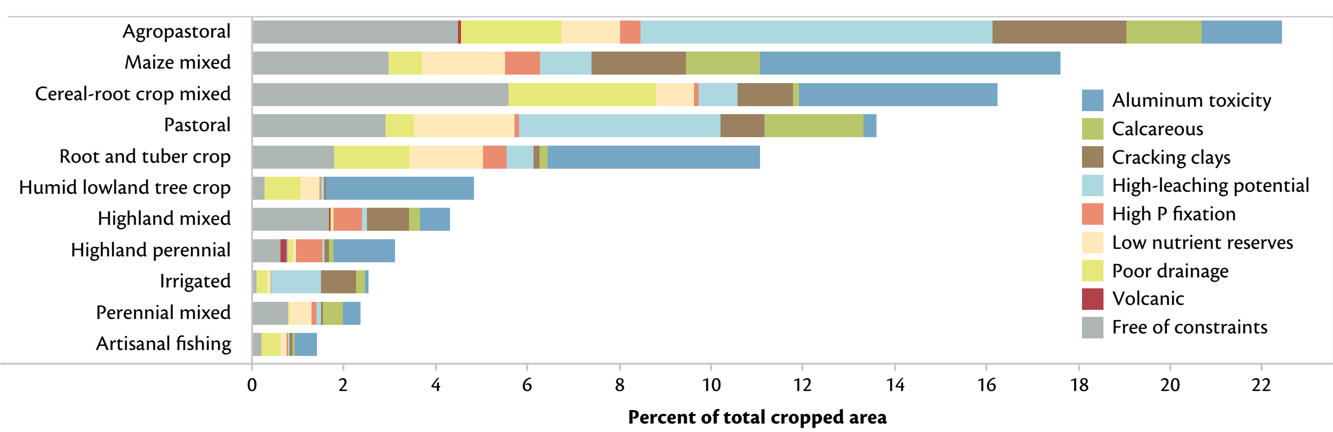
The underlying spatial data for major soil constraints was taken from an updated version of the Soil Functional Capacity Classification System (FCC) (HarvestChoice 2010). HarvestChoice updated the FCC by applying version 4's methodology (Sanchez, Palm, and Buol 2003) to FAO's Harmonized World Soil Database version 1.1. The pixel-level FCC data (Palm et al. 2007) was aggregated using HarvestChoice's cropland extent estimate (You et al. 2012) and FAO's Farming Systems (Dixon, Gulliver, and Gibbon 2001; p. 14).

WHERE CAN I LEARN MORE?

"Updating Soil Functional Capacity Classification System," HarvestChoice 2010: http://harvestchoice.org/node/1435

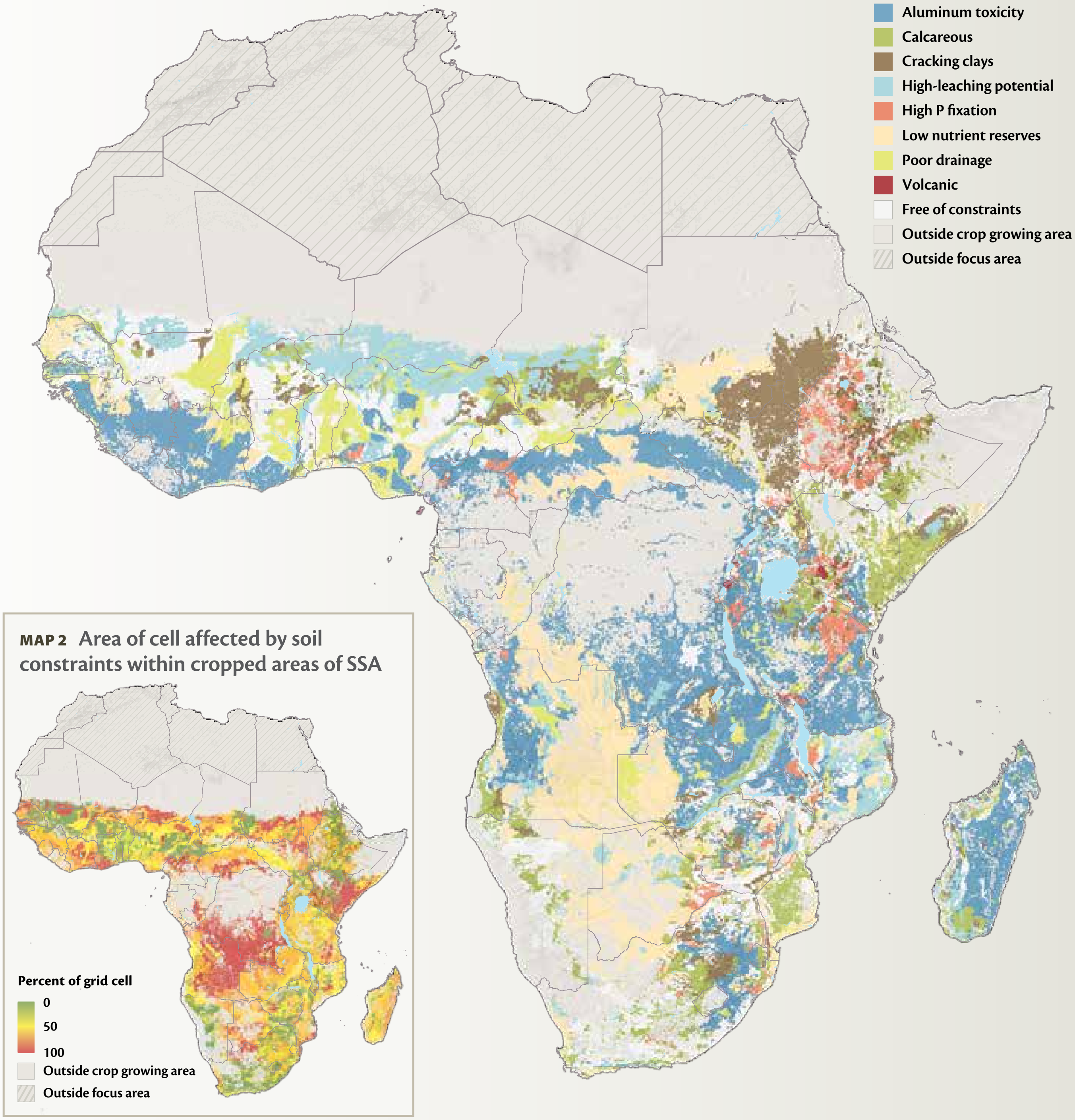
Africa Soil Information Service data: http://africasoils.net

FIGURE 1 Dominant soil constraint by farming system type in Africa south of the Sahara



Data source: Dixon, Gulliver, and Gibbon 2001; Sanchez, Palm, and Buol 2003; HarvestChoice 2010.
Note: See glossary for definitions of specific soil constraints.

MAP 1 Dominant soil constraints within cropped areas of Africa south of the Sahara (SSA)



MAP 2 Area of cell affected by soil constraints within cropped areas of SSA

Data source: Map 1—Sanchez, Palm, and Buol 2003; HarvestChoice 2010; You et al. 2012; Map 2—HarvestChoice 2010 and You et al. 2012.

Note: Grid cells are approximately 100 km² at the equator. See glossary for definitions of specific soil constraints.

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ROLE OF WATER

Effects of Rainfall Variability on Maize Yields

Jawoo Koo and Cindy Cox

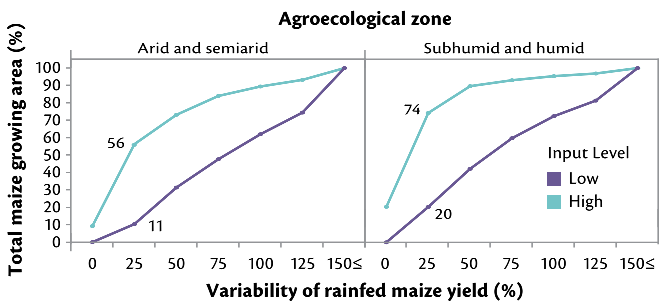
WHAT ARE THESE MAPS TELLING US?

Farmers in SSA depend largely on rainfed crops for food security and their livelihood. But how reliable is rainfall across Africa, and how does the variability of rainfall from season to season affect crop yields? The following maps indicate where the variability of total rainfall in SSA (Map 1) may influence maize yields (Map 2), depending on the level of inputs such as fertilizer used in maize cultivation (Map 3 and Map 4) and the environment (Figure 1). A comparison of Maps 1 and 2 shows a correlation between rainfall and rainfed maize yields. Yields tend to correspond to seasonal fluctuations in rainfall, although in SSA, yields fluctuate year to year more than rainfall since crops are at the mercy of many other factors, including total rainfall, cultural practices, pests, and soil quality. Maps 3 and 4 show how the variability in yields may be affected by changes in inputs. Figure 1 shows with more inputs, such as hybrid seeds and more fertilizer (50 kilograms of nitrogen per hectare), the probability of achieving acceptable levels of yield variability—assumed to be 25 percent or less—rises, although the effect of increased inputs, or intensification, varies by agroecological zone (p. 34). When shifting from low to high inputs, the share of total maize growing area considered more reliable—that is, exhibiting lower estimated variability in yield—rises from 20 percent to 74 percent in the subhumid and humid regions of SSA. In contrast, high inputs in arid and semi-arid regions of SSA have a smaller impact on crop reliability with a change from 11 percent to 56 percent, as the yield potential in this region, including the southern portions of Mali and Niger and central Chad, is more limited by water availability than in the humid and subhumid regions of western Africa. In some areas, such as the northern edge of the Sahel, the variability may even rise (Map 4).

WHY IS THIS IMPORTANT?

While estimates of yearly rainfall averages are important, yield reliability, predicted by fluctuations in growing conditions from year to year, concerns farmers worldwide. Knowing how rainfall variability affects yields helps stakeholders make climate-based decisions about what crops to grow, which farming systems and management practices are most suitable at a particular location, and where more investments and resources are needed to improve farm productivity and welfare. These may include decisions related to scaling up technologies such as irrigation, synthetic fertilizers, hybrid maize, and improved crop varieties that are more resistant to or better tolerate moisture fluctuations and drought.

FIGURE 1 **Variation in share of total maize growing area under varying input levels by agroecological zone**



Data source: Elliott et al. 2014 and Sebastian 2009.

Note: The variability of rainfed maize yield is measured by the coefficient of variation (CV).

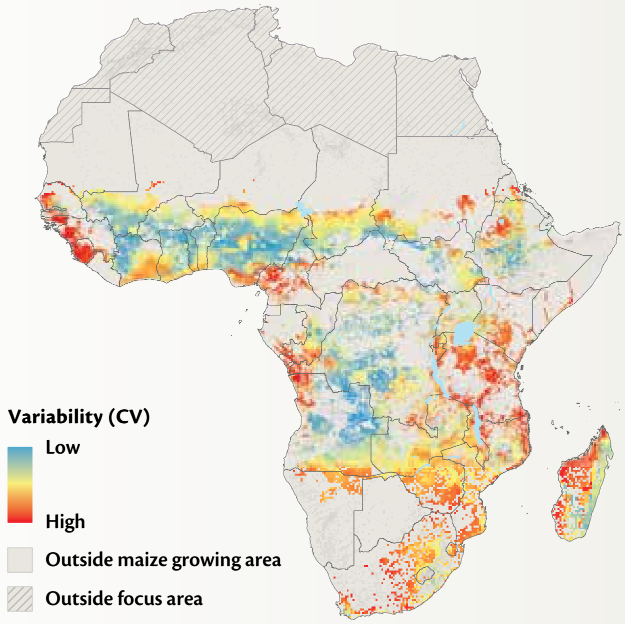
WHAT ABOUT THE UNDERLYING DATA?

Grid-based historical daily weather and soil databases were used as inputs for the CERES-Maize model in the Decision Support System for Agrotechnology Transfer (DSSAT) v4.5 (Jones et al. 2003). Historical daily weather data for 1980–2010 generated by Elliott et al. (2014) based on the AgMIP Hybrid Baseline Climate Dataset (Ruane and Goldberg 2014) was used to retrieve site-specific solar radiation, temperature, and rainfall. The season-to-season variability in rainfall was measured using the coefficient of variation (CV). The CV divides the standard deviation by the mean, thus indicating the likelihood that rainfall in a given area will vary from the long-term average. A gridded soil database was derived from FAO's Harmonized World Soil Database v1.1 (FAO et al. 2009) and the ISRIC WISE Global Soil Profile Database v1.1 (Batjes 2002). The CERES-Maize model simulated rainfed maize production across the region in areas where rainfed maize production is biophysically possible. The modeling was performed at a resolution of 5 arc-minutes, where a grid cell is approximately 100 km² at the equator.

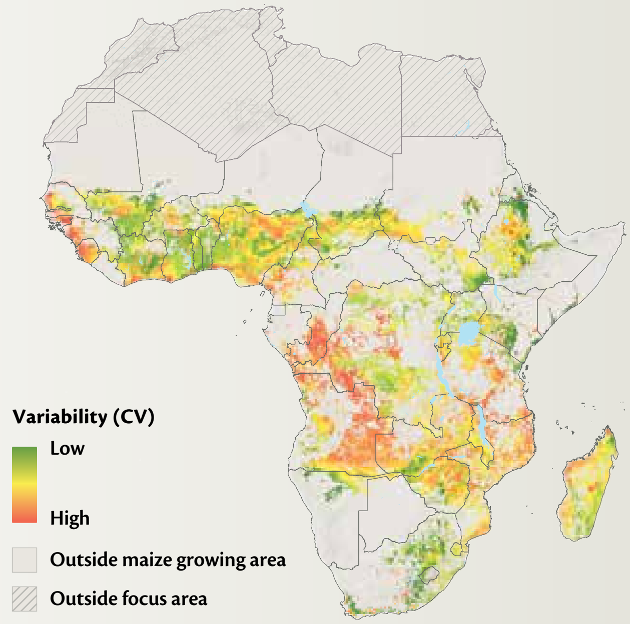
WHERE CAN I LEARN MORE?

Rainfall Variability and Crop Yield Potential: http://bit.ly/1jCMRbN

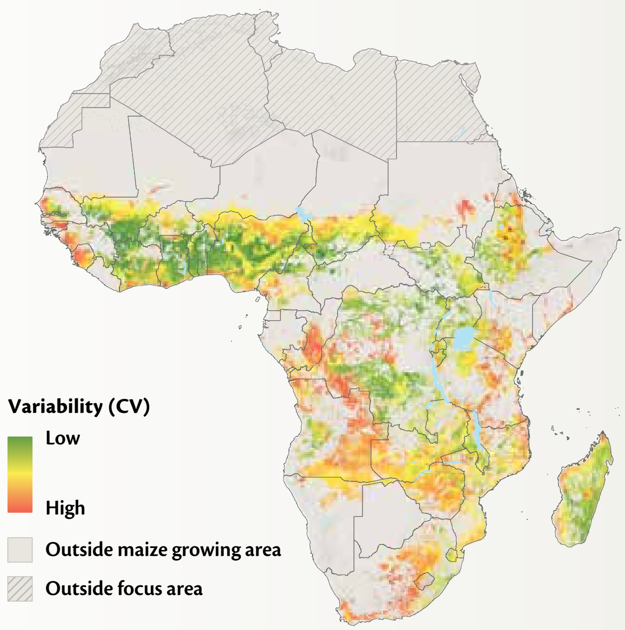
MAP 1 Variability of total rainfall during maize growing season



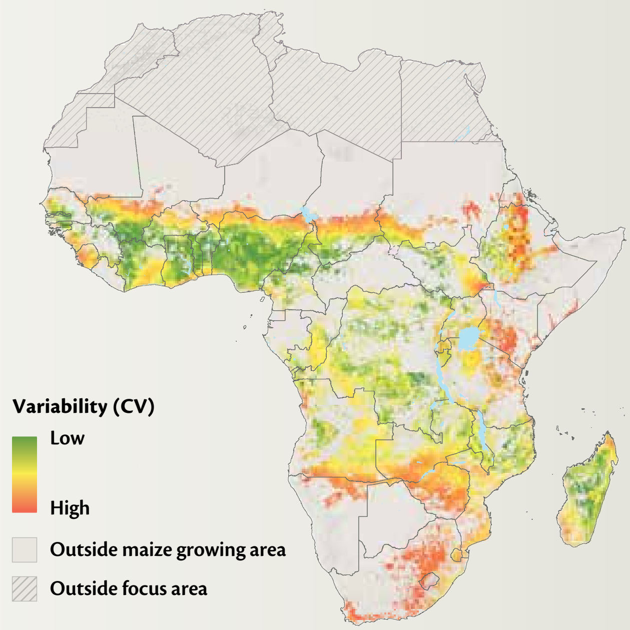
MAP 2 Variability of estimated maize yields



MAP 3 Variability of maize yield potential under low inputs



MAP 4 Variability of maize yield potential under high inputs



Data sources: Map 1—Ruane and Goldberg 2014; Elliott et al. 2013; Elliott et al. 2014;
Maps 2–4—Authors using DSSAT model in Hoogenboom et al. 2011; Elliott et al. 2013; Elliott et al. 2014.

Notes: Rainfall variability based on seasonal total rainfall during maize growing period. Rainfed maize yield variability estimated from simulated seasonal maize yield. Low inputs=open-pollinated seeds with no fertilizer. High inputs=hybrid seeds with 50 kg nitrogen fertilizer per ha. All data simulated for 1950–1990.

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Blue and Green Virtual Water Flows

Stefan Siebert and Petra Döll

WHAT ARE THESE MAPS TELLING US?

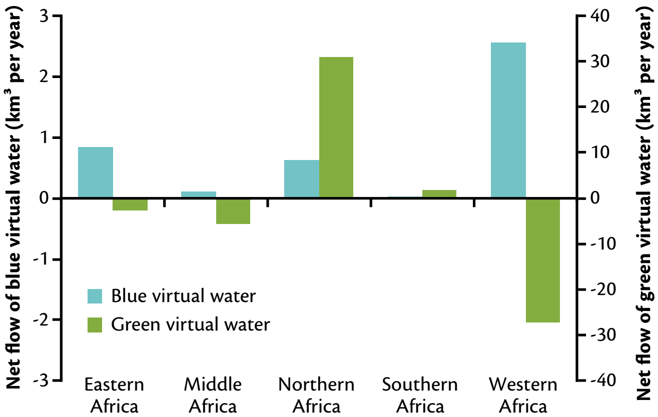
The term virtual water content refers to the volume of water used by a crop per unit of crop harvest. Virtual water flows are then determined by commodity flows between the locations where crops are produced and consumed. Virtual water flows are further distinguished as flows of blue (irrigation) and green (precipitation stored in the soil) water. The maps show blue and green net virtual water flows caused by the production and consumption of 19 major crops (wheat, barley, rye, maize, rice, sorghum, millet, pulses, soybeans, groundnuts, sunflower, rapeseed, potatoes, cassava, grapes, citrus, dates, cocoa, coffee). Negative values in the maps indicate a net outflow of virtual water and show major production areas where the amount of water used locally to produce crops consumed elsewhere is greater than the amount contained in crops consumed locally. Positive values indicate a net inflow of virtual water to major consumption areas.

The major irrigation regions are the source regions of blue virtual water flows (blue in Map 1) while concentrations of rainfed crop production are the source of green virtual water flows (green in Map 2). Cities and other densely populated regions represent the sinks of virtual water flows (red in Maps 1 and 2). In total, northern and southern Africa see a net inflow of both blue and green virtual water while eastern, middle, and western Africa have a net inflow of blue water but a net outflow of green water, indicating that crop imports from irrigated production compensate for exported rainfed crops (Figure 1).

WHY IS THIS IMPORTANT?

Production and consumption of agricultural commodities used to be local. Now, with the rapid growth in trade and urban areas, food may be produced in one place and consumed far away. With globalization, new links and dependencies between producers and consumers have formed. Demand from faraway markets for agricultural commodities may elevate local resource use. On the other hand, resource shortages in major production regions may result in reduced crop yields and send price signals to commodity markets worldwide. Mapping virtual water flows helps policymakers to better understand the importance of links between resource use and trade and of dependencies between producers and consumers of commodities.

FIGURE 1 Net virtual water flows, 2000



Data source: Hoff et al. 2014 and FAO 2012.

Note: Blue virtual water=irrigation water drawn from groundwater bodies (aquifers) or surface water bodies (rivers, lakes, wetlands, or canals). Green virtual water=precipitation stored in the soil and used by rainfed and irrigated crops. Positive values represent net flows into each region.

WHAT ABOUT THE UNDERLYING DATA?

Crop production, crop water use, and corresponding blue and green virtual water content were computed by applying the Global Crop Water Model (Siebert and Döll 2010). Crop consumption within each country was computed by adding imports of the respective crop commodity to domestic crop production and then subtracting the corresponding commodity exports derived from the Comtrade database for the period 1998–2002 (UN 2009). It was assumed that per capita commodity consumption is similar for all people belonging to the same country. Production surpluses and deficits within each country were leveled out by commodity flows (and linked virtual water flows) across increasingly larger distances and finally the whole country, if required (Hoff et al. 2014). The dataset refers to 1998–2002 and has a spatial resolution of 5 arc-minutes.[1]

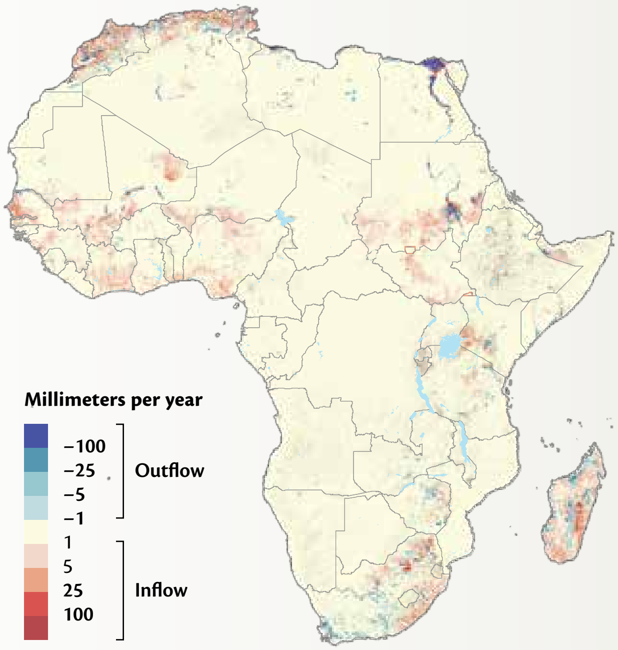
WHERE CAN I LEARN MORE?

Water Footprint Network: www.waterfootprint.org/

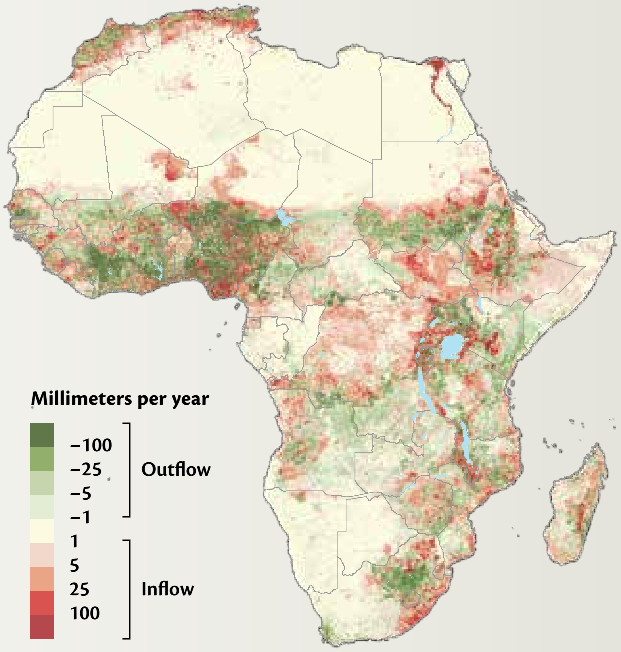
"Water Footprints of Cities: Indicators for Sustainable Consumption and Production." Hoff et al. 2014: http://bit.ly/1ogjdK1

1 Each cell measures approximately 100km² or 10,000 hectares at the equator.

MAP 1 Net virtual water flow of blue water (irrigation), 2000



MAP 2 Net virtual water flow of green water (precipitation stored in the soil), 2000



Data source (all maps): Hoff et al. 2014.

Note: Virtual water content refers to the volume of water used by the crop per unit of crop harvest. Virtual water flows are then established by commodity flows between the locations of crop production and crop consumption.

Blue and Green Water Use by Irrigated Crops

Stefan Siebert and Petra Döll

WHAT ARE THESE MAPS TELLING US?

In these maps, blue water refers to irrigation water while green water is precipitation stored in the soil that is also used by irrigated crops. The values refer to the amount of water that is evapotranspirated, or converted from soil water to vapor and evaporated off plant stems and leaves. Blue and green water use by irrigated crops is highest in regions with a large extent of irrigated land (p. 18), high cropping intensity (p. 28), and climate conditions causing a high evaporative demand, for example, along the Nile River, in the northern African countries of Morocco, Algeria, Tunisia, and Libya, and in South Africa (Maps 1 and 2). The contribution of blue water to total water use of irrigated crops (Map 3) depends on the aridity of the site because irrigation is mainly used to replace missing precipitation. The staple food crops with the highest irrigation water use are rice (12.1 km^3 per year), wheat (11.1 km^3 per year), and maize (9.0 km^3 per year) (Figure 1). Combined they account for a third of the total blue water used for irrigation in Africa. More than 77 percent of the total irrigation water use is in northern Africa.

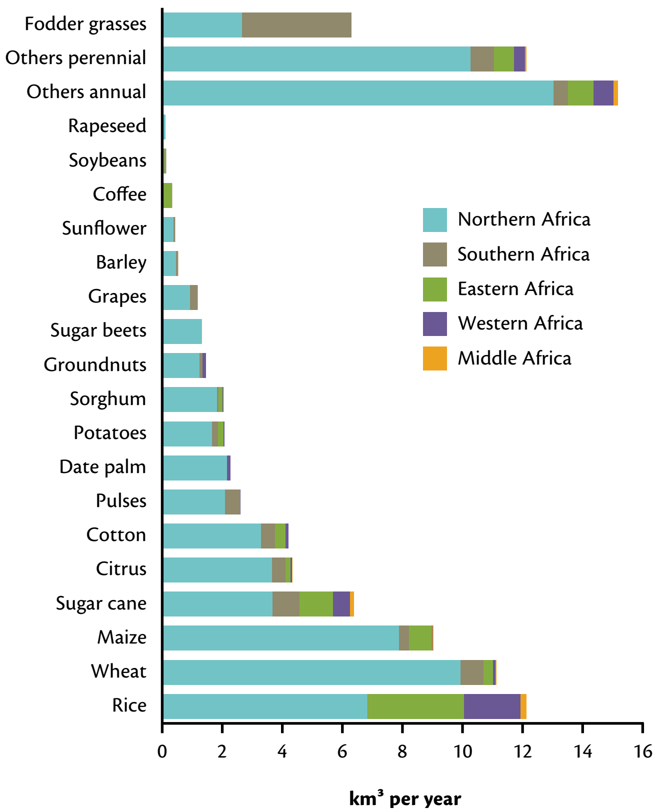
WHY IS THIS IMPORTANT?

Although only 9 percent of the harvested crop area in Africa is under irrigation, cereal production would decline by about 24 percent in Africa without the use of irrigation (Siebert and Döll 2010). This highlights the importance of irrigation for food security. On the other hand, irrigation accounts for 86 percent of global consumptive freshwater use (Döll et al. 2012) with contributions of more than 90 percent in many African countries. Availability of freshwater therefore may limit the use of irrigation in many regions. To identify regions where expanding irrigation could increase future crop production, it is necessary to consider irrigated crops' blue water use along with freshwater availability (Bruisma 2009). Green water use is also important to consider, because blue and green water can be substituted for each other.

WHAT ABOUT THE UNDERLYING DATA?

Crop evapotranspiration was calculated by the Global Crop Water Model (GCWM, Siebert and Döll 2008, 2010), distinguishing blue water use, or the evapotranspiration of irrigation water (also called consumptive irrigation water use) from green water use (evapotranspiration of precipitation). GCWM is based on the global land use dataset MIRCA2000 (Portmann, Siebert, and Döll 2010), which provides monthly growing areas for 26 irrigated and rainfed crop classes for the period 1998–2002 and also represents multicropping. By computing daily soil water balances, GCWM determines evapotranspiration of blue and green water for each crop and grid cell. GCWM assumes that crop evapotranspiration of irrigated crops is always at the potential level and not restricted by water shortage. Water withdrawals for irrigation are higher than consumptive use because of losses and water requirements for soil preparation and salt leaching.

FIGURE 1 Blue water use by irrigated crop and region, 1998–2002



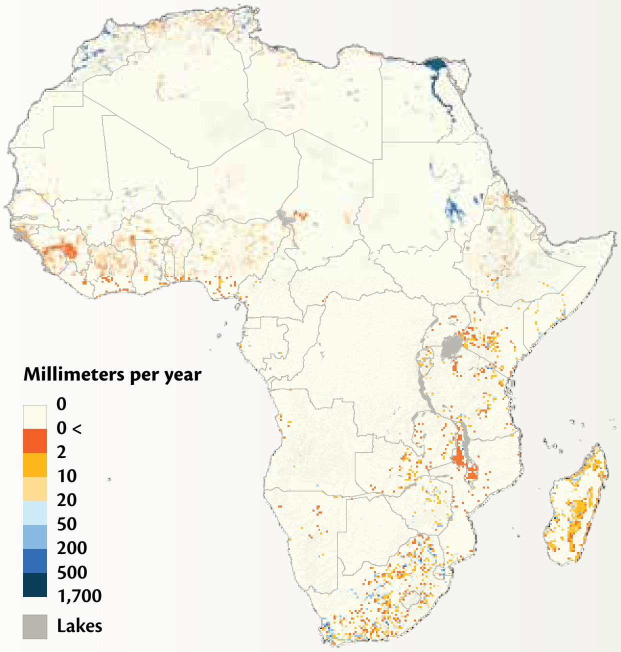
Data source: Siebert and Döll 2010 and FAO 2012.
Note: Blue water use refers to the net irrigation water used by irrigated crops.

WHERE CAN I LEARN MORE?

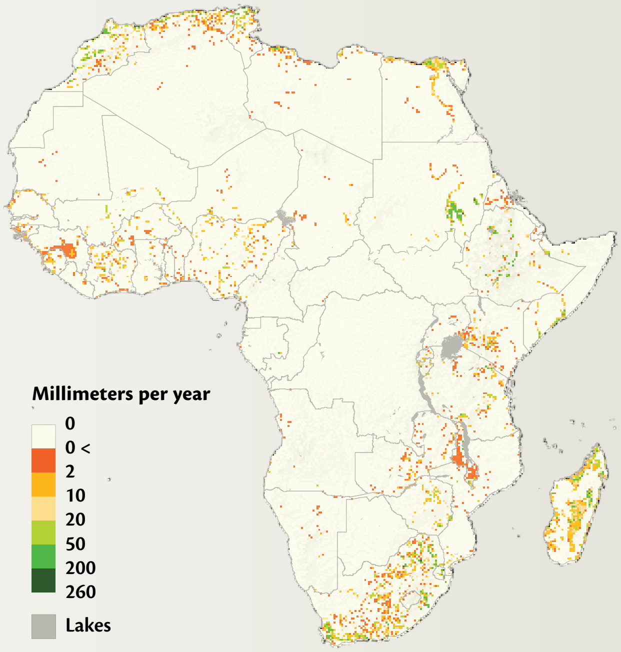
FAO Aquastat: http://bit.ly/1dUQWqj

The Global Crop Water Model (GCWM): Documentation and First Results for Irrigated Crops. Siebert and Döll 2008..

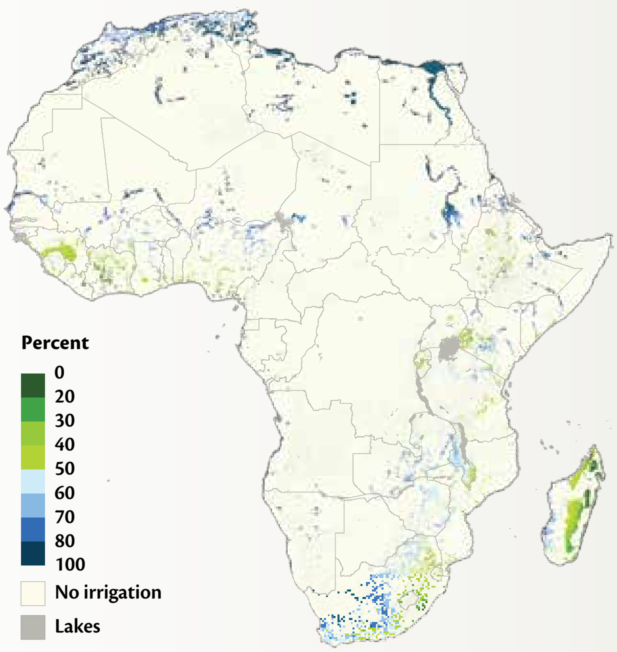
MAP 1 Blue water use by irrigated crops, 2000



MAP 2 Green water use by irrigated crops, 2000



MAP 3 Contribution of blue water to total water use of irrigated crops



Data source (all maps): Siebert and Döll 2010.

Note: Blue water use refers to the net irrigation water used by irrigated crops. Green water use refers to precipitation water stored in the soil and used by irrigated crops.

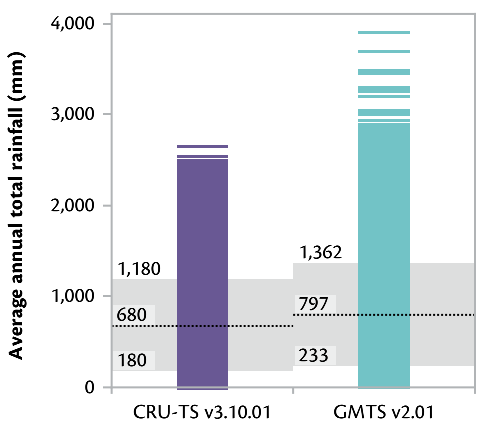
Rainfall Data Comparison

Jawoo Koo and Cindy Cox

WHAT ARE THESE MAPS TELLING US?

Regional rainfall data estimates for Africa can look significantly different depending on which data sources are used and how the data are analyzed. Estimates rely on precipitation records from a variety of land-based weather station networks with varying levels of data quality and spatiotemporal coverage. For example, Maps 1 and 2 illustrate average annual rainfall for 2000–2008 in Africa south of the Sahara (SSA) at the same 0.5° spatial resolution, but are derived from different data sources. Data from the University of East Anglia's Climate Research Unit Time Series (CRU-TS) v3.10.01 (Map 1) shows less pixel-to-pixel variability than the University of Delaware's Gridded Monthly Time Series (GMTS) v2.01 data (Map 2). This suggests different modeling algorithms and possibly the use of fewer observations. Map 3 shows the percentage difference between the two, indicating where the rainfall estimation of GMTS is relatively higher (green) or lower (red) than CRU-TS. The differences are particularly evident in areas with low annual rainfall such as the Sahel, since the significance of the difference between averages will be greater when average rainfall values are low. Significant differences in rainfall estimations in areas of southern Africa, particularly in Mozambique, also exist. Compared with the CRU-TS dataset, GMTS calculates a 17 percent higher average rainfall for the entire SSA region (Figure 1).

FIGURE 1 **Distribution of average annual total rainfall from two climate data sources**



Source: University of East Anglia 2013 and University of Delaware 2009.

Note: Each bar indicates a grid-cell-level value. The dotted black line indicates the average across the SSA region, and the gray area shows +1/-1 standard deviation. The y-axis precipitation totals are nine-year averages (2000–2008) at 0.5° grid cells.

WHY IS THIS IMPORTANT?

Gridded climate data allow researchers to compare variations in climate with other phenomena, such as crop yields or areas suitable for crop growth. Variables other than precipitation—including cloud cover, diurnal temperature range, frost day frequency, daily mean temperature, and monthly average daily maximum temperature—are also available and can be used for similar comparisons. Rainfall averages and patterns are important not only to African farmers and stakeholders who rely on rainfed crops for food security and livelihoods, but also to researchers and decision-makers who need climate information to predict patterns of agricultural productivity, effects of water management technologies (such as drought-adapted crop varieties or conservation agriculture), and potential changes in climate projected over the coming decades. Climate-related datasets from different sources are not identical because of limited source data—perhaps because the network of weather stations is not dense enough—and differences in interpolation methods. For this reason, researchers should not rely on just one dataset. Depending on the research questions and geographical areas of interest, the data source chosen may introduce bias to the results. If possible, researchers should compare data across multiple datasets to better understand the range of uncertainties and to avoid reaching conclusions that may inflate or understate the truth.

WHAT ABOUT THE UNDERLYING DATA?

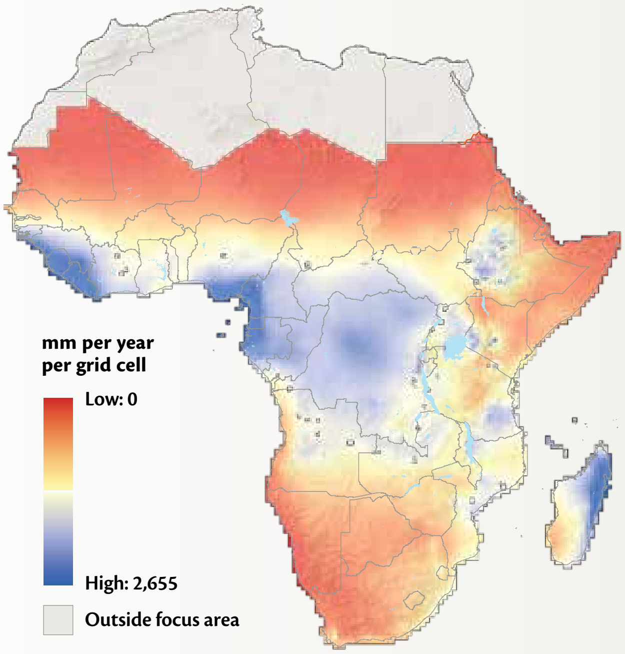
Historic gridded climate databases from two sources, the University of East Anglia's CRU-TS v3.10.01 (2013) and University of Delaware's GMTS v2.01 (2009), were used in the mapping and intercomparison analysis for the years 2000–2008. Both datasets are based on the same 0.5 degree spatial resolution (~3,600 km² at the equator). Annual rainfall data were computed for each grid cell, and their average values across the years were mapped and compared with each other.

WHERE CAN I LEARN MORE?

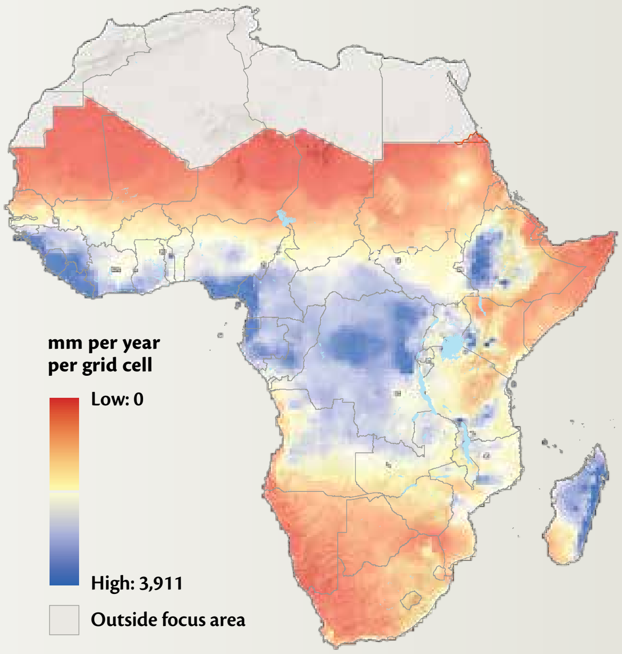
University of East Anglia CRU climate data: www.cru.uea.ac.uk

University of Delaware's Gridded Monthly Time Series (GMTS) v2.01 data: http://bit.ly/1m7HvHk

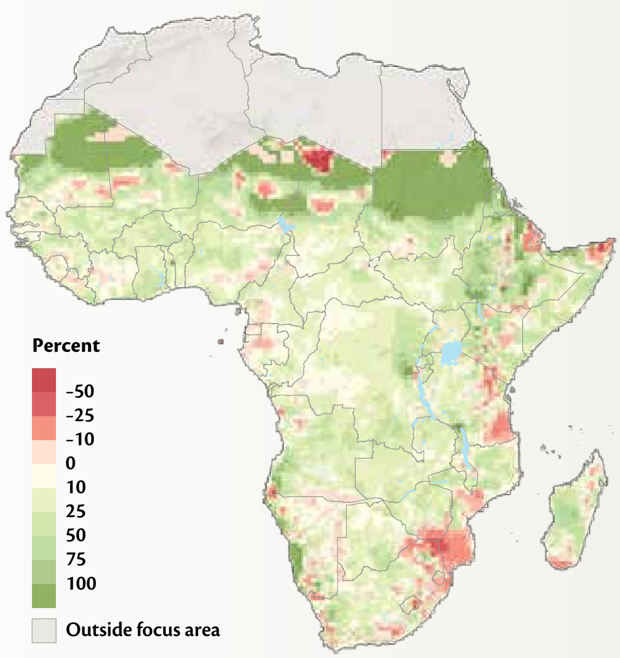
MAP 1 Average annual rainfall for 2000–2008 from the University of East Anglia CRU-TS



MAP 2 Average annual rainfall for 2000–2008 from the University of Delaware GMTS



MAP 3 Difference between CRU-TS and GMTS average annual rainfall, based on CRU-TS



Data sources: Map 1—University of East Anglia 2013; Map 2—University of Delaware 2009; Map 3—Calculation based on University of East Anglia 2013 and University of Delaware 2009.

Note: Each grid cell measures 0.5 degrees or ~3,600 km² at the equator.

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RAINFALL DATA COMPARISON

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DRIVERS OF CHANGE

Influence of Aridity on Vegetation

Antonio Trabucco and Robert Zomer

WHAT IS THIS MAP TELLING US?

The aridity index measures the adequacy of the precipitation to satisfy vegetation water requirements. Large areas of northern and southern Africa are dry with an aridity index of less than 0.65. In contrast, central Africa is more humid, with an aridity index that exceeds 0.65. Variations in dryness reflect Africa's geography and topography. For example, hyperarid zones, such as the Sahara and Namibia deserts, which receive less than 100 mm of precipitation annually, correspond to prevailing high pressure systems preventing cloud formation over the western edges of subtropical areas. Equatorial areas are more humid than other parts of Africa, because low pressure systems and strong air convection condense the moisture into clouds, which lead to high precipitation. Dry northeast monsoon winds blowing in from the Arabian Desert make eastern Africa less humid than other equatorial regions, such as central Africa and the Gulf of Guinea, to the west. Mountains, such as Mt. Kenya and Mt. Kilimanjaro, block the passage of rain-producing weather systems, creating more humid conditions in highland areas and drier conditions on the shielded side of these highlands.

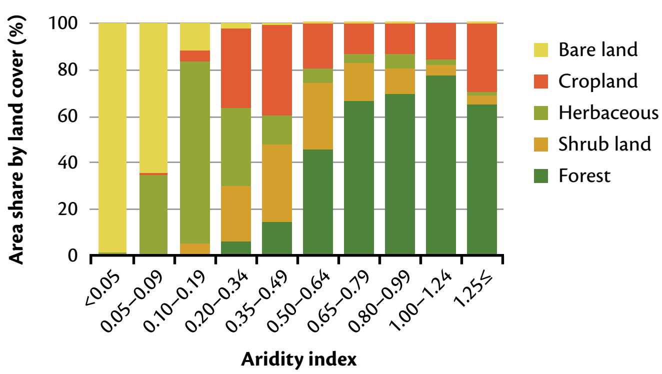
WHY IS THIS IMPORTANT?

More than half of Africa's population lives in arid, semiarid, or dry subhumid areas. This means nearly 600 million people spread across 75 percent of the continent's land area live under ecological conditions where subsistence agriculture may be only partially suitable. In such regions, people may find it difficult to increase incomes from agriculture and improve food security. In fact, there is a direct correlation between aridity and prevailing vegetation and land use (Figure 1). While humid conditions encourage plant growth, arid conditions do not. One way plants adapt to the lack of rain is by limiting their growth. Figure 1 shows the natural process where ecosystems evolve from bare land to herbaceous areas, shrub land, and forests, as more humid conditions prevail. Land use, in turn, also reflects human needs. In particular, agriculture follows specific patterns according to aridity. In semiarid areas farmers rely mainly on rainfed subsistence agriculture, which limits crop yields unless irrigation is adopted. In contrast, highly productive agriculture systems are found in places with more humid conditions, such as in southern Nigeria.

WHAT ABOUT THE UNDERLYING DATA?

Because precipitation alone does not properly characterize vegetation water stresses across large regions, an aridity index is calculated as the ratio of annual precipitation to potential evapotranspiration (PET). Thus, the aridity index measures how much rainfall is available to satisfy the water demand of a type of vegetation. Using this formula, aridity index values increase with more humid conditions and decrease with more arid conditions. Annual precipitation was derived from the WorldClim database (Hijmans 2005). PET was calculated using the Hargreaves method applied to temperature parameter layers from the WorldClim database and extraterrestrial radiation (Allen et al. 1998; Trabucco and Zomer 2009). Although the aridity index map reflects average conditions between 1950 and 2000, rainfall in arid and semiarid regions is highly variable across space and time (Map 2, p. 39). This variability relates to the randomness of prevailing convective rains in arid regions, where short, heavy storms can either hit or miss an area.

FIGURE 1 Land cover types, by aridity



Source: Trabucco and Zomer 2009.
Note: Aridity index=precipitation (mm)/potential evapotranspiration (PET mm).

WHERE CAN I LEARN MORE?

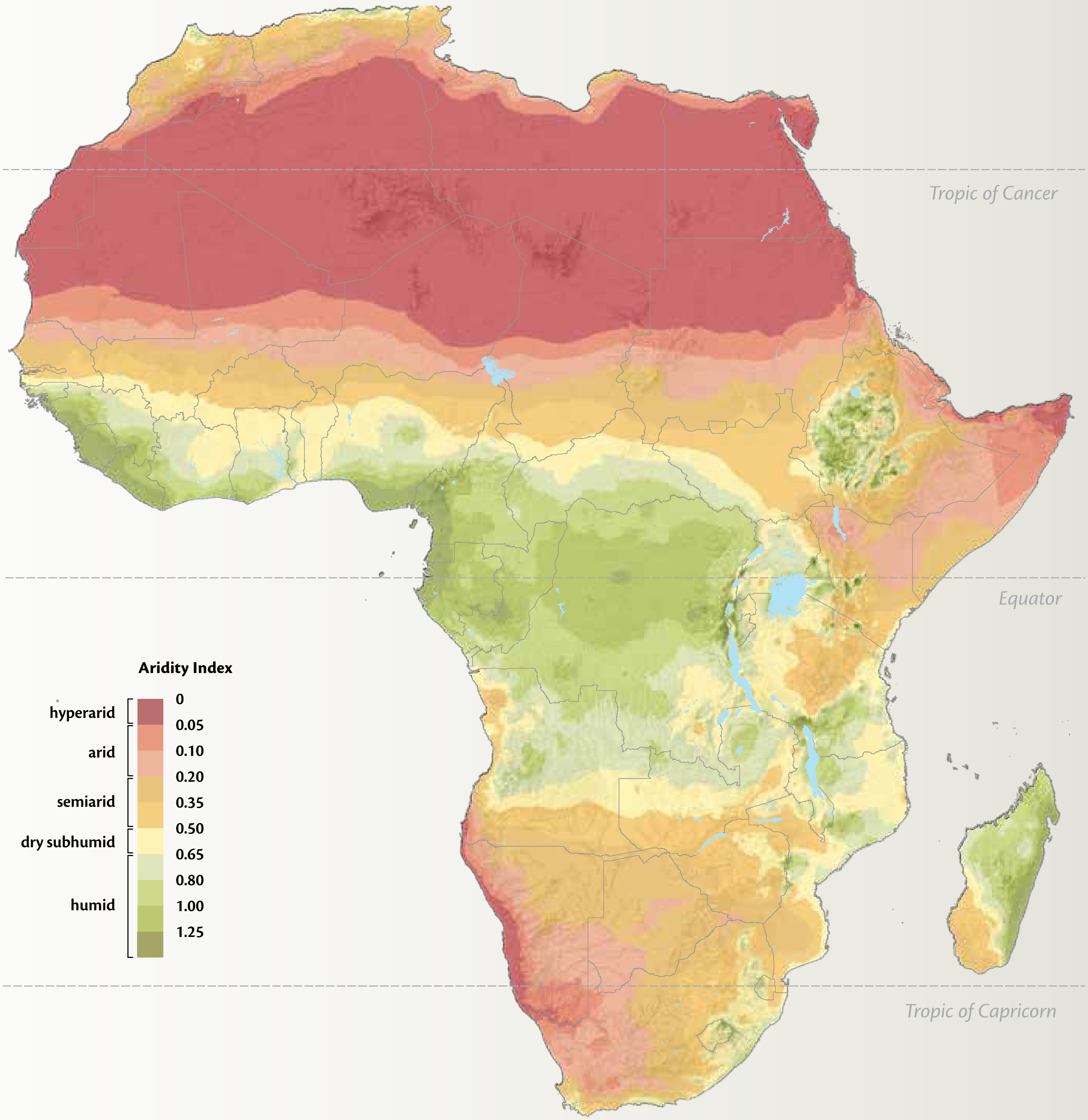
Global Aridity and PET (Potential Evapo-Transpiration) Database: http://bit.ly/1hYD3Iv

"The Climatology of Sub-Saharan Africa." Nicholson 1983.

Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements: http://bit.ly/1kCFdzq

"Carbon Sequestration in Dryland Soil," Chapter 2 in *The World's Drylands*: http://bit.ly/13HBTpc

MAP 1 Aridity index



Data source: Trabucco and Zomer 2009.

Note: Aridity Index=precipitation (mm)/potential evapotranspiration (PET mm). The aridity index classes are based on United Nations Environment Programme classifications (UNEP 1997).

Impacts of Climate Change on Length of Growing Period

Philip Thornton

WHAT ARE THESE MAPS TELLING US?

Projections show that climate changes between now and the 2050s may significantly affect the length of growing periods (LGP) in Africa. LGP, expressed as number of days per year, is a metric that integrates rainfall, temperature, and some soil conditions to determine when crops grow in certain areas (Map 1). It is a useful proxy for season type in the water-limited conditions that prevail in many parts of the tropics. LGP ignores intervening drought periods and so it is not always a good indicator of cropping success, but it is often highly correlated with yields. Map 2 shows the projected percentage change in LGP in the 2050s compared with current conditions, using a scenario of high greenhouse gas emissions and several global climate models. Most of the continent will see reductions in LGP, some of them severe. Parts of eastern Africa, particularly the Horn of Africa, may see some increases, but in these areas, current LGP is low (90 days or less, Map 1). The climate models used to project LGP do not all agree on how the climate may change by 2050. Map 3 shows the variability in projections for LGP estimated from several climate models. Since areas with lower values, such as much of central Africa, show more agreement between the various climate models, one can have more confidence in projected LGP changes in these areas. In areas with higher values, the climate models agree less, meaning the projections of LGP change are less reliable.

WHY IS THIS IMPORTANT?

To effectively adapt to climate change, farmers, governments, and other stakeholders must understand the potential effects on crop and livestock production. A contracted growing season can impact crop and livestock productivity, particularly in areas where growing seasons are already short. Temperature increases and rainfall changes could push some of these areas to a point where cropping may fail in most years. Some farmers may be able to adapt to shorter growing seasons by planting varieties that mature more quickly; other farmers may need to change to more drought- and heat-tolerant crops. Increase in LGP may present more growing opportunities, but it is uncertain how the change in growing time would impact soil moisture. As climate changes, the distribution of crop pests and diseases may change, too. Of course, LGP is only one metric; the information shown here can be combined with or compared to other aspects of projected climate change—such as temperature changes—to create a more detailed picture of how climatic shifts could affect crop growth and development.

TABLE 1 Atmosphere–Ocean General Circulation Models used to estimate LGP changes to the 2050s

Model Name (Vintage)	Institution	Resolution (degrees)
BCCR_BCM2.0 (2005)	Bjerknes Centre for Climate Research	1.9 × 1.9
CNRM-CM3 (2004)	Météo-France/Centre National de Recherches Météorologiques, France	1.9 × 1.9
CSIRO-Mk3_5 (2005)	Commonwealth Scientific and Industrial Research Organisation Atmospheric Research	1.9 × 1.9
ECHam5 (2005)	Max Planck Institute for Meteorology	1.9 × 1.9
INM-CM3_0 (2004)	Institute Numerical Mathematics	4.0 × 5.0
MIROC3.2 (medres) (2004)	Center for Climate System Research, National Institute for Environmental Studies, and Frontier Research Center for Global Change	2.8 × 2.8
Ensemble average	Average climatology of the above models	

Source: For model details, see Randall et al. 2007.

WHAT ABOUT THE UNDERLYING DATA?

The data are from downscaled climate projections. Because differences between climate models may be quite large, particularly for projected changes in rainfall patterns and quantities, the means of six climate models (Table 1) form the basis for generating daily weather data sequences plausible for future climatologies. Jones and Thornton (2013) provide details of the models used and the methods applied. LGP is calculated daily using a water balance model that calculates available soil water, runoff, water deficiency, and the ratio of actual to potential evapotranspiration (Ea/Et). The growing period begins with 5 consecutive growing days and ends with 12 consecutive nongrowing days; a growing day has an average air temperature greater than 6°C and Ea/Et exceeding 0.35.

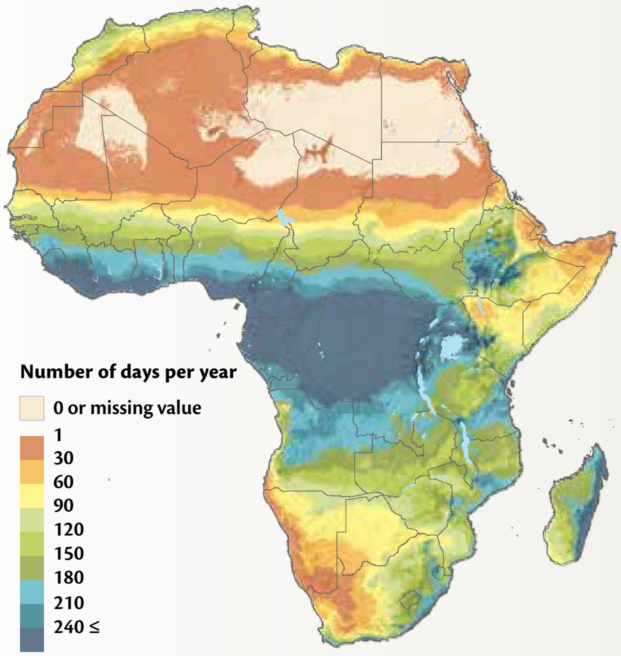
WHERE CAN I LEARN MORE?

Methods used to develop this data and create these maps: www.ccafs-climate.org/pattern_scaling/

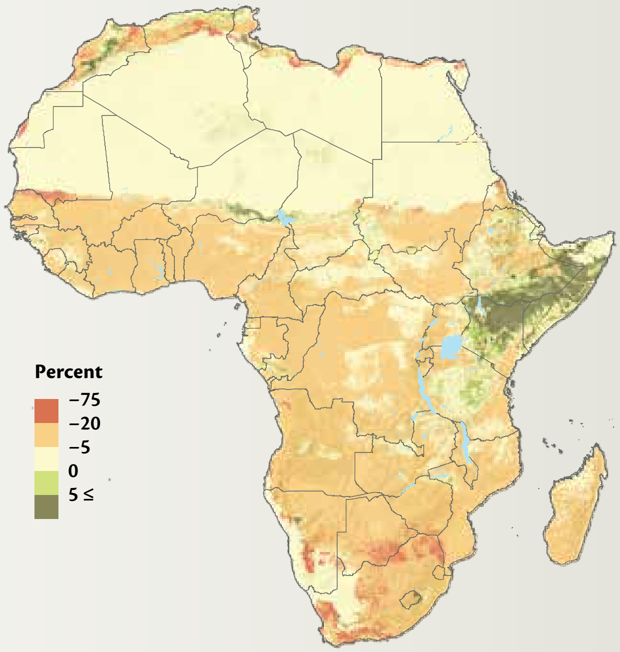
More information on the effects of climate change: Easterling et al. 2007.

Details on models used and methods applied: Jones and Thornton 2013; and Jones, Thornton, and Heinke 2009.

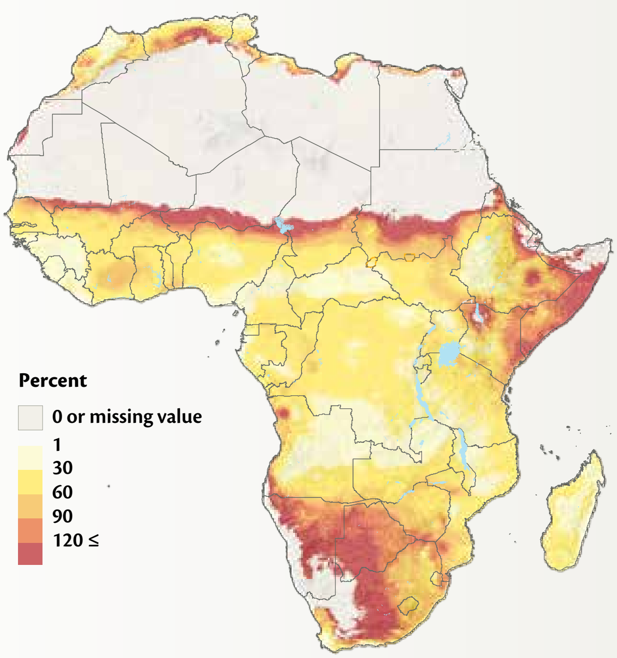
MAP 1 Average length of growing period (LGP) for current conditions, 2000s



MAP 2 Projected mean change in length of growing period (LGP) in 2050



MAP 3 Variability among length of growing period (LGP) projected values for 2050



Data source (all maps): Jones et al. 2009.

Note: LGP variability is represented by the coefficient of variation (CV), calculated as the standard deviation divided by the average LGP, expressed as a percentage.

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Maize Yield Potential

Jawoo Koo

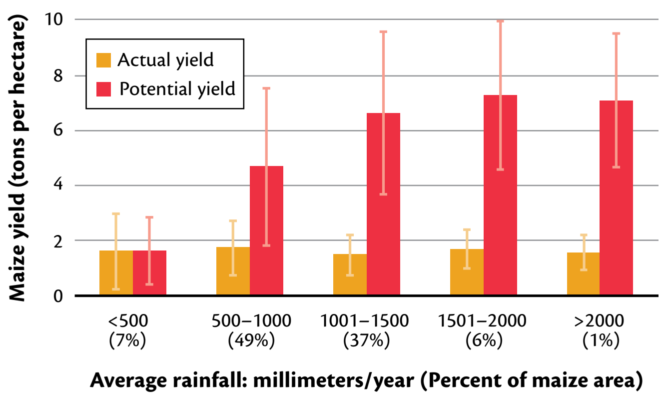
WHAT ARE THESE MAPS TELLING US?

Map 1 portrays the broad spatial distribution of farm-level rainfed maize production in Africa south of the Sahara. While South Africa, the region's largest producer, consistently achieves national average yields in excess of 4 tons per hectare (t/ha), the best performing of the remaining countries, including major producers such as Ethiopia, Malawi, and Zambia, typically average only around 2 t/ha. Farmers in other large-producer nations, notably Nigeria, Tanzania, and Kenya, have lower yields, around the regional norms of 1.3–1.7 t/ha. Map 2 shows potential rainfed maize yield, or the modeled patterns of achievable yields if key yield constraints, in this case soil nutrient deficiencies, could be overcome. If concerted development efforts helped to achieve this goal, approximately 55 percent of the current maize production area could attain yields in excess of 3 t/ha, a threshold that signals the basic subsistence cereal needs of smallholder families can likely be met, assuming typical farm holdings and family size (UN Millennium Project 2005). The gap between actual and potential yields tends to vary systematically by production environment (Figure 1). In drier regions (those areas with less than 500 millimeters of rainfall per year, such as the Sahel), estimated yield gaps are relatively modest, because the lack of rainfall remains a key limiting factor to increased yields even if soil fertility is improved.

WHY IS THIS IMPORTANT?

The maize yield analysis and mapping shown here helps target and prioritize specific geographic areas where researchers and farmers can work to overcome common sets of production constraints to enhance local livelihoods and food security. Yield potential in many areas is much higher than what farmers now achieve. In areas with higher levels of rainfall, improving soil quality can provide much bigger payoffs for farmers. However, reducing soil nutrient deficiencies is not a cure-all; other challenges, such as the increasing prevalence of pests and weed competition need to be addressed. Also, some production areas are inherently less suited to maize production using existing technologies and practices. Particularly in drier areas, farmers may already be achieving the potential that current varieties can support without further investments in small-scale irrigation or more drought-tolerant varieties.

FIGURE 1 Actual (2000) vs. potential maize yields, Africa south of the Sahara



Data source: Actual yield–You et al. 2012; potential yield–author's calculations.

Note: Bars indicate the average yield in each annual rainfall category weighted with maize harvest area, and the error bars indicate one standard deviation. Percentages in parentheses indicate the approximate share of maize production area in each rainfall category.

WHAT ABOUT THE UNDERLYING DATA?

Historical daily weather and soil databases generated by HarvestChoice were used as inputs to the DSSAT v4.5 CERES -Maize model (Jones et al. 2003; Hoogenboom et al. 2012) in order to simulate yields across a 5 arc-minute grid (with ~100km² grid cells at the equator) covering Africa. Historical monthly rainfall data for 1950–90 were extracted from the University of East Anglia CRU-TS v3.10 database (UEA 2011) and temporally downscaled to daily weather by applying satellite-observed daily rainfall patterns for 1997–2008 retrieved from the NASA-POWER Agroclimatic Database. Gridded soil texture classes (sandy, loamy, and clayey) were extracted from the updated Soil Functional Capacity Classification (FCC) System (HarvestChoice 2010a). Achieved yields were extracted from the SPAM database (You et al. 2012).

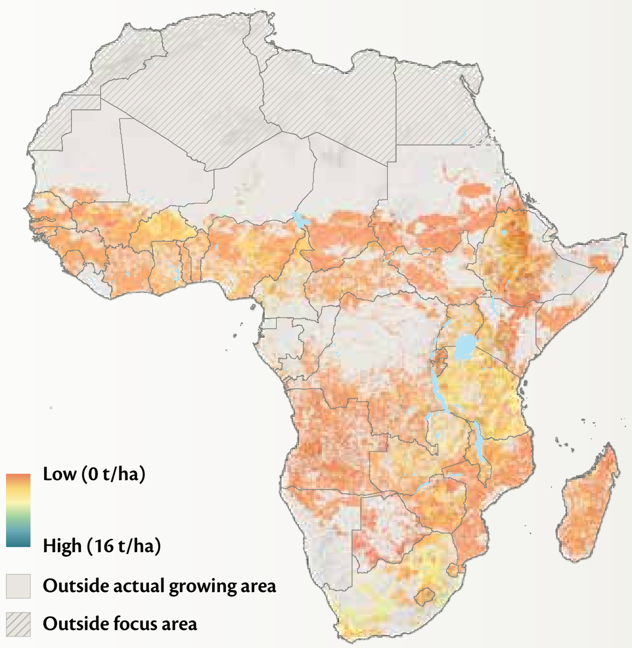
WHERE CAN I LEARN MORE?

Spatial Production Allocation Model: http://mapspam.info

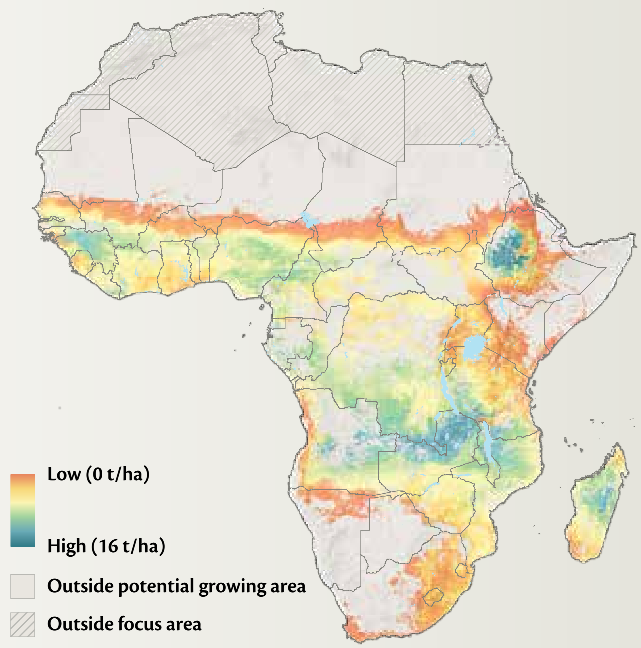
Synthesized 100-Year Weather Data. HarvestChoice 2010b: http://harvestchoice.org/node/1441

Updating Soil Functional Capacity Classification Systems HarvestChoice 2010: http://harvestchoice.org/node/1435

MAP 1 Actual rainfed maize yield, c. 2000



MAP 2 Potential rainfed maize yield



Data sources: Map 1—You et al. 2012; Map 2—Author.
Note: t/ha=tons per hectare.

Wheat Stem Rust Vulnerability

Yuan Chai and Jason Beddow

WHAT IS THIS MAP TELLING US?

Much of the wheat-growing area of Africa is susceptible to stem rust, a fungal disease of wheat. The map shows where crops might be vulnerable to stem rust infection. Almost all African areas where wheat production is relatively concentrated are vulnerable to the disease, including the northern growing areas in Morocco, Tunisia, Algeria, and the Nile Valley, along with major growing areas in central Ethiopia, southern Kenya, and South Africa. The map shows the disease's potential to pose a problem if wheat were grown throughout the continent, although it is not grown in all of the colored areas. In a typical year, the pathogen can persist year-round in the red areas, infecting wheat, rye, and barley. The climate of the blue areas is also hospitable to the pathogen, but it cannot survive the entire year in those locations, usually because they become too hot, cold, or dry. For infection to occur in these areas, the pathogen must be transported (primarily by wind) to the area each year.

WHY IS THIS IMPORTANT?

Stem rust negatively affects food security by limiting wheat production, which increases food prices. Though much of the wheat grown worldwide is somewhat resistant to the disease, most of the older cultivars used by many low-input farmers in Africa and elsewhere offer little resistance. Further, most of the world's wheat varieties have little resistance to new strains of the stem rust pathogen, collectively known as Ug99, that were first discovered in Uganda in 1998. These new strains could severely shrink global wheat supplies. From its emergence in Uganda, Ug99 has spread to infect wheat crops grown in other African countries, including major wheat-producing countries such as Kenya, Ethiopia, and South Africa.

On average, Africa's wheat-growing areas are highly susceptible to stem rust compared with global norms (Table 1). Based on these estimates along with the cereal crop distributions (p. 20), about 64 percent of the world's wheat area, representing 71 percent of global wheat output, is climatically vulnerable to stem rust infection, and the disease can persist year-round in about 13 percent of that area. By contrast, 90 percent of Africa's wheat-growing area, representing 87 percent of its wheat output, is susceptible to stem rust, and the disease can persist year-round in about 71 percent of the continent's wheat-growing area, representing 67 percent of Africa's wheat output. Thus, not only is Africa's wheat crop more vulnerable to stem rust infection, the disease is more likely to be present every year.

TABLE 1 Stem rust vulnerability and persistence in Africa and major wheat-growing areas of the world

Region	Vulnerable to stem rust		Persistent year-round	
	Area (%)	Output (%)	Area (%)	Output (%)
China	91.6	90.6	6.6	3.9
India	60.6	63.0	2.8	1.2
United States	53.5	56.6	0.7	1.1
Russia	22.8	21.9	0.0	0.0
Africa	90.0	86.9	70.6	66.6
Global	63.8	71.2	12.6	9.4

Data source: Calculated based on Beddow et al. 2013b and You et al. 2012.

Note: The percentages show the portions of the wheat harvested area (area %) and wheat produced (output %) that are susceptible to stem rust infection. Authors' calculations based on stem rust potential and harvested area and annual production for wheat. The climate in vulnerable areas allows the pathogen to infect a host during the growing season. Persistent year-round=areas where the pathogen can become established and survive year-round.

WHAT ABOUT THE UNDERLYING DATA?

Global estimates of climatic suitability were derived by modeling the response of the stem rust pathogen, *Puccinia graminis,* to climatic factors such as soil moisture and temperature as described by Beddow et al. (2013a). For each 10 arc-minute pixel (~344 km² at the equator) globally, the model was used to estimate the relative climatic suitability for the pathogen to infect a crop host during the growing season (vulnerability) and to survive year-round (persistence).

WHERE CAN I LEARN MORE?

Puccinia graminis. Beddow et al. 2013a.

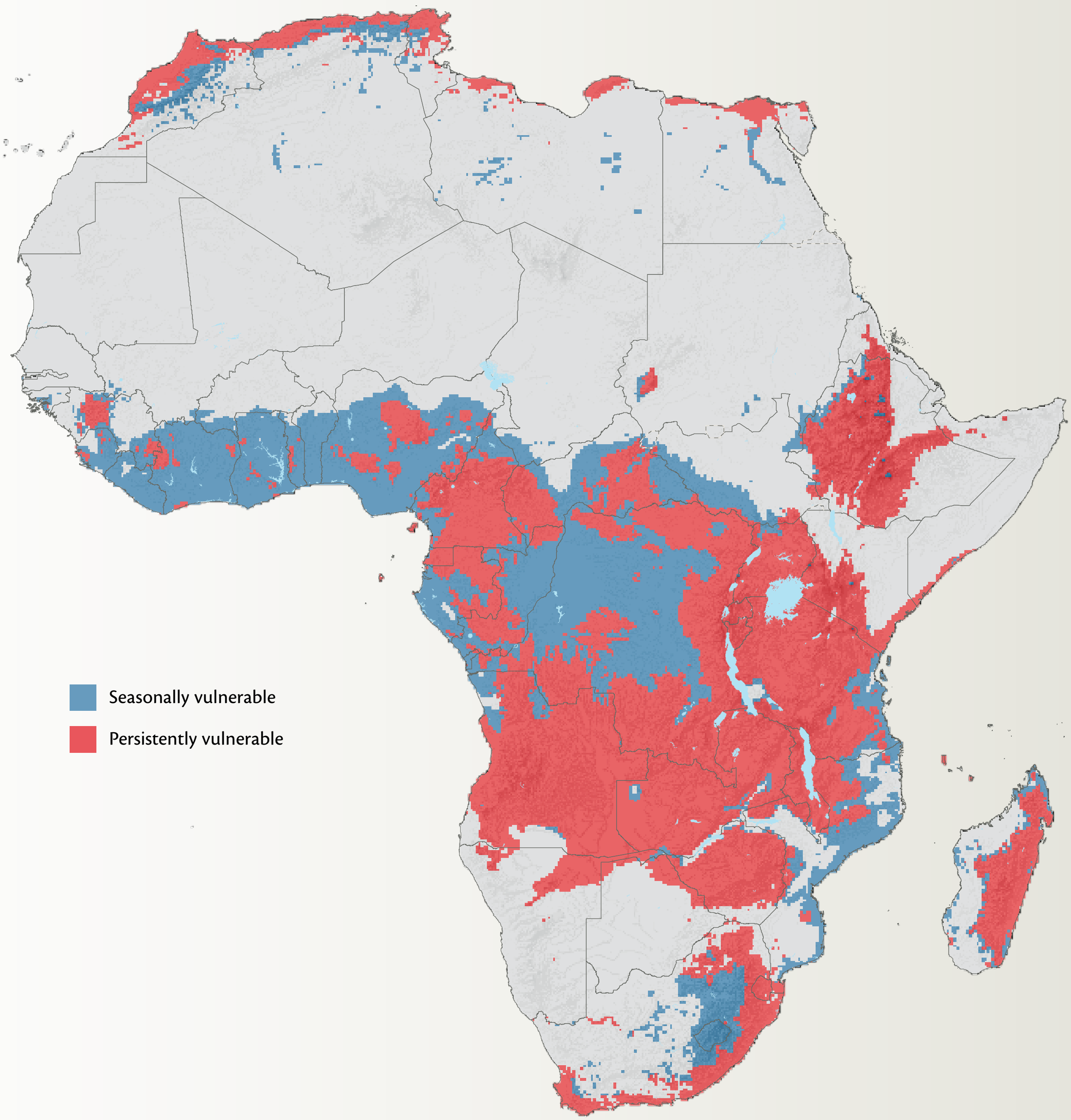
Measuring the Global Occurrence and Probabilistic Consequences of Wheat Stem Rust. Beddow et al. 2013b.

Potential Global Pest Distributions Using Climex: HarvestChoice Applications. Beddow et al. 2010.

Right-Sizing Stem-Rust Research. Pardey et al. 2013.

Tracking the movement of Ug99—CIMMYT Rust Tracker: http://rusttracker.cimmyt.org

MAP 1 Areas vulnerable to wheat stem rust



Data source: Beddow et al. 2013b.

Notes: Seasonally vulnerable=areas in which the pathogen can grow during the favorable season but cannot survive year-round. Persistently vulnerable=areas where the pathogen can become established and survive year-round.

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Benefits of Trypanosomosis Control in the Horn of Africa

Timothy Robinson, Giuliano Cecchi, William Wint, Raffaele Mattioli, and Alexandra Shaw

WHAT ARE THESE MAPS TELLING US?

Using the Horn of Africa as an example, the maps illustrate different steps in a methodology developed to estimate and map the economic benefits to livestock keepers of controlling a disease (Shaw et al. 2014). Cattle are first assigned to different production systems as shown in Map 1, illustrating for example, where mixed farming is heavily dependent on the use of draft oxen in Ethiopia, areas of Sudan and South Sudan where oxen use is much lower, and the strictly pastoral areas of Somalia and Kenya. Information on the location of cattle and production systems is combined with the distribution of tsetse fly species in the area (Map 2) to estimate the presence and absence of trypanosomosis, a parasitic disease transmitted by the tsetse fly. Herd growth and spread is modelled for the current situation, and for the simulated removal of trypanosomosis. The outputs of the model are then presented as a map of the financial benefits to livestock keepers that would be realized from trypanosomosis removal, expressed as US$ per km² (Map 3). The estimated total maximum benefit to livestock keepers, interpreted also as the maximum level of losses avoided, in the Horn of Africa amounts to nearly $2.5 billion, discounted at 10 percent over 20 years to account for the opportunity cost of funds—an average of approximately $3,300 per square kilometer of tsetse-infested area (Table 1). Map 3 shows how these benefits vary spatially.

WHY IS THIS IMPORTANT?

African animal trypanosomosis reduces the productivity of livestock, especially cattle, when it sickens or kills them. It also affects rural development and livelihoods more generally by limiting options for mixed farming and hindering a balanced use of natural resources. Moreover, in many areas the parasite causes sleeping sickness in people; a highly debilitating disease which if not treated is lethal. Deciding where and how to intervene against this disease requires knowledge of relevant socioeconomic dimensions, such as poverty levels (p. 76) and the role of livestock in people's livelihoods. The map of potential benefits from trypanosomosis removal in the Horn of Africa can help decisionmakers prioritize interventions by highlighting areas, such as Ethiopia, South Sudan and Kenya, where the financial return on investments to control the disease would be highest (Table 1).

TABLE 1 **Projected maximum benefits (US$) over 20 years of eliminating bovine trypanosomosis**

Country	Area of tsetse infestation (000 km²)	Total benefit from absence of trypanosomosis (US$ million)	Average benefit per km² infested (US$)
Ethiopia	157	834	5,317
Kenya	129	590	4,576
Somalia	38	158	4,181
South Sudan and Sudan	310	485	1,564
Uganda	103	390	3,786
Total	737	2,457	3,335

Source: Shaw et al. 2014.

Note: The total benefit represents the cumulative amount of money accrued over 20 years, discounted at 10 percent to account for the opportunity cost of funds, if trypanosomosis were removed in these countries over a five-year period.

WHAT ABOUT THE UNDERLYING DATA?

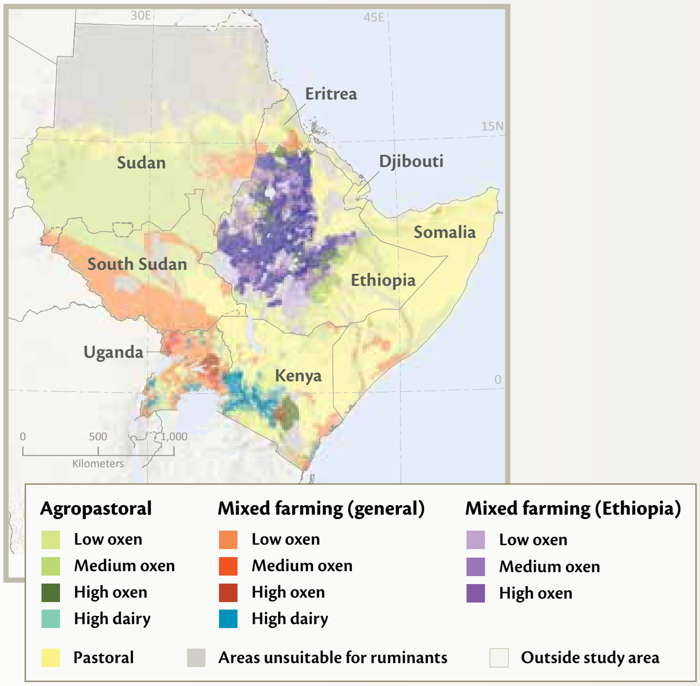
The model used information on cattle densities and production systems to account for herd growth and spatial spread of cattle over a 20-year period. For this analysis, pastoral, agropastoral, and mixed farming systems, as described in Cecchi et al. (2010), were further characterized to measure dairy and draft power in the Horn of Africa, using reported statistics on improved cattle that were cross-bred with higher yield varieties and on the use of draft oxen. The cattle distribution map used for the analysis was an earlier version of that presented for the whole of Africa (Map 1, p. 27). The predicted presence of six tsetse fly species of veterinary importance in eastern Africa at one kilometer resolution (Wint 2001) were combined into a single regional map that predicts the absence or presence of the genus *Glossina* (tsetse fly). Shaw et al. (2014) describe the herd model used and the detailed data on herd parameters with and without trypanosomosis in the region.

WHERE CAN I LEARN MORE?

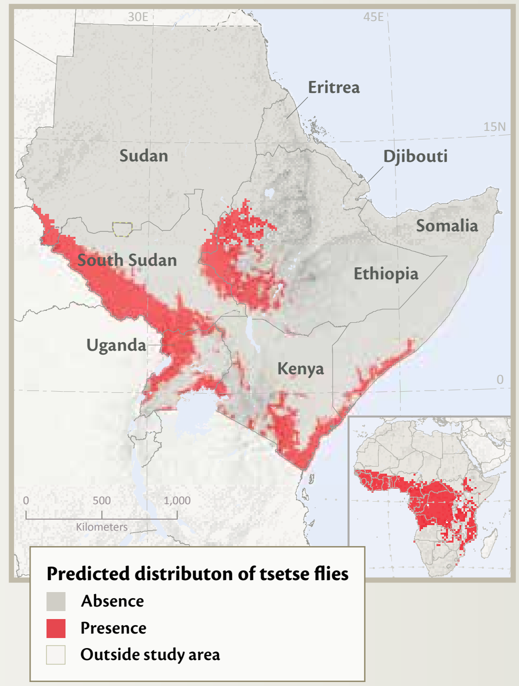
"Mapping the Economic Benefits to Livestock Keepers from Intervening Against Bovine Trypanosomosis in Eastern Africa." Shaw et al. 2014.

"Geographic Distribution and Environmental Characterization of Livestock Production Systems in Eastern Africa." Cecchi et al. 2010.

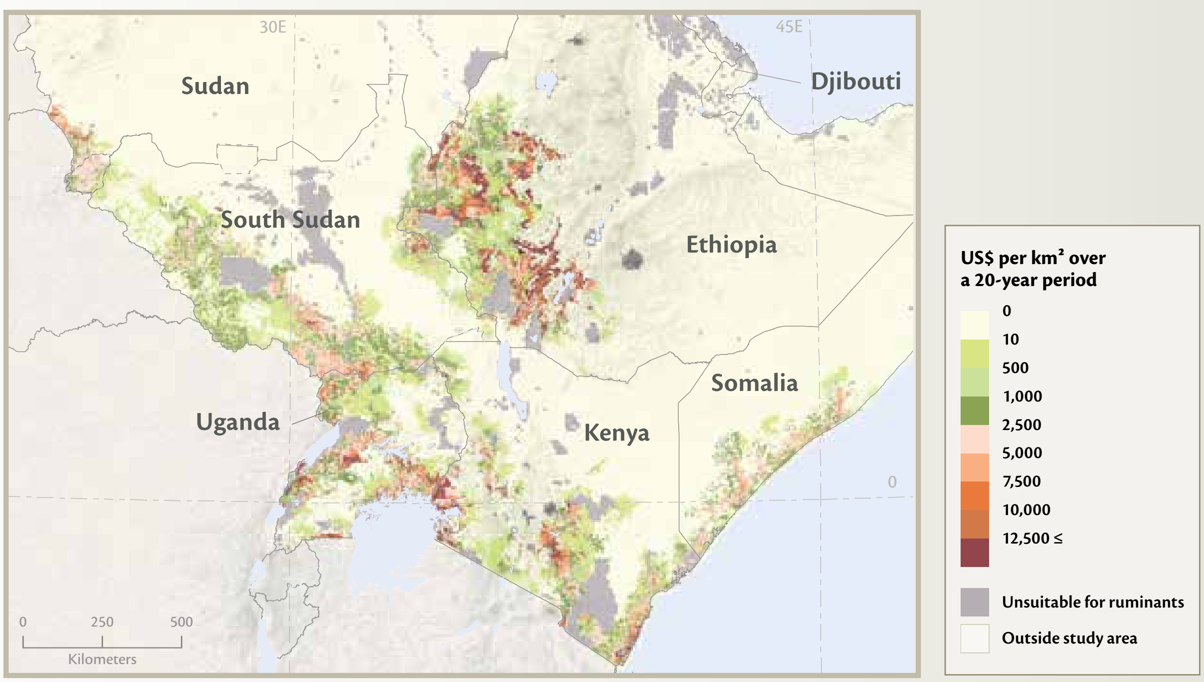
MAP 1 Cattle production systems



MAP 2 Tsetse fly distribution



MAP 3 Potential benefits of eliminating bovine trypanosomosis



Data source: Maps 1 and 2—Shaw et al. 2014; Map 3—Calculation based on Wint 2001.

Note: Map 3—The benefit=total amount of money accrued over 20 years, discounted at 10 percent to account for the opportunity cost of funds if trypanosomosis were eliminated in a five-year period.

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ACCESS TO TRADE

Market Access

Zhe Guo and Cindy Cox

WHAT ARE THESE MAPS TELLING US?

Most Africans do not have easy access to markets. To reach a city of 50,000 people, a farmer in western Africa may only have to travel 1 to 2 hours, whereas farmers in less densely populated areas such as eastern Angola may need to travel 8 hours or more. The maps show travel time to major settlements with populations of 20,000 or more (Map 1), 50,000 or more (Map 2), 100,000 or more (Map 3), and 250,000 or more (Map 4). Travel time is a proxy for accessibility and shows how likely farming households are to be physically integrated with or isolated from markets. Travel time is influenced not only by distance but also by infrastructure quality and road conditions. For example, because South Africa has better infrastructure and more well-maintained roads than the Democratic Republic of the Congo, it would take a South African farmer less time to travel the same distance to a market than a Congolese farmer. Another factor in determining market accessibility is the density of large cities in a country. A country with many large cities, like Nigeria, has highly accessible markets.

WHY IS THIS IMPORTANT?

Improved market access for the poorest countries is widely regarded as necessary to support agricultural and rural development. In Africa the practice of trading agricultural products is highly constrained by agricultural policies and poor transportation networks. Challenging road conditions, long distances, and inadequate road infrastructure add to travel times and transportation costs and therefore limit opportunities for farmers to sell their goods. Poor market access can also negatively impact farm production, because the accessibility of critical agricultural inputs such as fertilizer, pesticides, and seed is also limited. Compared to urban households and those with easy access to markets, rural farm households without market access typically rely on their own production for most of their calorie intake. Inadequate market access, therefore, puts these households at greater risk of food insecurity. The more accessible markets are, the greater the population's ability to remain economically self-sufficient and maintain food security. A comparison of the maps, which express travel time to different-sized cities (market centers), can help stakeholders better understand factors that determine farm performance. A simple cost-benefit analysis reveals whether it is more profitable to travel longer distances to larger markets or travel shorter distances to reach the nearest market.

WHAT ABOUT THE UNDERLYING DATA?

Accessibility was determined using a cost-distance function to measure the "cost" in hours to the nearest market center for each location, or 1 km² grid cell. Market centers and their size were determined using population estimates from Global Rural Urban Mapping Project data for the year 2000 (CIESIN et al. 2011). Travel time was estimated based on the combination of global spatial data layers, including road and river networks, assessed in terms of their "friction" or kilometers per hour travel time. Travel time was adjusted based on a number of input variables, including road location, road type, elevation, slope, country boundaries, bodies of water, coastline, and land cover. Each input variable was converted to a value representing the time it takes to travel 1 km. In the case of road type, for example, paved roads were given a value of 60 km per hour, while gravel roads were given a value of 15 km per hour. Bodies of water, land cover, slope, country boundaries, and elevation were also used to modify the speed of travel. For example, steeper areas were assigned slower speeds and time delays were factored into travel that crossed borders. The results are not meant to be accurate travel times but to estimate accessibility.

WHERE CAN I LEARN MORE?

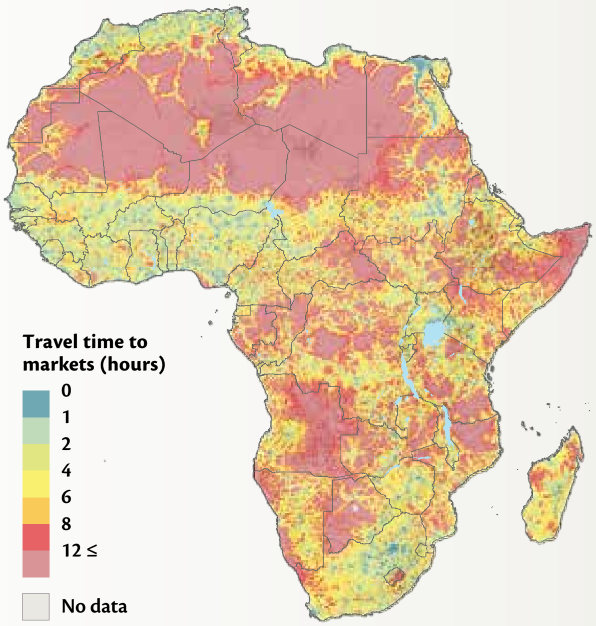
Market access:
http://harvestchoice.org/topics/market-access

Market access data for SSA:
http://harvestchoice.org/products/data/218

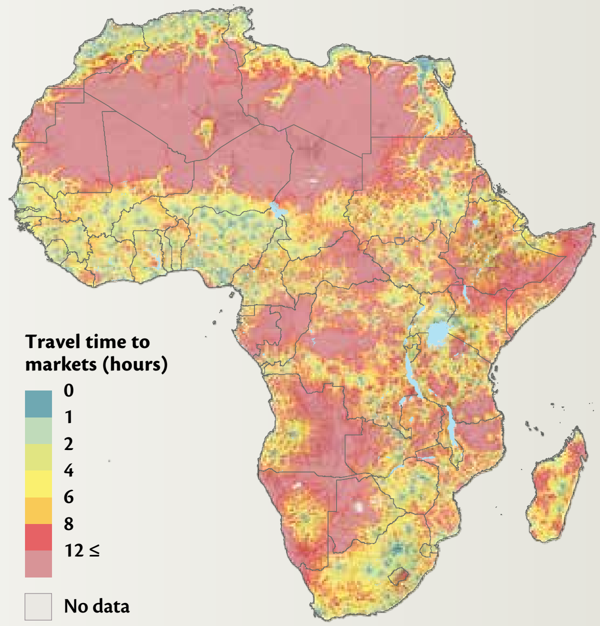
Global Rural-Urban Mapping Project population data:
http://bit.ly/KbKxJD

Market access based on population size of market centers

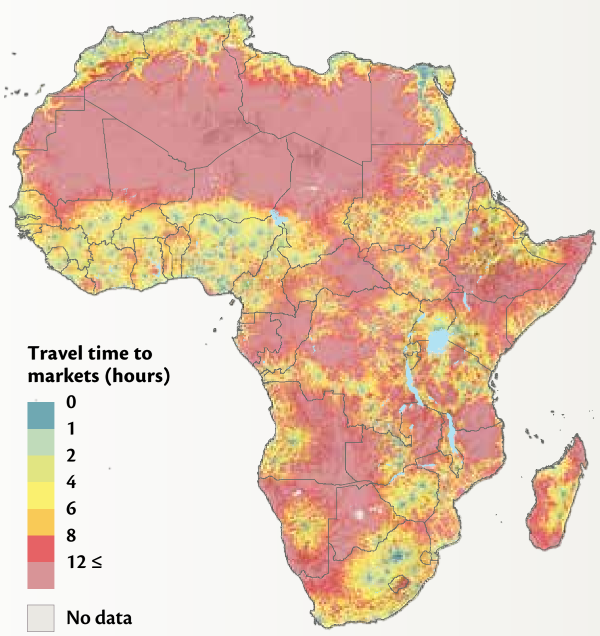
MAP 1 Population 20,000 ≤



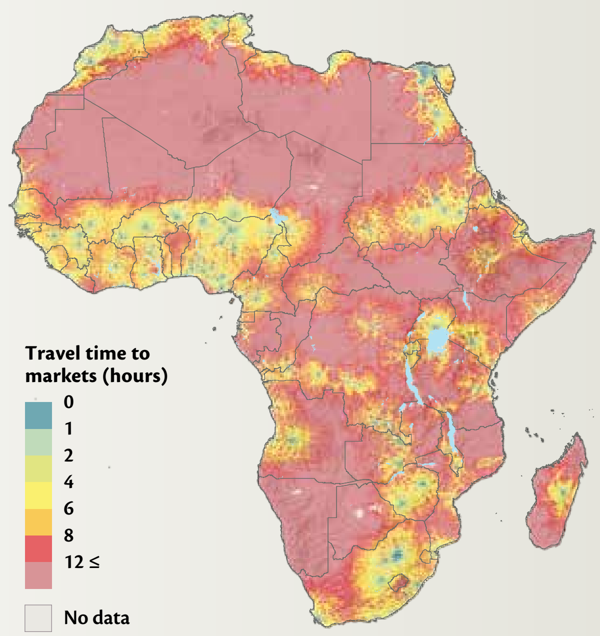
MAP 2 Population 50,000 ≤



MAP 3 Population 100,000 ≤



MAP 4 Population 250,000 ≤



Data source: Map 1—HarvestChoice 2011a; Map 2—HarvestChoice 2011b; Map 3—HarvestChoice 2011c; Map 4—HarvestChoice 2011d.

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

Accessing Local Markets: Marketsheds

Zhe Guo and Cindy Cox

WHAT ARE THESE MAPS TELLING US?

Across Africa buying and selling connects people. For a small-scale farmer, this trade takes place primarily within a limited geographic area based on access to market centers of a given size. The maps illustrate these areas using different colors to represent marketsheds—geographical areas and associated populations that are part of real or potential trade networks with a given market. From any location within a marketshed, it takes less time to travel to the corresponding market compared to any neighboring markets. In theory, farmers within a marketshed prefer to trade their commodities at the corresponding market, which minimizes travel cost (p. 66). The maps show that the density of marketsheds in Nigeria is high compared to that of other countries, because the country has many large cities. The high concentration of marketsheds also shows that it takes less time to travel to markets in Nigeria compared to neighboring countries. This suggests a denser and perhaps higher-quality infrastructure. The progression of Maps 1–4 shows that as the size of market centers, based on population, increases, there are fewer markets across the continent. Farmers thus have to travel farther, often across country boundaries, to reach larger market centers which may represent more lucrative trade opportunities.

WHY IS THIS IMPORTANT?

When analyzing factors that influence current and future farm performance, development planners and researchers need to know which markets are closest to agricultural producers. Farmers customarily select markets close to them so they can get to the market in the least amount of time to trade their goods; buy critical agricultural inputs, such as fertilizer, seed, and pesticides; or tap into a range of public and private services (extension, credit, and veterinary services being prime examples). A relatively large marketshed could mean that the population density for that shed is so low that few markets exist, and therefore that farmers have limited opportunities to sell their products (such as in Namibia). Or it might mean that the market within the shed serves a large population most likely due to adequate investments in road infrastructure. The maps show that the marketsheds are not restricted by country borders, which means that a farmer's preferred market of a given size may be in a neighboring country. In that case, restrictions posed by border crossings and trade laws need to be considered when determining the optimal market for a farmer. Because each map is based on market centers of different sizes, they can be used to determine the best markets for selling a farmer's goods. Farmers with an abundance of high-value goods will often prefer to sell or trade at larger commercial markets where demand and prices are higher than at smaller local markets.

WHAT ABOUT THE UNDERLYING DATA?

Marketsheds are based on the cost of travel to a market center of a given size. The number of marketsheds in a country indicates the number of market centers of that size within the country (for example, Map 1 is based on a market-center population of 50,000 or greater). The population cutoffs used in the maps are based on population estimates from Global Rural-Urban Mapping Project (GRUMP) data for the year 2000 (CIESIN et al. 2011). Proximity to a market was determined by measuring the lowest accumulated cost, or travel time, to each market location. Every market is surrounded by a marketshed. All points within the marketshed area offer the shortest travel time to the corresponding market center. Points along the boundary between two sheds have equal travel time to both of the centers. Travel time is estimated based on a combination of spatial data layers and variables that affect the time required to travel to the cities or market centers. These variables include elevation, slope, land cover, roads, road types, rivers, borders, and major bodies of water (Guo 2010).

WHERE CAN I LEARN MORE?

Marketsheds for Africa south of the Sahara (SSA): http://harvestchoice.org/labs/market-sheds

Market access: http://harvestchoice.org/topics/market-access

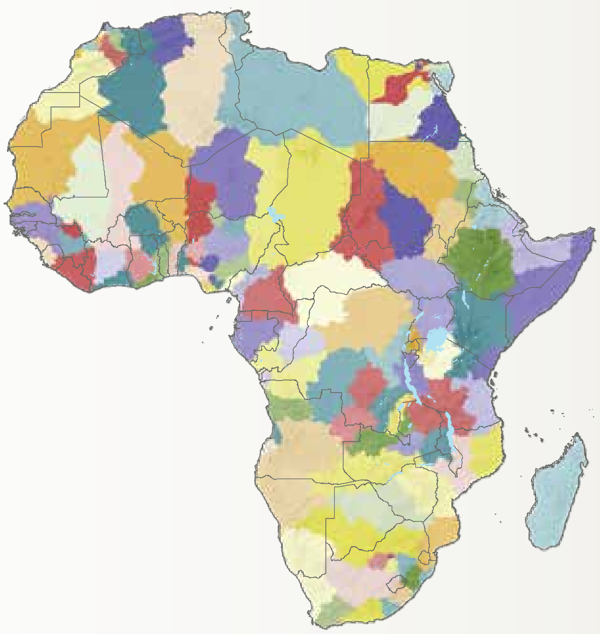
Marketshed data for SSA: http://bit.ly/1oFyB1B

Marketsheds based on population size of market centers

MAP 1 Population 50,000 ≤

MAP 2 Population 100,000 ≤

MAP 3 Population 250,000 ≤



MAP 4 Population 500,000 ≤

Data source (all maps): HarvestChoice 2012.

Note: Population data used are for the year 2000 (CIESIN 2011). The different colors represent marketsheds. A marketshed is the total area surrounding a market center of a given size. From any point within the marketshed, it is quicker to travel to that market center than to any neighboring marketshed's main market.

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Accessing International Markets: Ports and Portsheds

Zhe Guo

WHAT ARE THESE MAPS TELLING US?

More than 300 million Africans, about 30 percent of the total population, live more than one day away from the nearest port. Even when ports lie within a few hundred miles, typically sparse road networks, poor maintenance, and limited transportation infrastructure translate into high access costs. The larger map illustrates cost-of-travel accessibility to 63 major African ports, based on port type, size, and capacity in terms of the estimated total number of hours, both off and on the road network, required to travel from any location in Africa to the nearest port. The populations, traders, and haulage operations of countries such as South Africa and Egypt that maintain more and better ports as well as better transportation infrastructure have significantly better port access than those in landlocked countries such as Chad and South Sudan or large countries such as Democratic Republic of the Congo where infrastructure is limited. The travel time analysis underpinning the map is further summarized in Map 2, which shows portsheds. A portshed is a port's catchment area. Each portshed includes all the locations that are closer to a given port in terms of travel time than to any other port. Ports with large catchment areas, such as Mombasa in Kenya, have few competing ports and are connected to more extensive road networks. Ideally each port should be endowed with transportation corridors, infrastructure, and port facilities that maximize the trading opportunities within its specific portshed.

WHY IS THIS IMPORTANT?

Seaports play a significant role in enabling both export opportunities for agricultural products and import potential for new technologies and production inputs. Indeed, more than 90 percent of the international trade in African countries is conducted using maritime transport. Most African countries import vital agricultural inputs such as fertilizers, seeds, pesticides, and herbicides. Crops (especially cash crops) and livestock products (including skins and hides and, in the Horn of Africa, live animals) are primary agricultural exports. Map 1, showing travel time, provides a picture of how isolated many Africans are from such import and export hubs that could connect them with world markets and expand their earning potential. This information is valuable to policymakers and investors, both public and private. It allows them to identify intervention priorities that will, assuming sufficient competition in the transportation sector, reduce transaction costs and increase the capacity and efficiency of transportation systems. This ultimately improves production incentives for farmers and raises farm-level productivity and profitability by lowering input costs and increasing output prices.

TABLE 1 Distribution of major African ports by region and size

REGION	PORT SIZE			TOTAL
	Large	Medium	Small	
Eastern Africa	1	7	6	14
Middle Africa	-	4	4	8
Northern Africa	3	15	4	22
Southern Africa	1	4	1	6
Western Africa	-	9	7	16
Total	5	39	22	66

Data source: World Port Source 2012 and FAO 2012.

Note: The classification of harbor size is based on several applicable factors, including area, facilities, and wharf space. It is not based on area alone, nor any other single factor (National Geospatial-Intelligence Agency 2012).

WHAT ABOUT THE UNDERLYING DATA?

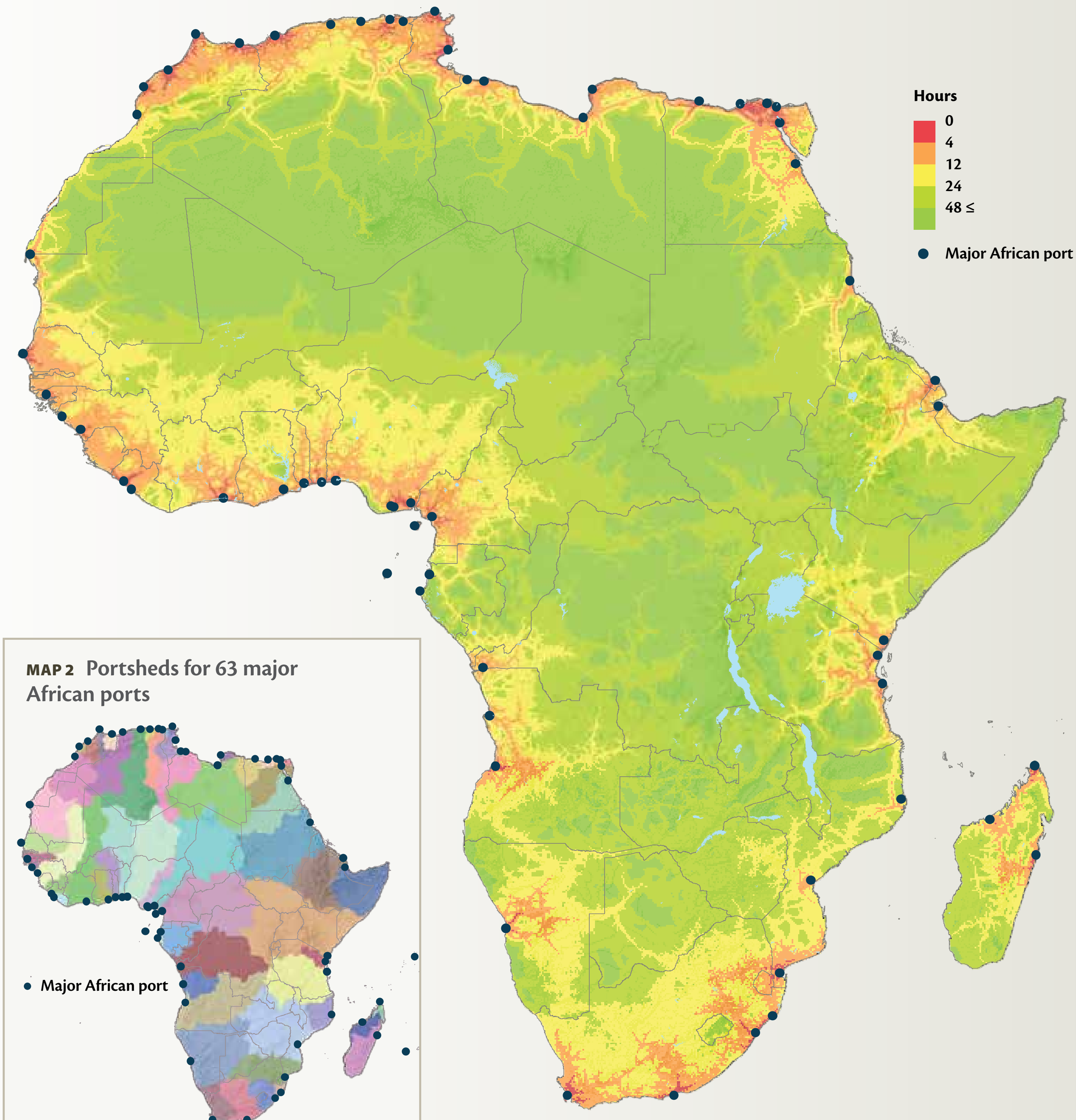
Travel time was estimated using a combination of spatial data layers and variables that influence accessibility, including elevation, slope, land cover, the road network, road types, rivers, borders, and major bodies of water. Esri's ArcGIS Spatial Analyst was used to develop spatial indicators of travel time to 63 major ports in Africa, which were selected based on port size and regional distribution (Table 1). The continent was then divided into portsheds, each defining the area associated with the closest corresponding port. The closest port was determined by estimating the lowest accumulated travel time (or cost) from a geographic location to the port. Using this approach, port A is the closest port for any geographic location within portshed A.

WHERE CAN I LEARN MORE?

Portshed data: http://bit.ly/1eRgKkI

World Port Source: www.worldportsource.com

MAP 1 Travel time to major African ports



MAP 2 Portsheds for 63 major African ports

Data source: Map 1—HarvestChoice 2012 and World Port Source 2012; Map 2—HarvestChoice 2012.

Note: Map 2—The different colors represent portsheds based on access to a major port. A portshed is the total area surrounding a major port for which the given port is closer in terms of travel time than any other port.

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HUMAN WELFARE

Severity of Hunger

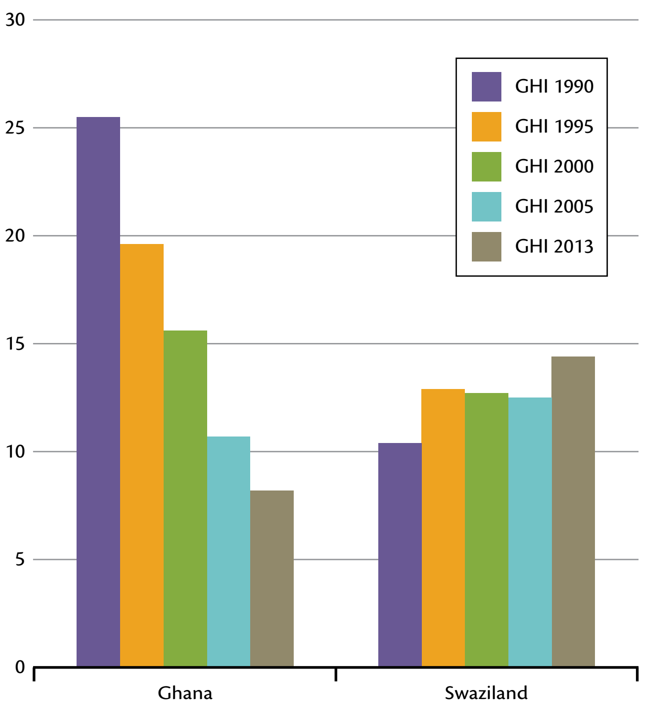
Klaus von Grebmer, Tolulope Olofinbiyi, Doris Wiesmann, Heidi Fritschel, Sandra Yin, and Yisehac Yohannes

WHAT ARE THESE MAPS TELLING US?

Map 1 shows the severity of hunger in Africa by categories—ranging from low to extremely alarming. These categories are associated with Global Hunger Index (GHI) scores. Higher scores indicate greater hunger; the lower the score, the better a country's situation. Of the 19 countries worldwide with alarming or extremely alarming levels of hunger, most (15) are in Africa south of the Sahara. Map 2 shows country progress in reducing GHI scores since 1990—that is, the percentage change in the 2013 GHI compared with the 1990 GHI. An increase in the GHI indicates a country's hunger situation is deteriorating. A decrease in the GHI indicates an improvement.

Overall, from the 1990 GHI to the 2013 GHI, six countries in Africa were able to reduce their scores by 50 percent or more. Twenty countries made modest progress, reducing their GHI scores by 25.0 to 49.9 percent, and 17 countries decreased their GHI scores by 0.0 to 24.9 percent. Hunger grew worse in Burundi, Comoros, and Swaziland (Map 2). Increased hunger in Burundi and Comoros can be attributed to prolonged conflict and political instability. For Burundi, the share of undernourished people in the population rose from 49 to 73 percent between the 1990 GHI and 2013 GHI. In Swaziland (Figure 1), the HIV and AIDS epidemic, along with high unemployment and adverse macroeconomic conditions, likely undermined food security. Ghana, the top performer in Africa in terms of improved GHI scores since 1990 (Figure 1), is the only country in Africa to appear on the top 10 list worldwide. Significant drops in the share of undernourished population and in the prevalence of underweight in children under five (p. 78) contributed to Ghana's 2013 GHI of 8.2, down from the 1990 GHI of 25.5 (Figure 1).

FIGURE 1 Trends in GHI scores for two countries



Source: von Grebmer et al. 2013.

WHY IS THIS IMPORTANT?

The GHI is designed to comprehensively measure and track hunger globally, by country, and by region. It highlights successes and failures in reducing hunger and provides insights into its drivers. By highlighting regional and country differences, the GHI aims to trigger actions to reduce hunger. The GHI is a multidimensional index of hunger that combines three equally weighted indicators (undernourishment, child underweight, and child mortality) in one number. This multidimensional approach takes into account the nutrition situation not only of the population as a whole, but also of a physiologically vulnerable group—infants and young children—for whom a lack of nutrients (p. 78) creates a high risk of illness, poor physical and cognitive development, and death.

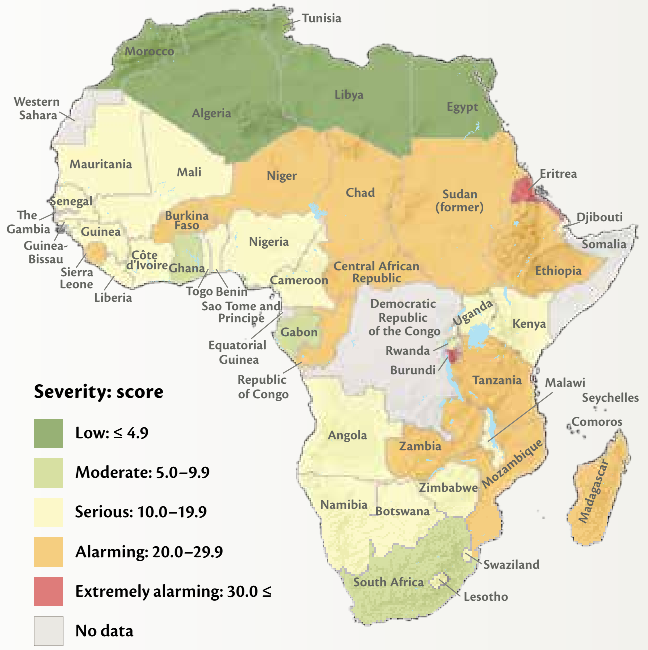
WHAT ABOUT THE UNDERLYING DATA?

The 2013 GHI was calculated for 120 countries globally for which data were available and where measuring hunger is considered most relevant. The GHI is only as current as the data for the three component indicators: undernourishment, child underweight, and child mortality. Source data for the 2013 GHI are from 2008 to 2012 (von Grebmer et al. 2013). Therefore, the GHI is a snapshot of the recent past, not the present. More up-to-date and extensive country data on hunger are urgently needed. The Democratic Republic of the Congo, for example, had the worst score in past GHI reports. But due to political instability and ongoing conflict, reliable data are no longer available to calculate its GHI.

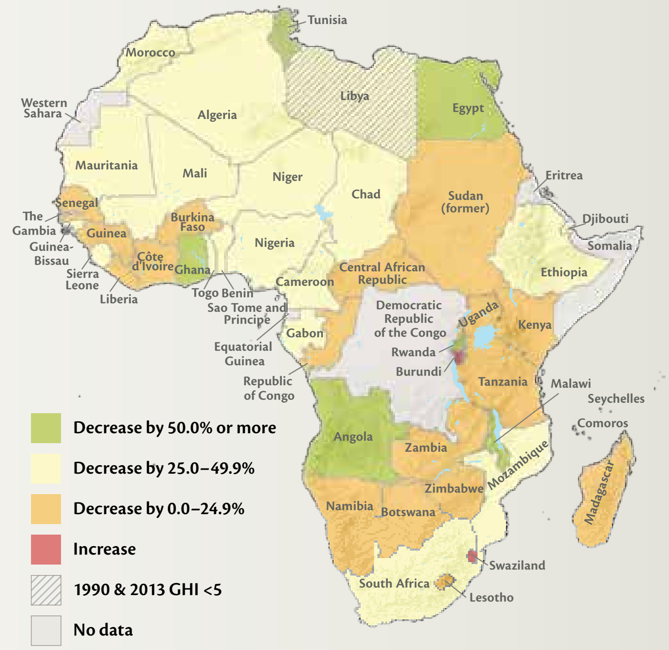
WHERE CAN I LEARN MORE?

2013 Global Hunger Index: http://bit.ly/KaKqhr

MAP 1 2013 Global Hunger Index scores



MAP 2 Percentage change in 2013 GHI compared with 1990 GHI



Data source (all maps): von Grebmer et al. 2013.

Note: The 2013 Global Hunger Index score could only be calculated for former Sudan, because separate undernourishment estimates for 2010–2012 were not available for (north) Sudan or South Sudan, which became independent in 2011.

Poverty

Carlo Azzarri

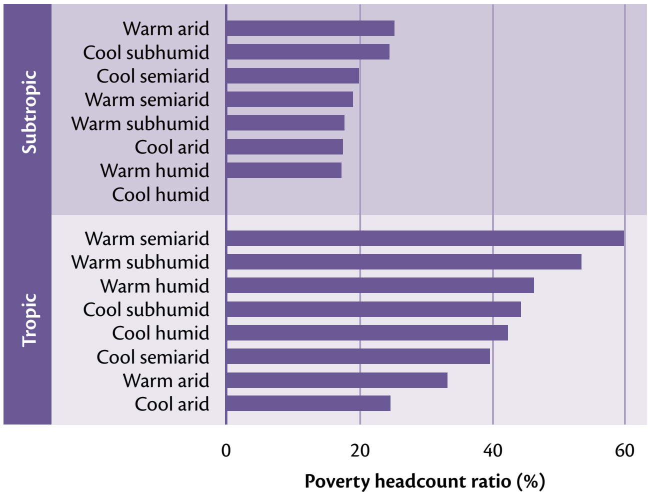
WHAT ARE THESE MAPS TELLING US?

Almost half of the population of Africa south of the Sahara (SSA) lives in extreme poverty, on less than $1.25 per capita per day.[1] Map 1 shows the distribution of the poor and highlights areas where over 80 percent of the population is extremely poor (for example, parts of Liberia, Nigeria, Tanzania, and Zambia). Map 2 shows the density of extremely poor across the continent, highlighting regions that are home to more than 100 extremely poor people per square kilometer. Moderate poverty is defined as living on a daily per capita expenditure between $1.25 and $2.00. Map 3 shows the distribution of poor using the $2.00 per day threshold, thus including both the moderately and extremely poor. This map shows a more even distribution of poor across Africa and consistently higher shares of the total population. Map 4 reinforces that the most densely populated poor areas are concentrated along the coast of western Africa, in much of Nigeria, in Malawi, in Ethiopia, and in the countries bordering or near Lake Victoria. Figure 1 shows that extreme poverty is also highly correlated with certain agroecological zones (p. 34). For example, poverty levels are highest in the warm semiarid and subhumid tropical areas immediately south of the Sahara and in the tropical warm humid forests of the Democratic Republic of the Congo. And, overall, poverty levels are lower in the subtropical zones of southern Africa (for example, Namibia and South Africa).

WHY IS THIS IMPORTANT?

Poverty prevalence (Maps 1 and 3) is crucial information for policymakers and international donors who are setting priorities for intervention and investment. Poverty density complements prevalence by showing the number of poor people per square kilometer (Maps 2 and 4). These maps together answer two important questions: Where is poverty a serious problem? Where might investments have the greatest impact on the highest number of people? Combining insights on both prevalence and density allows policymakers to more effectively target interventions to reach the greatest number of the poorest people. Once target populations are identified, information on the dominant types of existing livelihoods and agriculture-related opportunities can be helpful in formulating appropriate interventions.

FIGURE 1 Poverty headcount ratio by agroecological zone



Data source: HarvestChoice 2012 and HarvestChoice 2011.

Note: Poverty headcount ratio=the percentage of a population living in households where consumption or income per person is below the poverty line.

WHAT ABOUT THE UNDERLYING DATA?

Subnational poverty rates were extracted from 24 nationally representative household surveys conducted in various years. For countries without survey data, national average poverty prevalence extracted from PovcalNet (World Bank 2012) for the closest year to 2005 was uniformly applied to the entire country. As such, subnational poverty rate distributions reflect the relative ranking in the actual survey year, although all values are expressed in terms of 2005 average purchasing power parity exchange rates. Poverty ratios are therefore comparable across countries. Not all current data points refer to 2005, with a maximum variance of plus or minus two years for a limited number of countries (HarvestChoice 2012).

WHERE CAN I LEARN MORE?

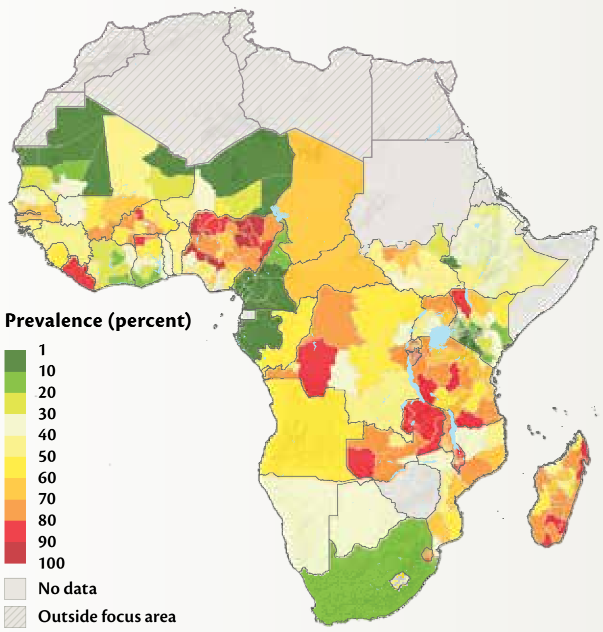
Poverty analysis at the World Bank: www.worldbank.org/en/topic/poverty

"Poverty Comparisons over Time and Across Countries in Africa." Sahn and Stifel 2000.

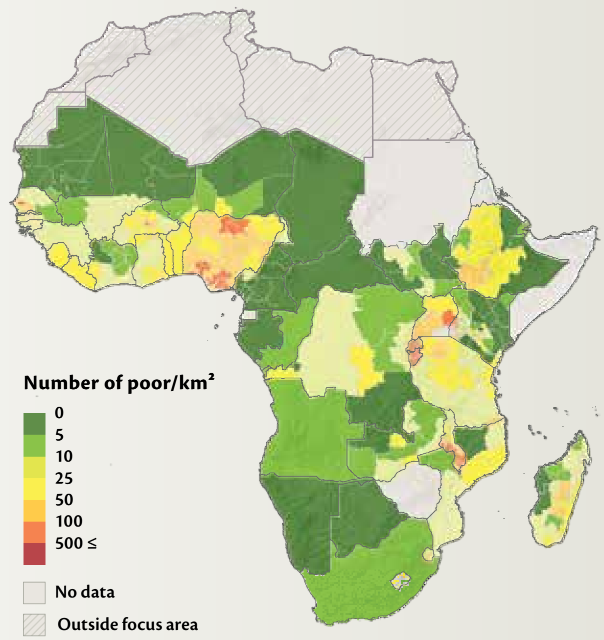
"Where Will the World's Poor Live?: An Update on Global Poverty and the New Bottom Billion." Sumner 2012.

1 The $1.25 and $2.00 poverty lines are the level of total household per capita consumption expenditure (a synthetic indicator of household welfare) expressed in terms of 2005 average purchasing power parity exchange rates.

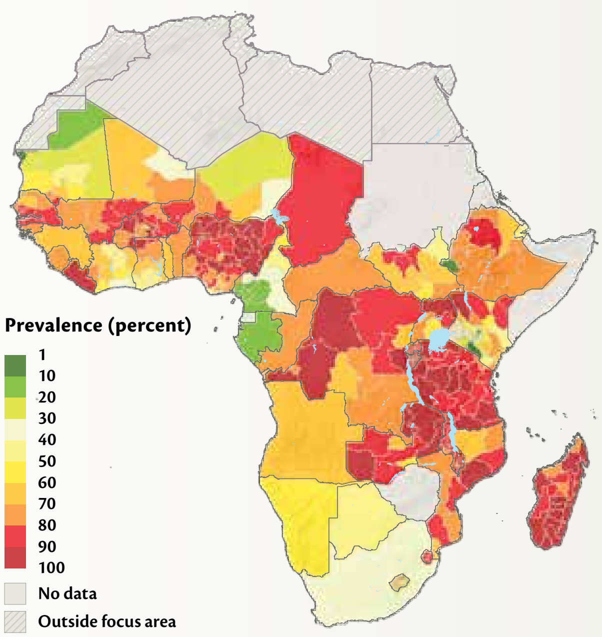
MAP 1 Share of population living at ≤ $1.25/day (extremely poor)



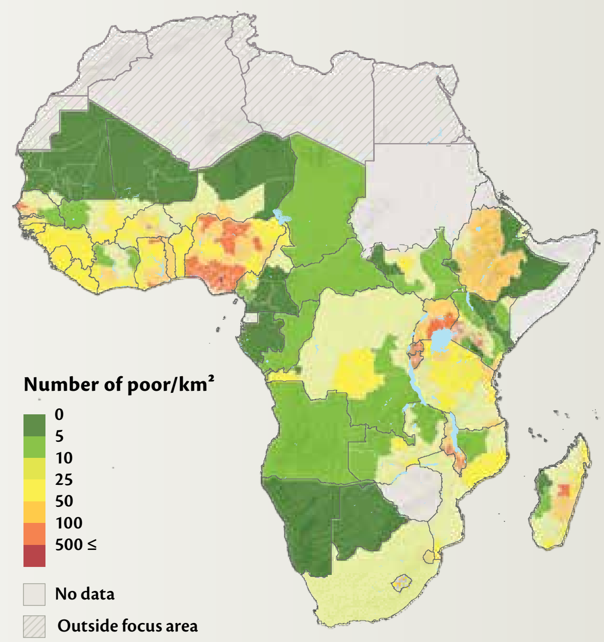
MAP 2 Poverty density at ≤ $1.25/day (extremely poor)



MAP 3 Share of population living at ≤ $2.00/day (includes moderately and extremely poor)



MAP 4 Poverty density at ≤ $2.00/day (includes moderately and extremely poor)



Data source (all maps): HarvestChoice 2012.

Note: All values are expressed in terms of average 2005 purchasing power parity rates.

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Early Childhood Nutrition and Health

Carlo Azzarri

WHAT ARE THESE MAPS TELLING US?

High levels of stunting, or lower than average height in children younger than five, are more widespread in Africa south of the Sahara (SSA) than high levels of wasting (lower-than-average weight for height) or underweight (low weight for age) in children under age five (Maps 1, 2, and 3). This reflects a longstanding nutritional problem that has proven difficult to eradicate in this region. Even with improved living conditions in SSA, the prevalence of stunting has not yet been sufficiently reduced. Stunting and underweight are manifestations of undernutrition—food energy deprivation that occurs when food intake is below standard nutritional requirements for a prolonged period and/or levels of food absorption are low. Wasting usually reflects an acute weight loss due to a recent period of hunger or disease and is often associated with shorter term limitations to food supplies. The maps show that high rates of undernutrition do not always correspond to high rates of diarrhea (Map 4), which contribute to undernutrition by interfering with the absorption of food consumed. This suggests that poor infrastructure and lack of access to clean water (the main causes of diarrhea) are just two of many reasons behind the severe undernutrition in SSA. The red areas of the maps reflect undernutrition levels classified as "very high"—40 percent or above for stunting; 15 percent or above for wasting; 30 percent and above for underweight (WHO 2006); and 20 percent or above for diarrhea—and highlight the key areas for concern across the continent.

WHY IS THIS IMPORTANT?

The information on these maps is crucial to policymakers and national and international donors who seek to direct resources to the most food-insecure regions of the world. Child nutrition is often used as an indicator of an area's nutrition security. According to the World Health Organization (WHO), child undernutrition is directly or indirectly responsible for one-third of the deaths among children under age five, and it is also related to other illnesses common in children, such as diarrhea and measles. Undernutrition carries long-term consequences for children, impairing their cognitive development and affecting their performance once they are adults. Better nutrition translates into a stronger and healthier population with greater opportunities to break the cycle of poverty and achieve better quality of life. Improving children's nutritional status is therefore fundamental to realizing a country's development potential, especially in nations in SSA where nearly half of the population is less than 15 years old.

WHAT ABOUT THE UNDERLYING DATA?

Measurements are usually taken from children from birth up to 60 months, as this captures the impact of possible deficiencies incurred during gestation, and it is when children are most vulnerable as they rapidly grow and develop. After the 1,000-day window of opportunity (from the start of a woman's pregnancy until her child's second birthday), any impaired height development or cognitive function is largely irreversible. To obtain anthropometric measures, we used the children's weight, height, and age information collected in the Demographic and Health Survey (DHS) Phase 5 (2003–2008) and Phase 6 (2008–2013). The DHS surveys are regularly conducted in many developing countries in different years, and these maps show the values for countries with survey years ranging from 2003 to 2011 (Measure DHS 2013).

WHERE CAN I LEARN MORE?

Measure DHS online: www.statcompiler.com/

WHO Child Growth Standards Publications: www.who.int/childgrowth/publications/en/

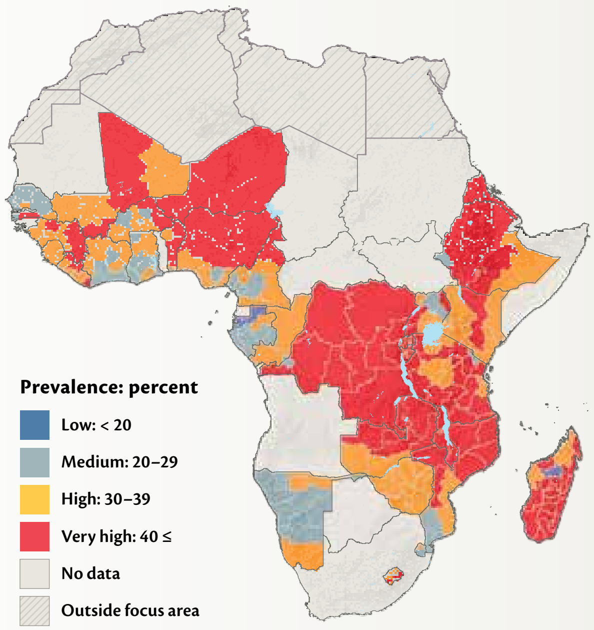
Explaining Child Malnutrition in Developing Countries: A Cross-Country Analysis. Smith and Haddad 2000.

Poverty and Undernutrition: Theory, Measurements, and Policy. Svedberg 2000.

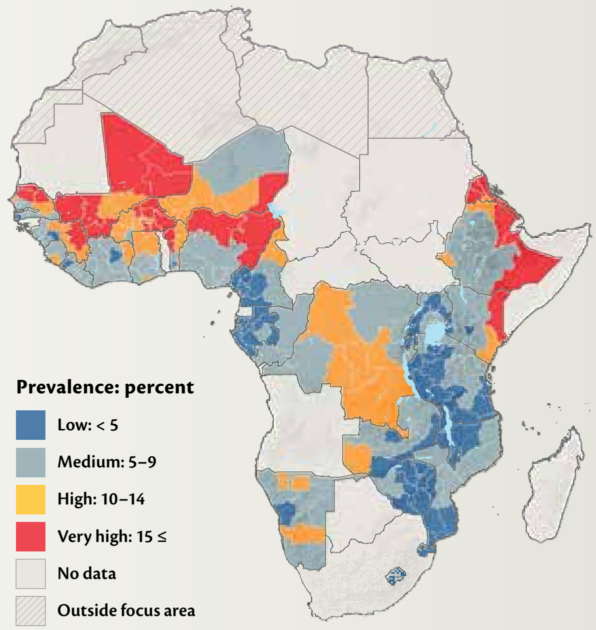
"Worldwide Timing of Growth Faltering: Revisiting Implications for Interventions." Victora et al. 2010.

Nutrition and health among children under age five

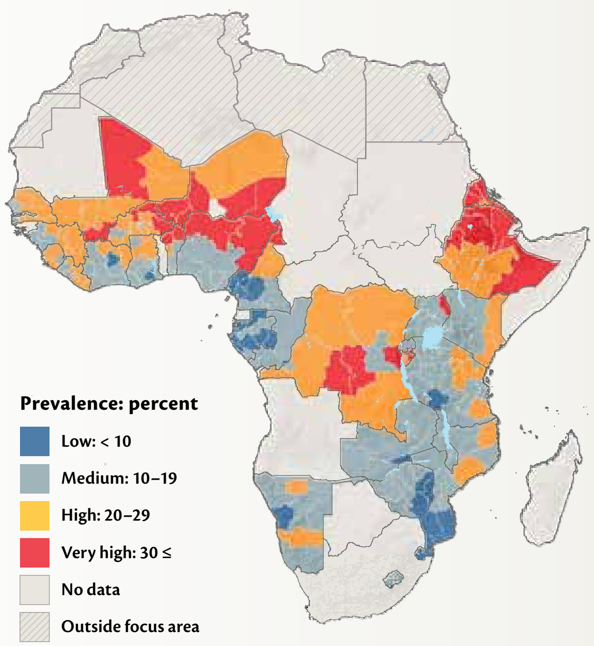
MAP 1 Stunting



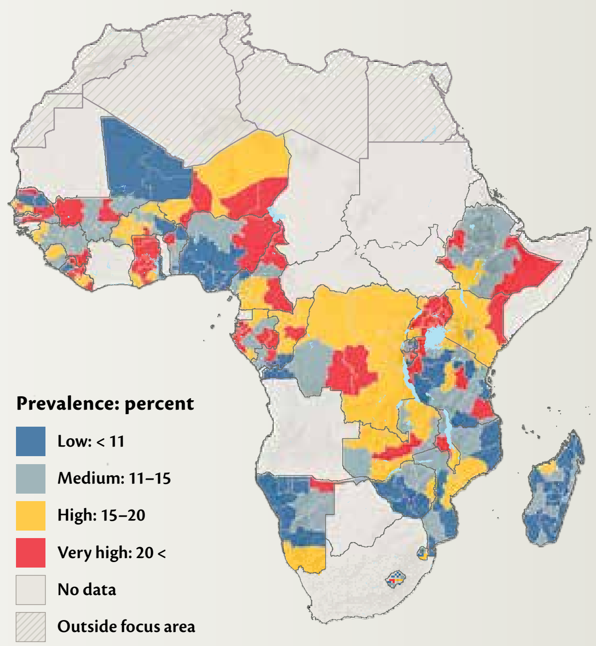
MAP 2 Wasting



MAP 3 Underweight



MAP 4 Diarrhea



Data source (all maps): Measure DHS 2013 and WHO 2006.

Note: The maps are based on DHS surveys conducted over the period 2003 to 2011. The maps show prevalence classes and corresponding undernutrition levels (as a share of total children under age five) as designated by the World Health Organization.

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Glossary

agricultural systems: crop management schemes selected by farmers to optimize the yield of a particular crop given sociological, economic, biological, and political constraints.

agroecological zone: geographical areas that exhibit similar climatic conditions that determine their ability to support rainfed agriculture. These zones broadly define environments where specific agricultural systems thrive.

agropastoral farming systems: farming systems located in semiarid areas of western, eastern, and southern Africa, dominated by sorghum, millet, and livestock. Livelihoods are derived from maize, pearl millet, pulses, sesame, sorghum, cattle, goats, poultry, sheep, and off-farm activities.

aluminum toxicity: occurs in weathered soils that have become highly acidic, making aluminum soluble and thus toxic to plants. Aluminum toxicity is the most common soil constraint in Africa south of the Sahara (SSA).

arable land: the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than five years). This category does not include abandoned land resulting from shifting cultivation.

arid: an area where the length of growing period (LGP) is less than 70 days per year.

arid pastoral oasis farming systems: farming systems in scattered communities in arid areas with average length of growing period less than 30 days, and located primarily in northwest, northeast, and southern Africa. Livelihoods are based on cattle, small ruminants, date palms, and off-farm activities.

aridity index: the ratio of annual total precipitation to annual total potential evapotranspiration (PET). Aridity index values increase with more humid conditions and decrease with more arid conditions. The aridity index measures how much rainfall is available to satisfy the evapotranspiration water requirements for different reference vegetation types.

blue water: water withdrawn from groundwater bodies (aquifers) or surface water bodies (rivers, lakes, wetlands, canals) and used for irrigation of agricultural land, for drinking water, or by the industrial sector for processing and cooling.

calcareous: a kind of soil that contains high levels of calcium carbonate. Calcareous soils can be highly fertile, but extremely calcareous soils can lead to crop nutrient deficiencies by fixing phosphorus (see P fixation).

cereal-root crop mixed farming systems: farming systems located in subhumid areas of western and central Africa, distinguished by cereal crops along with roots and tubers. Livelihoods are based on cassava, cattle, legumes, maize, millet, sorghum, yams, and off-farm activities.

coefficient of variation: a measure of variability from an average calculated as the standard deviation divided by the mean and expressed as a percentage, such as year-to-year rainfall variability.

Comprehensive Africa Agriculture Development Program (CAADP): an Africa-led program designed to promote increasing investments in agricultural growth in Africa through research, extension, education, and training. CAADP is a program of the New Partnership for Africa's Development (NEPAD).

consumptive water use: in agriculture, typically refers to crop evapotranspiration only and excludes return flows.

cracking clay: soils with high amounts of clay that shrink and swell upon wetting and drying—also called expansive clay. These soils can be difficult to manage because they can be too wet (reducing gas exchange in the soil) for good plant growth. When wet, cracking clay can greatly expand in volume and create additional soil problems. Extensive soil cracking can disturb plant roots, and crusting can reduce water infiltration, when dry.

crop evapotranspiration: the sum of evaporation from the soil and transpiration of the plants.

dryland systems (also known as dryland agricultural production systems): agroecosystems characterized by low and erratic precipitation, persistent water scarcity, extreme climatic variability, high susceptibility to land degradation—including desertification—and higher loss rates for natural resources, including biodiversity. In dryland systems, the lack of water is the key factor that limits profitable agricultural production.

Ea/Et: ratio of actual to potential evapotranspiration.

evapotranspiration: the conversion of soil water into water vapor. Estimating evapotranspiration rates is important when planning irrigation schemes.

farming system: population of farm households that have broadly similar resource and livelihood patterns, face similar constraints and opportunities, and could benefit from similar development strategies and interventions. Household livelihoods are based on farm production as well as off-farm activities.

fish-based farming systems: farming systems that are close to major inland or coastal water bodies with fish as a major source of livelihoods. Although located throughout Africa, these fish-based farming systems are concentrated along the coast and around major lakes. Livelihoods are based on fish, bananas, cashews, coconuts, fruit, yams, poultry, goats, and off-farm activities.

forest-based farming systems: farming systems in humid lowland, heavily forested areas of central Africa. Livelihoods are based on subsistence food crops, including beans, cassava, cocoyams, maize, taro, and off-farm activities.

free of constraints: soils free from fertility constraints.

Global Hunger Index (GHI): a multidimensional measure of hunger that combines three equally weighted indicators (undernourishment, child underweight, and child mortality) in one index number. It takes into account the nutrition situation of not only the population as a whole, but also of a physiologically vulnerable group—children—for whom a lack of nutrients creates a high risk of illness, poor physical and cognitive development, and/or death.

Global Yield Gap Atlas Extrapolation Domain (GYGA-ED): a climate zone scheme or domain based on three variables: (1) growing degree days with base temperature of 0°C; (2) temperature seasonality (quantified as the standard deviation of monthly average temperatures); and (3) an aridity index (annual total precipitation divided by annual total potential evapotranspiration). (See aridity index, potential evapotranspiration, and transpiration).

green water: precipitation stored in the soil and used by rainfed and irrigated crops.

growing degree days (GDD): a measure of heat accumulation used to estimate plant development rates. GDD are calculated as the difference between current temperatures and a minimum base threshold temperature (where growth rate=0). Plant growth rates can be measured through the accumulation of GDD, with different species requiring different numbers of accumulated GDD to reach maturity.

highland mixed farming systems: farming systems in cool highland areas (above 1,600 meters), dominated by temperate cereals and livestock, located in eastern and southern Africa. Livelihoods are based on broadbeans, goats, lentils, peas, potatoes, rape, teff, wheat barley, poultry, sheep, and off-farm activities.

highland perennial farming systems: farming systems in moist highland areas (above 1,400 meters) of eastern Africa, with relatively good market access and with a dominant perennial crop, either food or commercial. Livelihoods are based on diverse activities, including bananas, beans, cassava, coffee, enset (or false banana, *Enset ventricosum*, in Ethiopia), maize, sweet potatoes, tea, livestock (including dairy), and off-farm activities.

humid: an area where the length of growing period (LGP) is greater than 270 days per year.

humid lowland tree crop farming systems: farming systems located in western and central Africa that appear in humid lowland areas where commercial tree crops have replaced forest and provide more than one-quarter of household cash income. Livelihoods are based on coffee, cocoa, oil palm, and rubber, as well as cassava, maize, yams, and off-farm activities.

insurance crops: crops that increase food security because they can be left in the ground until needed. Roots and tubers, including cassava, fall into this category.

intensity ratio of investment: public R&D investment measured as a share of agricultural output.

irrigated farming systems: large-scale contiguous irrigation schemes, with almost no rain-fed agriculture. Located mostly in areas with low rainfall. Livelihoods are largely based on irrigated commercial crops, notably rice, cotton, and vegetables, as well as cattle and small ruminants.

land cover: the physical material at the surface of the earth, such as crops, pasture, trees, bare rock, water, and urban areas.

leaching: occurs when water percolating through the soil moves soluble nutrients below the crop root zones. Over time leaching can reduce the availability of nutrients to crops. Old, highly weathered soils in areas of moderate to high precipitation are typically nutrient depleted and acidic as a result of nutrient leaching.

length of growing period (LGP): generally calculated as the period (in days) during a year when precipitation exceeds half the potential evapotranspiration, while also taking into account soil moisture holding capacity. It is used to determine the number of days per year that are suitable for crop growth in a given location.

livestock system: a farming system where more than 90 percent of dry matter fed to animals comes from rangelands, pastures, annual forages, and purchased feed and less than 10 percent of the total value of production comes from nonlivestock farming activities.

low nutrient reserves: soils with less than 10 percent reserves of weatherable minerals that naturally supply phosphorus, potassium, calcium, magnesium and micronutrients.

major climate divisions: major latitudinal thermal or temperature shifts in climate zones.

maize mixed farming systems: farming systems located in subhumid and humid areas of eastern, middle, and southern Africa, dominated by maize with legumes. Livelihoods are based mainly on maize, tobacco, cotton, legumes, cassava, cattle, goats, poultry, and off-farm activities.

marketshed: geographical area and associated population that has real or potential trade relationships with a market center. Each market shed is associated with the closest corresponding market in terms of the least-cost travel time to that market.

MarkSim: a statistical weather generator that produces weather records (rainfall, maximum and minimum air temperature, and solar radiation) on a daily basis. It is able to simulate the variation in rainfall observed in both tropical and temperate regions.

mixed crop-livestock farming systems: a farming system in which more than 10 percent of the dry matter fed to animals comes from crop by-products (for example, stubble) or more than 10 percent of the total value of production comes from nonlivestock farming activities. Livestock convert organic material not fit for human consumption into high-value food products (meat, milk) and nonfood products (traction, manure, leather, bone).

net primary production (NPP): the amount of biomass produced by a plant or ecosystem, excluding the energy it uses for the process of respiration. This typically corresponds to the rate of photosynthesis, minus respiration by the photosynthesizers.

New Partnership for Africa's Development (NEPAD): a vision and a policy framework of the African Union for pan-African socioeconomic development in the 21st century.

North Africa dryland mixed farming systems: farming systems in dry semi-arid areas with rainfall of 150–300 mm, based on rainfed barley and wheat grown in a rotation with one- or two-year fallows and a strong small ruminant component. Livelihoods also include off-farm activities.

North Africa highland mixed farming systems: farming systems dominated by rainfed cereal and legume cropping with tree crops, fruits, and olives on terraces, together with vines and/or raising livestock (mostly sheep) on communally managed lands and characterized by moderately high population densities. Livelihoods also include off-farm activities.

North Africa rainfed mixed farming systems: farming systems in subhumid areas characterized by tree crops (olive and fruit), melons, grapes, irrigated vegetables, and flowers as well as rainfed wheat, barley, chickpea, lentil, and fodder crops. Livelihoods are supplemented by dry-season grazing of sheep migrating from the steppe areas and off-farm activities.

P fixation: occurs when phosphorus (P) becomes insoluble and therefore is not available to plants. Extremely calcareous soils, which contain high levels of calcium carbonate, and soils that are rich in iron and aluminum oxides fix phosphorus and can lead to nutrient deficiencies in a crop.

pastoral farming systems: farming systems with low population density in arid areas of western, eastern, and southern Africa, dominated by livestock. Livelihoods are based on camels, cattle, goats, sheep, some cereal crops, and off-farm activities.

perennial mixed farming systems: commercially oriented farming systems predominantly found in South Africa and comprising deciduous fruits and vineyards in the Western Cape and eucalyptus, pines, and wattle as well as sugarcane in the southeastern region (KwaZulu-Natal, Mpumalanga and Eastern Cape Provinces) interspersed with cereals, oilseeds, and pulses. Livelihoods include off-farm activities.

permanent crops: crops—such as cocoa, coffee, and rubber—that are sown or planted once and then occupy the land for several years and do not need to be replanted after each annual harvest. This category includes flowering shrubs, fruit trees, nut trees, and vines, but excludes trees grown for wood or timber.

permanent meadows and pastures: land used five years or more to grow herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

poor drainage: soils characterized by the inability to properly drain.

portshed: an area associated with the closest corresponding port in terms of the least-cost travel time to that port.

potential evapotranspiration (PET): the energy available in the system to remove water through the processes of evaporation and transpiration. It is generally associated with a reference crop, namely short grass completely covering the ground, and assumes no limitation on water availability.

rain-use efficiency (RUE): the amount of biomass produced (kilograms of dry matter per hectare) per millimeter of rainfall calculated as the ratio of net primary production (NPP) over rainfall.

root and tuber crop farming systems: farming systems located in lowland areas of western and middle Africa where systems are dominated by roots and tubers without a major tree crop. Livelihoods are based mainly on cassava, legumes, yams, and off-farm activities.

seasonality: the way in which climate (such as rainfall or temperature) varies regularly through the year in a particular place.

semiarid: an area where the length of growing period (LGP) is 70–180 days per year.

Spatial Production Allocation Model (SPAM): a model that produces estimates of crop distribution and can be used to generate maps showing area harvested per cell by crop and production system (technology). The model draws on many datasets, including land cover imagery, crop suitability maps, irrigation maps, subnational crop statistics, FAO country totals of crop production and area, and data on production systems in each country.

stem rust: a fungal disease that affects wheat.

stunting: low height for age in children (under age five). Stunting reflects a sustained past episode or episodes of chronic undernutrition.

subhumid: an area where the length of growing period (LGP) is 180–270 days per year.

subtropics: areas where mean monthly temperature adjusted to sea-level is less than 18° C for one or more months in a year.

transpiration: the evaporation of water from the leaves and stems of plants.

tropics: areas where the monthly temperature adjusted to sea-level is greater than 18° C for all months.

trypanosomosis: a parasitic disease transmitted by the tsetse fly. The African animal form of the disease reduces the productivity of livestock, especially cattle, when it sickens or kills them.

Ug99: the collective name for new strains of stem rust pathogen, first discovered in Uganda in 1998. Most of the world's wheat varieties offer little resistance to Ug99 (see stem rust).

undernutrition: a measure of food energy deprivation. Undernutrition results when prolonged food energy intake is below standard nutritional requirements and/or low levels of absorption of food consumed.

underweight: low weight for age in children (under age five). Underweight reflects a current condition resulting from inadequate food intake, past episodes of undernutrition, and/or poor health conditions.

virtual water: the water needed to produce a product. If a country exports such a product, it exports water in virtual form.

virtual water content: the volume of water used by a crop per unit of crop harvest.

volcanic: amorphous soils characterized by large reserves of weatherable minerals (which are unstable in humid climates) and soil organic matter making them highly fertile. Volcanic soils also have a high phosphorus fixation capacity which can slightly limit their fertility.

wasting: low weight for height in children under age five. Wasting generally reflects an acute weight loss associated with a recent period of hunger or disease.

ATLAS
OF AFRICAN AGRICULTURE RESEARCH & DEVELOPMENT

The work of agricultural researchers and development workers in Africa has the potential to significantly improve the lives of the poor. But that potential can only be realized with easy access to high-quality data and information. *The Atlas of African Agriculture Research & Development* highlights the ubiquitous role of smallholder agriculture in Africa; the many factors shaping the location, nature, and performance of agricultural enterprises; and the strong interdependencies among farming, natural-resource stocks and flows, and the well-being of the poor.

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