BOOSTING INVESTMENT IN AGRICULTURE RESEARCH IN AFRICA

BUILDING A CASE FOR INCREASED INVESTMENT IN AGRICULTURAL RESEARCH IN AFRICA

REPORT COMMISSIONED BY AU-SAFGRAD[1]

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About ASTI

Since 2001, the International Food Policy Research Institute's (IFPRI's) Agricultural Science and Technology Indicators (ASTI) program has provided trusted open-source data on agricultural research systems in low- and middle-income countries. ASTI collects, compiles, and disseminates information on financial, human, and institutional resources at both country and regional levels across government, higher education, nonprofit, and (where possible) private for-profit agricultural research agencies. Indicators derived from such information allow the performance, inputs, and outcomes of agricultural innovation systems to be measured, monitored, and benchmarked. As such, ASTI fulfills a unique role in promoting an understanding of the status and direction of national agricultural research systems in developing countries. Its data constitute a powerful resource for national and regional research managers, policymakers, donor organizations, and other stakeholders. Over the years, ASTI has become widely recognized as the authoritative source for information on the structure, financing, and capacity of agricultural R&D in low- and middle-income countries.

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Related ASTI Outputs

- **ASTI's country briefs** provide visual, highly accessible presentations of recent institutional, financial, and human resource trends in national agricultural research. They also feature a more in-depth analyses of the key challenges that individual agricultural research systems currently face, along with policy options to address these challenges.
- **ASTI's interactive country pages** allow users to access detailed data on investment and human resource trends in agricultural research, and to download country-level publications and other information.
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- **ASTI's data download tool** allows users to explore in-depth datasets, to filter the data by country and indicator, and to view the data graphically.
- **ASTI's agency directory** allows users to search and filter agencies by a number of criteria, including by country, and to locate agencies on a map.

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List of Acronyms

AgGDP	agricultural gross domestic product
AIS	agricultural innovation system
APPSA	Agricultural Productivity Program for Southern Africa
ASTI	Agricultural Science and Technology Indicators
AU	African Union
AUC	African Union Commission
BAU	business as usual
BR	Biennial Review
CAADP	Comprehensive Africa Agriculture Development Program
CNRA	National Center for Agricultural Research (Côte d'Ivoire)
EAAPP	East Africa Agricultural Productivity Program
FARA	Forum for Agricultural Research in Africa
FDI	foreign direct investment
FIRCA	Inter-Professional Fund for Agricultural Research and Extension
FTE(s)	full-time equivalent [agricultural researcher(s)]
GDP	gross domestic product
IFPRI	International Food Policy Research Institute
NARI(s)	national agricultural research institute(s)
NARS(s)	national agricultural research system(s)
NEPAD	New Partnership for Africa's Development
PHR	poverty headcount ratio
PoU	prevalence of undernourishment
PPP(s)	purchasing power parity [index]
R&D	research and experimental development
S3A	Science Agenda for Agriculture in Africa
SAGFRAD	Semi-Arid Food Grain Research and Development
SRO(s)	subregional organization(s)
SSA	Africa south of the Sahara
STISA-2024	Science, Technology and Innovation Strategy for Africa 2024
TFP	total factor productivity
WAAPP	West Africa Agricultural Productivity Program

Executive Summary

Agricultural research and development (R&D) investment is positively associated with high returns, but these returns take time—often decades—to develop. Consequently, the inherent lag from the inception of research to the adoption of new technologies calls for sustained and stable R&D funding. In 2016, Africa invested just 0.39 percent of its agricultural GDP (AgGDP) in agricultural R&D, down from 0.54 percent in 2000. Even though in absolute terms total R&D investment has increased since the turn of the millennium—after a period of stagnation—most of the funds have been directed toward research staff expansion, salary increases, and rehabilitation of derelict research infrastructure and equipment, rather than actual research programs. In fact, in a large number of African countries, the national government funds the salaries of researchers and support staff, but little else, leaving nonsalary-related expenses highly dependent on donors and other funding sources.

Although African leaders recognize that agriculture is a critical engine for economic development, job creation, and poverty reduction, countries are still underinvesting considerably in agricultural research. Continued underinvestment will constrain long-term agricultural productivity growth and the capacity of countries to develop value chains, achieve self-sufficiency in a broader range of commodities, reduce poverty, and ensure food security. To address agricultural production challenges more effectively, governments need to substantially raise their agricultural research investment levels in the coming years, while donor funding needs to be better aligned with national and regional priorities. The private sector is still a relatively untapped source of funding for agricultural R&D. To provide much-needed higher and sustainable levels of funding into the future, innovative mechanisms need to be explored that tap into private funds for research on a broad range of commodities.

Funding for agricultural research not only needs to increase, but also be targeted more directly to priority areas. Given the relatively long lag between investing in research and reaping its benefits, the decisions countries make about the allocation of their agricultural research resources today will have profound implications on agricultural productivity for decades. The forward-looking projections presented in this report can support countries in assessing the risks and potentials of different research investment scenarios, and in establishing long-term research priorities and investment allocations that align with national and regional development and innovation plans.

This report presents evidence that economies of scale and scope are critical drivers behind the performance of agricultural R&D systems, emphasizing the critical importance of R&D collaboration and coordination among countries. Small countries generally record much lower returns to agricultural R&D compared to their larger counterparts, and their R&D efforts have been less effective in reducing poverty and malnutrition, two of CAADP's main goals. Further integration of agricultural R&D at the (sub-)regional level is therefore essential, as it allows scarce R&D resources to be used more efficiently. It also allows countries with limited domestic research capacity to benefit from gains achieved in countries with more developed R&D systems. Continued support to regional bodies, networks, and mechanisms will further aid in defining, implementing, and funding a research agenda focused on issues of regional interest. Better coordination and a clear articulation of mandates and responsibilities among national, (sub-)regional, and global R&D players are key in ensuring that scarce R&D resources are optimized, research duplication minimized, and synergies and complementarities enhanced.

1. Introduction and Policy Context

Agriculture is the single most important economic activity in Africa by far. The sector provides employment to roughly two-thirds of the continent's labor force and it contributes between 30 to 60 percent of African countries' gross domestic product (GDP), on average (FAO 2021, World Bank 2021). The vast majority of African farmers are smallholders. Productivity of these smallholder farms, however, is low compared to other developing regions, and this has perpetuated rural poverty throughout the continent. Rapid population growth, deteriorating soils, climate change, volatile food prices, and the recent COVID-19 pandemic are all adding further pressure on agricultural production and food security across Africa.

Within the next 15 years, an additional 400 million people will enter the African labor force (ILO 2021) and the continent's agri-food sector will need to absorb the bulk of these new entrants. African leaders recognize that agriculture is a critical engine for economic development, job creation, and poverty reduction. In 2003, the African Union Commission (AUC) launched the Comprehensive Africa Agriculture Development Program (CAADP) that laid out a vision towards 6 percent annual growth of the agricultural sector and an allocation of at least 10 percent of public expenditures to agriculture. Through its Pillar IV, CAADP emphasized the essential role of agricultural research and development (R&D), technology dissemination, and adoption. In 2014, the African Union (AU) member states reconfirmed their CAADP commitments by adopting the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods. This Declaration provides direction to transform the agricultural sector within the broader CAADP framework and is an important vehicle to achieve the objectives of the First Ten Year Implementation Plan of Africa's Agenda 2063, which is an essential policy initiative that helps AU member states achieve agriculture-led growth, halving hunger and ending poverty by 2025, boosting intra-African trade in agricultural goods and services, enhancing resilience to climate variability, and increasing public and private investment in agriculture.

Across Africa, agricultural growth will be highly dependent on technological advancement to enable yield increases, more efficient use of scarce resources, and a reduction in crop losses. Investments in agricultural R&D are critical in this regard. Well-financed agricultural research and innovation systems enhance agricultural productivity and support sustainable agricultural growth and transformation in Africa, which in turn have an important impact on employment, stability, and peace. Extensive evidence indicates that agricultural R&D has had a tremendous impact on agricultural productivity around the world (World Bank 2007; IAASTD 2008). Despite this well-documented evidence, many African countries continue to underinvest in agricultural R&D. Given the substantial time lag between investing in research and reaping its rewards—which is typically decades, not just years—agricultural research requires a long-term commitment of sufficient levels of sustained funding. Recognizing this, the AU Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024) and the Science Agenda for Agriculture in Africa (S3A)—both of which are very closely aligned with CAADP and the Agenda 2063—have put agricultural science, technology, and innovation at the forefront of Africa's socio-economic development and growth.

Tracking, monitoring, and reporting on advancements towards achieving the CAADP and Malabo goals and targets are key to measuring progress over time and to holding countries accountable for delivering on their agricultural growth and transformation commitments. A Biennial Review (BR) process of the AUC evaluates country performance against 24 performance categories and 47 indicators. One of these indicators is *"total agricultural research spending as a share of AgGDP"*. The AU's New Partnership for

Africa's Development (NEPAD), for instance, has set a target for government spending on *agricultural* R&D of at least 1 percent of *agricultural* GDP (AgGDP), in line with the 2007 AU Assembly commitment to allocate at least 1 percent of *overall* GDP to R&D (African Union 2007). Over the past two decades, the International Food Policy Research Institute's (IFPRI's) Agricultural Science and Technology Indicators (ASTI) program has collected detailed data on African agricultural R&D expenditure and funding levels at regular intervals, thereby providing an important input into the AUC's BR process.

This report assesses trends in agricultural R&D investment, funding, and human capacity in Africa over time, based on ASTI data. It analyzes the continent's and individual countries' agricultural R&D intensity ratios and proposes an alternative multi-factored indicator that takes a broader set of variables into account to better assess a country's capacity to invest in agricultural R&D. The report also provides various forward-looking investment scenarios that are based on different investment growth targets and it assesses the long-term impacts on agricultural productivity growth for each of these scenarios.

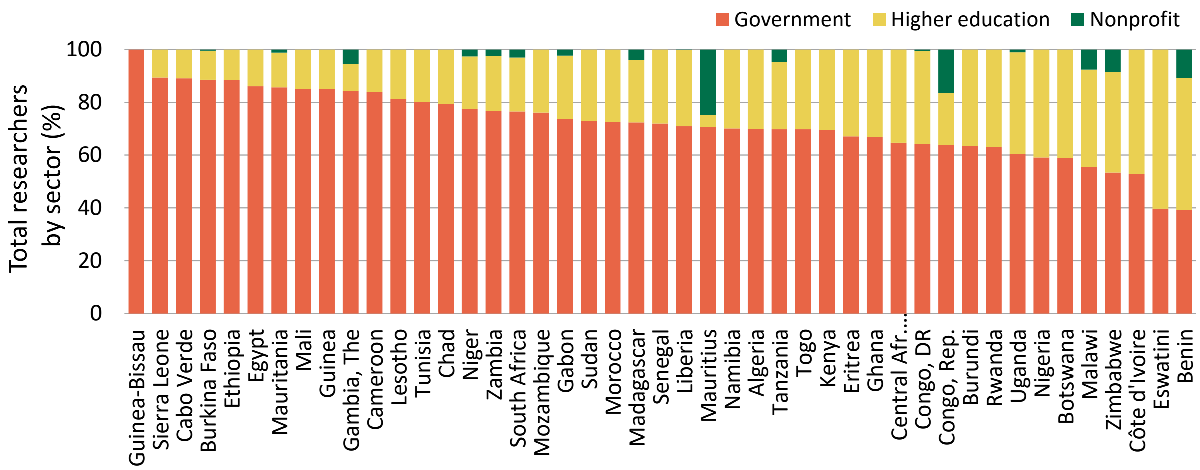
2. Institutional Context of African Agricultural R&D

With the exception of a handful of large countries like Egypt, Nigeria, and South Africa, and a number of mid-sized countries, most national agricultural research systems (NARSs) in Africa are quite small, but they tend to focus their research on the same range of issues as their larger neighbors, thereby often exceeding the limits of their capacity. As a result, these smaller systems mostly conduct research focused on adapting technologies developed elsewhere to meet their local needs. Spillovers of relevant technologies from larger neighboring countries tend to be limited because many of the small countries are clustered together.[2] Most African NARSs are also heavily fragmented in terms of the number of individual agencies (often without well-defined research mandates) conducting R&D, and this has hindered the effective use of the available resources. More cost-effective structures that minimize duplication and promote synergy and complementarity (both within and across countries) are needed to enhance the efficiency and effectiveness of many African NARSs. Given the important extent of cross-country diversity, it is difficult to generalize about the composition of NARSs, but most systems typically comprise a national agricultural research institute (NARI); a number of smaller government agencies; a series of higher education agencies; and in some cases, one or more nonprofit research entities (such as nongovernmental or producer organizations) (Figure 1). The role of the private (for-profit) sector in agricultural research remains limited in most countries.

NARIs across Africa are set up in several ways: i) as a research department within a ministry of agriculture or equivalent; ii) as a semiautonomous government institute with the flexibility to determine key internal policies; iii) as multiple agencies (within one or more agricultural-related ministries) focusing on specific agricultural subsectors, such as agriculture, livestock, and forestry; and iv) as numerous institutes organized under a council of agricultural research. Although the NARIs' share in national agricultural R&D capacity has declined over time, they still anchor most NARSs in Africa.

[22] In West Africa, CORAF/WECARD has tried to address this by establishing National Centers of Specialization and Regional Centers of Excellence, with varying degrees of success and major challenges in realization.

Figure 1—Institutional composition of agricultural research, 2016



Source: Calculated by authors based on ASTI data (various years).

Notes: Totals exclude the private for-profit sector. Values for Guinea-Bissau, Eritrea, Liberia, and Sudan are based on 2011 data; values for Algeria, Egypt, Morocco, and Tunisia on 2012 data; values for Burkina Faso and Malawi on 214 data; and values for South Africa on 2015 data. The values for Nigeria, Sierra Leone, and South Africa include estimates for the higher education sector.

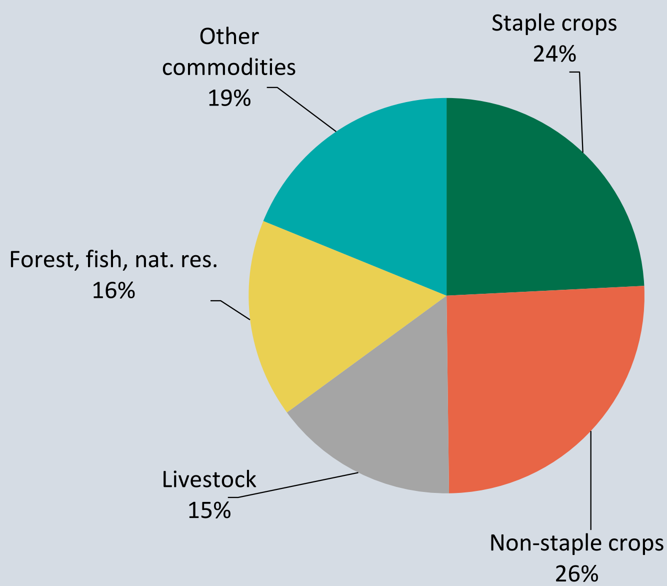
Overall, the number of higher education agencies in many countries has grown over the time through the creation of new universities or new departments and faculties within existing universities. This development has provided many benefits, key among them an increase in the number of PhD-qualified agricultural researchers and increased training opportunities. The downside of the increase, however, is an accelerated fragmentation of NARSs. Nonetheless, research performed by the government and higher education sectors tends to be somewhat complementary, with universities focusing on more basic types of research, and government research agencies mostly concentrating on applied research and the development of new technologies and processes. Many agencies in both the government and higher education sectors continue to face numerous challenges in terms of the scope and quality of their infrastructure, including poor (or lacking) laboratory space and equipment, farm equipment, vehicles, and funds for on-field research trials.

In general, the involvement of both for-profit and nonprofit private agencies in agricultural R&D remains limited in most countries. Nonprofit research institutions are often funded through levies on production or exports. Although the sector only accounted for a very small portion of the continent’s public agricultural research in 2016, it fulfills an important role in a few countries, and offers a potential area for growth in many others. Private for-profit agricultural research is extremely limited in Africa, with the exception of South Africa. Private companies mostly outsource their R&D to the public sector rather than perform research themselves, but this too is a potential growth area through which NARIs can generate revenue.

Box 1. The Allocation of Research Resources across Commodities

Governments and agricultural research agencies across Africa—especially in the many small countries—are limited in the choice of options they have to allocate scarce research resources. It is important, however, that they allocate sufficient resources to the types of research and commodities that are highly relevant to their country's agricultural sector. In most African countries, crop research dominates agricultural R&D. In 2016, half of all agricultural researchers in 44 African countries focused on crops; almost equally split between staple and non-staple crops (Figure B.1). Livestock research represented 15 percent of African agricultural research. The remaining researchers concentrated their attention on fisheries, forestry, natural resources, socioeconomics, or other areas. The research agendas of Benin, Burundi, Malawi, and Togo are very crop-centric, with crop researchers accounting for 70 percent or more of total agricultural research staff. Livestock research plays a relatively important role in the Central African Republic and Sudan, while fisheries research represents more than 30 percent of total agricultural research conducted in Mauritania, Morocco, and Namibia.

Figure—Focus of agricultural research by major commodity group, 2016



Source: Calculated by authors based on ASTI data (various years).
Notes: Based on total number researchers (in full-time equivalents). Staple crops include cereals, pulses, roots and tubers; non-staple crops include all other crops such as oil-bearing and horticultural crops.

Linkages between research agencies are often suboptimal due to the aforementioned fragmentation and a lack of coordination mechanisms. Linkages are also inadequate between agricultural research and extension providers caused by severe underinvestment in both sectors as well as frequent changes in extension modalities. Finally, agricultural research agencies are often poorly connected to other principal actors in the countries' agricultural innovation systems (AIS), including policymakers, farmers, traders, and processors. Strengthening such linkages will not only require advancement of innovative capacities and skill sets at the research agencies, but also the establishment of different institutional modalities such as innovation platforms and brokers (Roseboom and Flaherty 2016). This will ultimately lead to an increased effectiveness in the use of technologies and knowledge generated by the research agencies and a wider dependency on the innovative capacity in the broader agricultural sector, acknowledging that agricultural research is only one of the actors in AIS (Lynam et al. 2016).

African agricultural research remains for the most part structured around geographic boundaries. However, given that many African countries share agro-ecological conditions, structuring agricultural research at the pan-African level around agro-ecosystems would make a lot of sense. This would reduce duplication of research effort and enhance the overall effectiveness and impact of agricultural R&D. Cross-country collaboration across NARSs and their integration into broader AIS is facilitated through four subregional organizations (SROs), the Forum for Agricultural Research in Africa (FARA), CGIAR centers, and various other organizations and initiatives. The SROs and FARA—all of which are highly dependent on unstable donor funding—do not conduct research themselves, but instead promote the conduct of regionally beneficial agricultural research and innovation by their members. They also attempt to strengthen coordination and collaboration among NARIs.

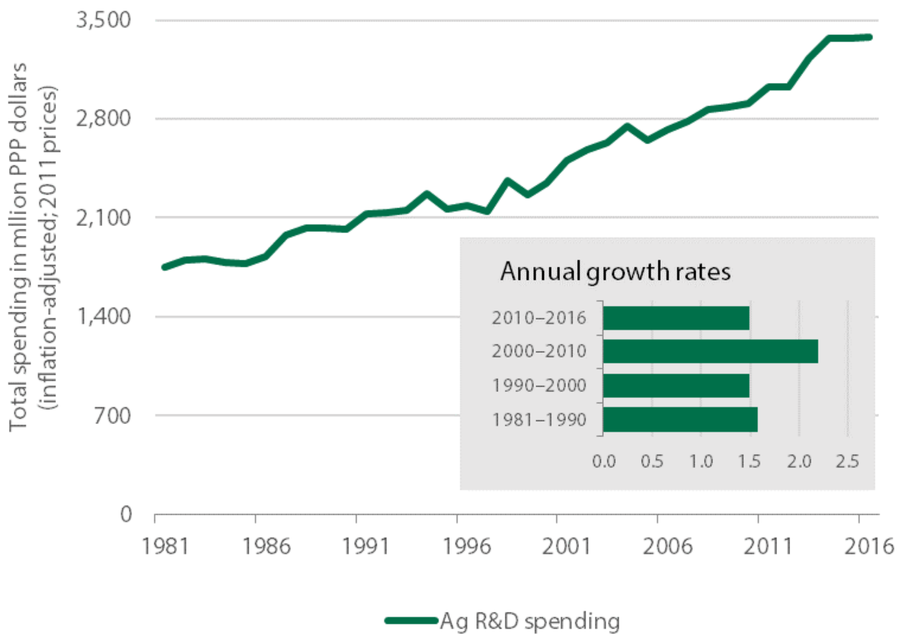
3. Trends in Long-Term Agricultural R&D Spending

Following a period of slow growth in the 1980s and 1990s, Africa's agricultural research spending—excluding the private for-profit sector—has increased since the turn of the millennium (Figure 2).[3] This growth in investment, however, stemmed primarily from salary increases for research staff, rehabilitation of derelict research infrastructure and equipment (not in the least as part of large World Bank-funded initiatives), and stronger involvement in agricultural research activities by the higher education sector due to the sector's capacity expansion. Although these are important investments, they have not been complemented with additional allocations to basic and adaptive research programs. In many African countries, funding for actual R&D activities is extremely low and dangerously dependent on often volatile, external funding sources.

Recent ASTI data also demonstrates that the period of sustained growth in R&D spending (that is salary, operating, and capital costs) since the turn of the millennium has ended, at least for the time being. Between 2014 and 2016 (the most recent year for which ASTI data were available for Africa), continentwide agricultural research stagnated. It is too premature to tell if this was an anomaly or an early sign of a longer-term trend. What is certain, however, is that spending declines were broad-based: Seventeen of the 35 countries in Africa south of the Sahara (SSA) for which long-term ASTI time series data were available reported cuts in their agricultural R&D expenditures over the 2014–2016 period. This raises important concerns, given the multitude of challenges the African agricultural sector is facing.

[3] PPPs measure the relative purchasing power of currencies across countries by eliminating national differences in pricing levels for a wide range of goods and services. See ASTI's methodology for more information: https://www.asti.cgiar.org/methodology.

Figure 2—Long-term agricultural research investment trends in Africa, 2000–2016

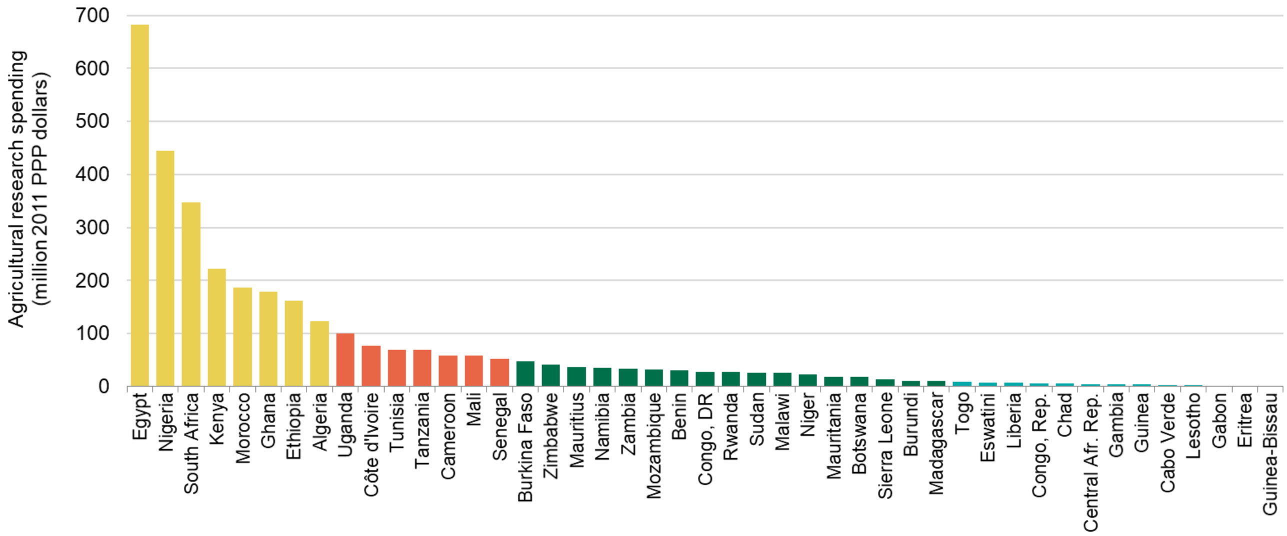


Source: Calculated by authors based on ASTI data (various years).
Notes: Totals exclude the private for-profit sector. Data for Djibouti, Libya, Somalia, and South Sudan were unavailable and have been excluded from this regional total. Data include estimates for Angola, Comoros, Equatorial Guinea, São Tomé and Príncipe, and Seychelles.

In 2016, the continent as a whole spent $3.4 billion on agricultural research, in 2011 PPP prices. [4] Spending is heavily concentrated in some the larger countries (Figure 3). Egypt ($682 million), Nigeria ($445 million), and South Africa ($346 million) combined accounted for 44 percent of continentwide agricultural research spending. Kenya is the fourth largest country in terms of agricultural research expenditures ($222 million in 2016), followed by Morocco ($187 million), Ghana ($179 million), Ethiopia ($162 million), and Algeria ($124 million).[5] Spending levels of the remaining countries were considerably lower. Seven countries (Uganda, Côte d'Ivoire, Tunisia, Tanzania, Cameroon, Mali, and Senegal) spent between $50 and $100 million on agricultural research; 18 countries between $10 and $50 million; and 17 countries between $0.2 and $10 million.[6]

[4] Agricultural research investment data in this report include government, higher education, and nonprofit agencies that conduct agricultural research. The private for-profit sector is excluded because data for the majority of private firms are not accessible.
[5] 2016 data for Algeria, Egypt, Morocco, and Tunisia was estimated based on these countries' expenditure data for 2012, and assuming that spending growth followed growth in these countries' AgGDP during 2012–2016.
[6] Data for Djibouti, Libya, Somalia, and South Sudan were unavailable.

Figure 3—Agricultural research spending by country, 2016



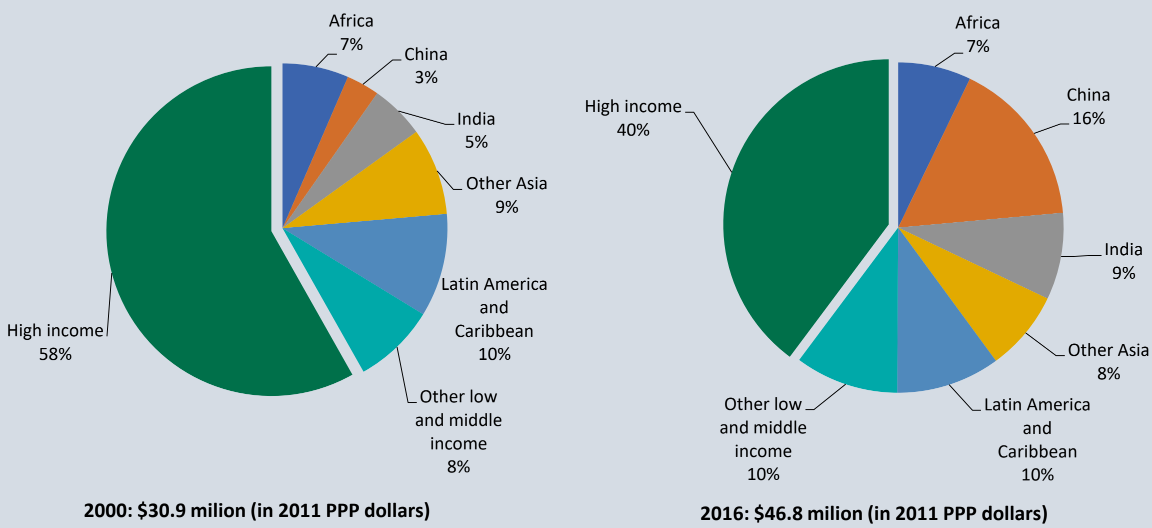
Source: Calculated by authors based on ASTI data (various years).
Notes: Totals exclude the private for-profit sector. Data for Angola, Comoros, Djibouti, Equatorial Guinea, Libya, São Tomé and Príncipe, Seychelles, Somalia, and South Sudan were unavailable and have been excluded. Values for Guinea-Bissau, Eritrea, Liberia, and Sudan are based on 2011 data; values for Algeria, Egypt, Morocco, and Tunisia on 2012 data; values for Burkina Faso and Malawi on 214 data; and values for South Africa on 2015 data. The values for Nigeria, Sierra Leone, and South Africa include estimates for the higher education sector.

The allocation of research budgets across salaries, operating costs, and capital investments has an important impact on the effectiveness and efficiency of agricultural research (see Section 9). No formula can determine the optimal allocation, however. It depends on numerous factors, including country size, agroecological diversity, the research mandate, and the composition of staffing. A breakdown of spending during 2009–2016 by cost category reveals important differences across countries. Based on a sample encompassing the principal government agencies of 35 SSA countries for which detailed cost category data were available, about half of the available finances was spent on staff salaries, close to 40 percent on operating and program costs, and the remaining 11 percent was invested in capital improvements (Figure 4). These regional averages mask a significant degree of cross-country variation. The NARIs in Mauritius, Ghana, Lesotho, and Cabo Verde spent more than 70 percent of their total budgets on salary-related expenses, leaving relatively few resources for the day-to-day running of research programs or the rehabilitation of infrastructure and equipment. In contrast, a large number of francophone countries fall at the other end of the spectrum, allocating two-thirds of agricultural research expenditures to operating and program costs and capital investments. Although there are important exceptions, these cross-country differences in the allocation of NARI expenditures by cost category can to a certain extent explained by an institute's dependency on donor funding, which is typically allocated to rehabilitation of research infrastructure or the cost of research programs. Countries where agricultural R&D is highly donor-dependent (especially in francophone West Africa) therefore tend to spend a larger portion of their R&D costs on nonsalary-related cost compared to countries that receive very little donor funding. The NARI in the Central African Republic stands out in that a considerable portion of its research costs consists of capital expenditures, notably for the rehabilitation of research centers and equipment damaged during the period of violence in the country.

Box 2. African Agricultural Research Spending in a Global Context

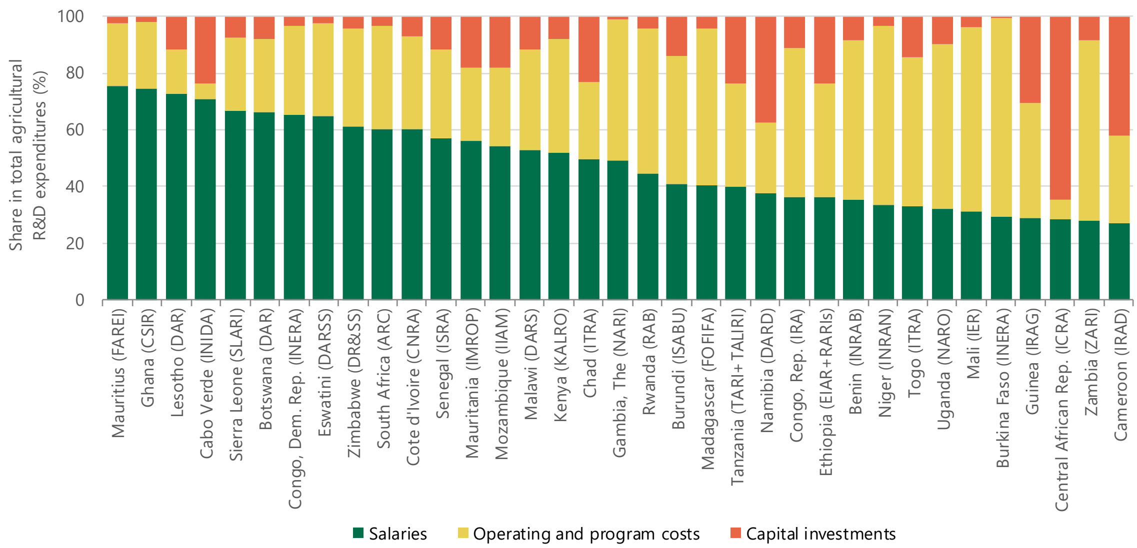
Following a decade of slow growth in the 1990s, global agricultural research spending (which includes salary, operating, and capital costs) increased by roughly half from $31 billion in 2000 to $47 billion in 2016 (excluding the private for-profit sector). China was a major driver of this global growth. In 2000, the country represented just 3 percent of global agricultural R&D spending. By 2016, this share had increased to 16 percent. Other low- and middle-income countries have also considerably increased their investment. As a group, low- and middle-income countries now invest more in agricultural R&D than high-income countries. Africa's relative position on the global stage has not shifted much over time. The continent continues to account for about 7 percent of global investment in agricultural R&D (Figure B.2).

Figure—Africa's share in global spending on agricultural research, 2016



Source: Calculated by authors based on ASTI data (various years) and various secondary sources.
Notes: See Beintema et al. (2020) for details on data sources and calculation methods.

Figure 4—NARI expenditures broken down by cost category, selected SSA countries, 2009–2016 averages



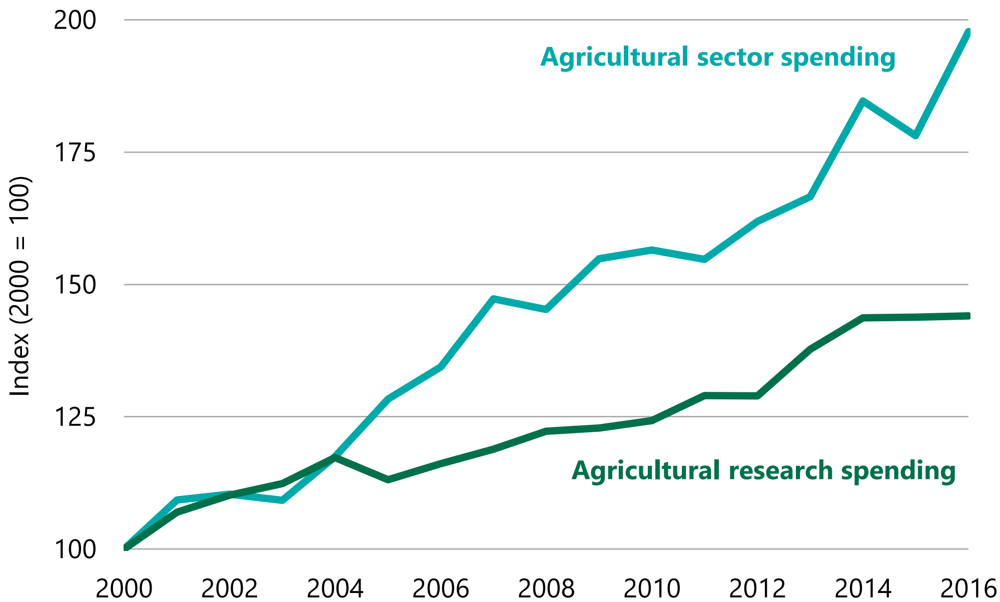
Source: Calculated by authors based on ASTI data (various years).
Note: North African countries have been excluded due to a lack of recent data.

4. Research Spending Falling Behind Agricultural Spending and Production Growth

The 2003 launch of CAADP elevated agriculture within Africa's political agenda. Although a large number of African countries have yet to attain CAADP's ambitious targets (i.e., spending at least 10 percent of their national budgets on agriculture in order to ensure 6 percent sectoral growth per year), substantial progress has been made over time. Investments in agriculture accelerated quickly after 2003, following a long period of neglect in prior decades (Figure 5). During 2000–2016, Africa doubled its agricultural sector spending (in inflation-adjusted terms). Agricultural research spending also grew during this timeframe, albeit at a considerably slower rate (44 percent during 2000–2016), but as previously indicated, most of this growth stemmed from salary increases of research staff and the rehabilitation of R&D infrastructure, rather than increased funding to actual R&D programs. The data thus indicate that, although many African countries have increased their investments in areas such as farm support and subsidies, training, and irrigation, levels of investment in agricultural research have seriously trailed.

Relative underinvestment in agricultural research is striking, given the well-documented evidence of the high returns to such investments in Africa, especially compared with investments in other agricultural inputs, such as fertilizer, machinery, labor, and land quality (Dias Avila and Evenson 2010; Fuglie et al. 2012; Alston et al. 2009). One of the major contributors to underinvestment in agricultural research in Africa (as elsewhere) is the length of time required for agricultural investments to manifest results and, hence, for decision-makers to reap the political benefit of prioritizing such investments (Mogues 2015).

Figure 5—Spending on agriculture and on agricultural research in Africa, 2000–2016



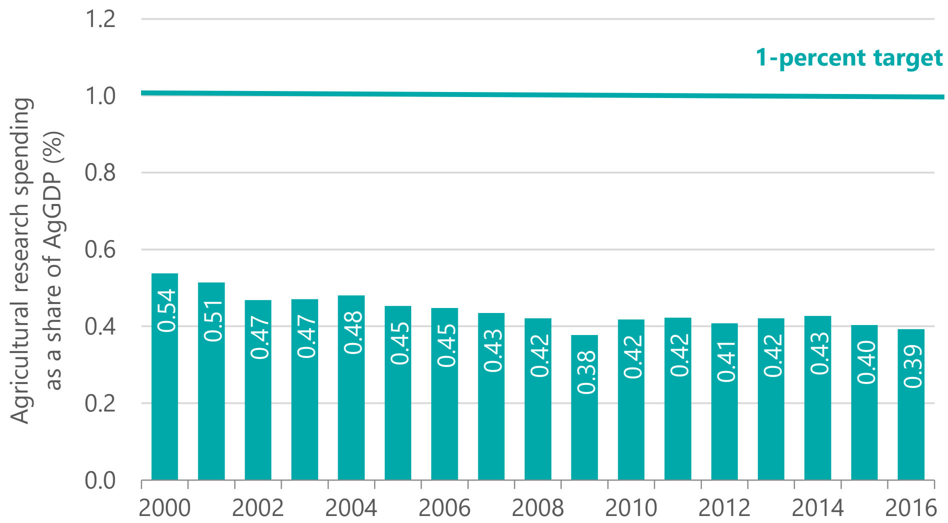
Sources: Data on agricultural spending are from ReSAKSS (2021); data on agricultural research spending are from ASTI (various years).

Note: Agricultural spending only includes funds derived from national governments; agricultural research spending includes funds derived from governments, donors, development banks, producer organizations, and revenues generated internally by research agencies.

Growth in spending on agricultural research has also been slower than growth in agricultural output over time. As a result, Africa's agricultural research intensity ratio—that is, its agricultural research spending as a percentage of AgGDP—dropped markedly, from 0.54 percent in 2000 to just 0.39 percent in 2016 (Figure 6). In 2016, 37 of the 44 African countries for which data were available invested less than 1 percent of their AgGDP in agricultural research, thereby falling short of the minimum investment target set by NEPAD. In fact, 24 of these 44 countries spent less than 0.5 percent of their AgGDP (Figure 7). Mauritius, South Africa, Namibia, Botswana, Zambia, and Zimbabwe all reached the 1-percent target in 2016. Cabo Verde was the only country outside the Southern African subregion to spend more than 1 percent of its AgGDP on agricultural R&D.[7]

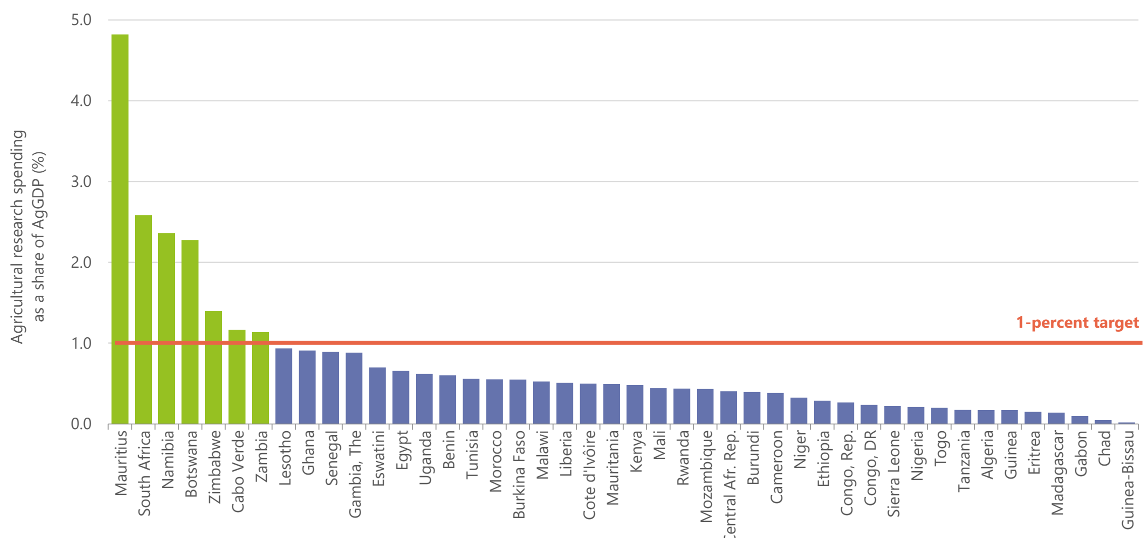
[7] It is important to note that the 2016 intensity ratios based on ASTI data can differ substantially from those tracked by the countries themselves as part of the BR process. Some of the countries that are reported to have met the 1-percent agricultural R&D investment target don't meet the target according to ASTI data, and vice versa.[7] ASTI does not have access to the underlying datasets on which the intensity ratios in the AU 2019 BR report are based (African Union 2019), but expects that some of the data differences can be explained by differences in the reporting year. Other differences are presumably due to variations in definitions, methodology, and agency coverage. The methodology behind ASTI expenditure datasets and intensity ratios is described in Annex A.

Figure 6—African agricultural research spending as a share of agricultural GDP, 2000–2016



Sources: Calculated by authors based on ASTI data (various years); data on AgGDP are from World Bank (2021).
Notes: Data for Djibouti, Libya, Somalia, and South Sudan were unavailable and have been excluded from this regional total. Data include estimates for Angola, Comoros, Equatorial Guinea, São Tomé and Príncipe, and Seychelles.

Figure 7—Country-level agricultural research spending as a share of agricultural GDP, 2016



Sources: Calculated by authors based on ASTI data (various years); data on AgGDP are from World Bank (2021).
Notes: Data for Angola, Comoros, Djibouti, Equatorial Guinea, Libya, São Tomé and Príncipe, Seychelles, Somalia, and South Sudan were unavailable and have been excluded. Values for Guinea-Bissau, Eritrea, and Liberia are based on 2011 data; values for Algeria, Egypt, Morocco, and Tunisia on 2012 data; values for Burkina Faso and Malawi on 214 data; and values for South Africa on 2015 data. The values for Nigeria, Sierra Leone, and South Africa include estimates for the higher education sector.

Although intensity ratios provide useful insights into relative investment levels across countries and over time, they fail to take into account the policy and institutional environment within which agricultural research occurs, the broader size and structure of a country's agricultural sector and economy, or qualitative differences in research performance across countries. For these reasons they need to be interpreted carefully, within the context of national circumstances. A one-size-fits-all investment target for the region as a whole is not desirable given that structural economic differences call for different investment strategies. For example, small countries often have higher intensity ratios based on an inability to take advantage of economies of scale. To be effective, national research systems in small countries need to establish minimum-level capacities across relevant disciplines and major commodities, regardless of the size of the agricultural sector they serve. Establishing this critical mass generally means spending more on agricultural research relative to larger countries to achieve the same results. Similarly, countries with arid climates typically have smaller agricultural sectors compared with their tropical neighbors. The smaller the country's AgGDP, the higher its agricultural R&D intensity ratio. Relatedly, an increase of a country's agricultural research intensity ratio over time can actually reflect reduced agricultural output rather than higher investment. Finally, a case can be made that AgGDP levels only partially indicate the importance of agriculture to a national economy. For example, more advanced economies invest significantly in research on agrochemicals and food processing, but these fields are not classified as "agriculture" under official definitions and hence are not reflected in these countries' intensity ratios.

For alle these reasons, ASTI does not recommend the use of arbitrary investment targets, such as the 1 percent target, to assess the performance of a country's agricultural R&D system. Countries like China and India, for example, have very well-managed and well-funded R&D systems producing world-class research. Yet, they only invest 0.5 and 0.3 percent of their AgGDP in agricultural research, respectively. It would be unfeasible for them to investment as much as 1 percent. Similarly, many African countries are in no position to invest 1 percent. A one-size-fits-all intensity target of 1 percent for all African countries is therefore undesirable, given the widely diverging structural characteristics of each country's economy and agricultural sector. An alternative indicator that takes a much more balanced and holistic look at a country's R&D investment and capacity is proposed in Section 8. Nevertheless, regardless of the indicator used to assess agricultural R&D investment, Africa needs to substantially raise its level of agricultural R&D investment to address its agricultural production challenges more effectively. The next section of this report shows the impact on agricultural productivity of increased R&D investment.

5. Future Investment Scenarios

Analyzing the past performance of agricultural research systems, as in previous sections of this report, is useful for identifying systems' strengths and weaknesses and detecting areas needing improvement. Conversely, strict reliance on historical data will not prepare an agricultural research system for its future challenges and opportunities. In the next 20 to 30 years, African economies will continue to grow, incomes will increase, and consumption patterns will change, as will the demand for agricultural products, imports, and exports. In this context, forward-looking scenario models are useful for assessing the risks and potentials of different portfolios of research investment.

As discussed in Section 4 of this report, investments in agriculture accelerated quickly after 2003, following a long period of neglect in prior decades. During 2000–2016, Africa doubled its agricultural sector spending while agricultural research spending also grew during that period but at a considerably slower rate (2.4 percent per year, mostly as a result of increased spending in salary costs and rehabilitation of infrastructure). What are the prospects for future agricultural growth in Africa if this trend of relatively slow growth in R&D investment is continued? Would historical growth in R&D investment and capital accumulation (mechanization, irrigation) be sufficient to achieve the Malabo commitment of sustaining growth in agricultural GDP at an annual rate of at least 6 percent?

To answer these questions and to assess the impact on agricultural productivity of countries increasing R&D investment, ASTI ran medium- to long-term projections. The analysis included four different scenarios of projected R&D investment and production inputs (capital, land, and labor):

(i) **Historical R&D–Historical input scenario.** Under this scenario, during 2017–2050, R&D investment and agricultural production inputs continue their historical trajectory of 2000–2016, i.e. growing at average annual rates of 2.4 and 2.2 percent, respectively.

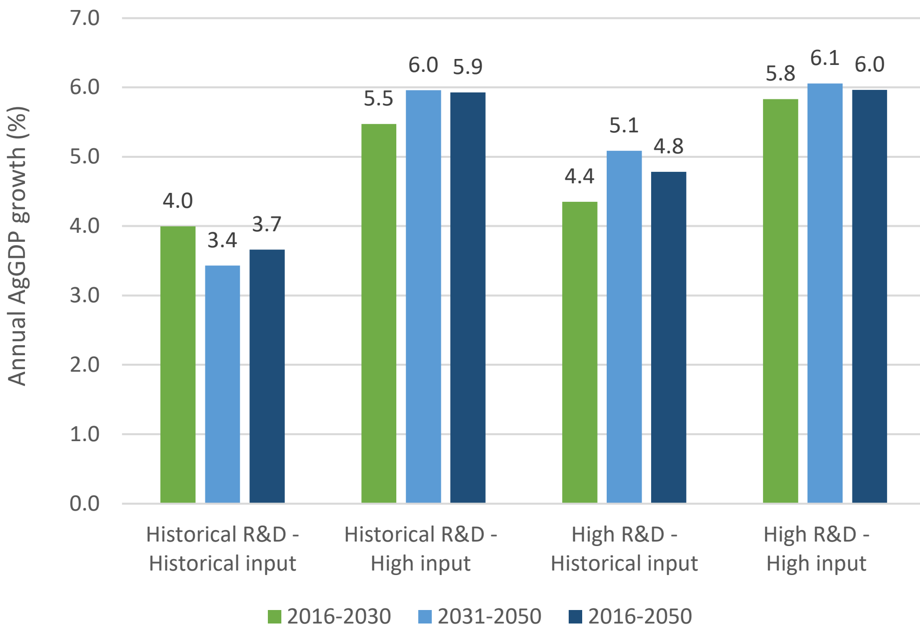
(ii) **High R&D–High input scenario**. Under this scenario, investments in agricultural R&D and physical capital triple during 2017–2050 relative to 2000–2016 levels. This translates to an annual growth rate of R&D investment of 7.2 percent and to an overall growth rate of agricultural production inputs of 3.4 percent per year (note that accelerated growth is only assumed for agricultural capital investment; land and labor inputs are assumed to continue growing at historical rates).

(iii) **High R&D–Historical input scenario** combines R&D growth rate of (ii) with input growth rate of (i).

(iv) **Historical R&D–High input scenario** combines R&D growth rate of (i) with input growth rate of (ii).

The high growth rates of R&D investment and input in these scenarios were selected to give a sense of the magnitude of the investment effort needed to achieve the 6 percent annual agricultural GDP growth that African Heads of State committed themselves to under the Malabo Declaration. Figure 8 shows projected GDP growth rates for different periods that result from growth in agricultural inputs and in TFP growth generated by accelerated R&D investment.

Figure 8—Regional agricultural GDP growth projections to 2050 under four investment scenarios



Source: Calculated by authors based on USDA-ERS (2019) and ASTI (various years).
Notes: Under the Historical R&D scenario, R&D investment increases at a yearly rate of 2.4 percent during 2016–2050; the growth rate in the High R&D growth scenario is 7.2 percent (three times the historical rate). The growth rates of input in the Historical input scenario is 2.2 percent and in the High input scenario is 3.6 percent which results from tripling the growth rate of capital while the historical growth rate of land and labor is used in all scenarios.

The projections in Figure 8 clearly demonstrate that historical growth rates of agricultural R&D and physical capital would not allow the region to achieve its ambitious goal of 6 percent annual agricultural sector growth by 2030. Under this scenario, average agricultural GDP growth would reach 4.0 percent per year during 2017–2030, falling to 3.4 percent per year after 2030.

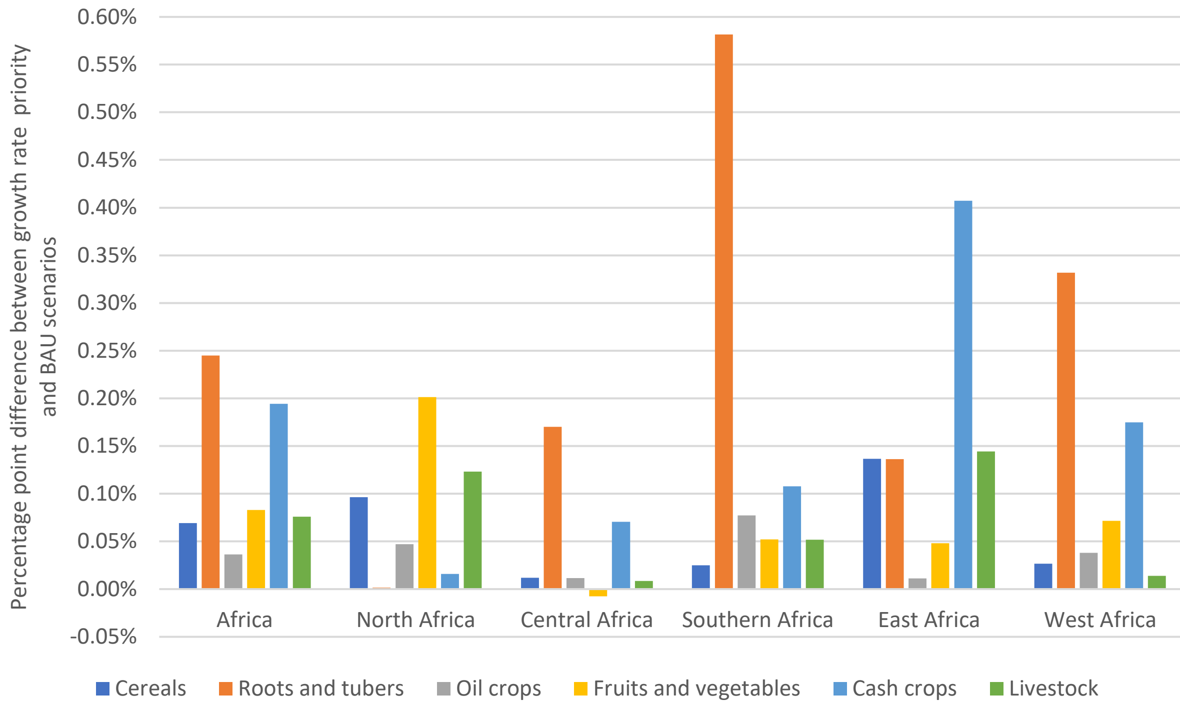
Tripling R&D investment would have a considerable impact on future growth of Africa's agricultural sector. Under the *High R&D–Historical input* scenario, AgGDP growth will reach about 5.0 percent per year after 2030, considerably higher than if Africa's historical investment trajectory was continued into the future. Please note that annual AgGDP growth is lower in the years leading up to 2030 than during years after 2030 because of the lagged effects of research. The *High R&D–Historical input* scenario demonstrates, however, that tripling R&D investment is still not enough to reach the ambitious CAADP growth targets. The only two possible pathways to reach 6 percent annual growth in agricultural GDP by 2030 are the *High R&D–High input* and the *Historical R&D–High input* scenarios. Unlike R&D investment, which is characterized by a long lead time between the moment of investment and the moment of tangible outputs, investments in agricultural inputs (land, labor, capital) have a more direct impact on agricultural production.

The implications of these results are that to achieve 6 percent growth in GDP by 2030, African countries will need to increase investment (mechanization, irrigation, animal stock) and spending in areas with potential to boost productivity (for example, extension and financial services) to maximize benefits of available technologies. At the same time, and given the lagged effects of research, there is the need to boost investment in R&D to sustain GDP growth above 5 percent after 2030 and the productivity of growing capital in agriculture. Increasing R&D investment at the levels projected in the High R&D scenarios is probably not feasible at present in the region, but increasing the efficiency of research systems through improved allocation of resources within and between countries should increase the efficiency and impact of R&D investment. The overall growth rate of agricultural R&D investment is not the only thing that matters. With a relatively small amount of resources stretched along dozens of different commodities and scientific specialties, it is also very important to draw attention to the returns of R&D on specific commodities and how different research priorities affect future productivity.

We ran long-term projections to determine the impact of different R&D investment priorities on agricultural TFP. The six scenarios gave investment priority to (1) cereals, (2) roots and tubers, (3) oil crops, (4) fruits and vegetables, (5) cash crops (including coffee, cocoa, tea, cotton, sugarcane, rubber, tobacco, and spices) , and (6) livestock. Under all six scenarios, R&D investment increased at an average yearly rate of 4.8 percent (i.e. twice the *Business-as-usual* rate described above) during 2016–2050 for the target commodity group, and by 2.4 percent per year (i.e. the *Business-as-usual* rate) for all other commodities. TFP growth was calculated for the agricultural sector and period as a whole to determine how the different scenarios affected sector-wide growth in Africa as a whole and in each of the subregions.

Projections indicate that increasing R&D investment in roots and tubers and in cash crops yields the highest TFP growth for the continent as a whole (Figure 9). Southern, West, and Central Africa are the regions to gain the most from higher R&D investment in roots and tubers, while prioritizing investment in cash crops will benefit East and West Africa more than other subregions. In the case of North Africa, the greatest impact on TFP growth results from prioritizing investment in fruits and vegetables, livestock, and cereals. In SSA, increasing investment in cereals and livestock would impact future productivity in East Africa the most.

Figure 9—Projected relative growth in agricultural productivity under six agricultural research investment prioritization scenarios, 2016–2050



Sources: Calculated by authors based on ASTI (various years), FAO (2021), and USDA-ERS (2019).
Notes: The six scenarios, respectively, prioritize investment in (1) cereals, (2) roots and tubers, (3) oil crops, (4) fruits and vegetables, (5) cash crops, and (6) livestock. In all these scenarios, investment in target commodities increases at a yearly rate of 4.8 percent, whereas investment in all other commodities increases at a yearly rate of 2.4 percent. BAU stands for business-as-usual.

The differences in projected long-term TFP growth rates between the six investment scenarios are considerable (Table 1). Take for example TFP growth under BAU in Southern Africa, which is projected to average around 0.7 percent per year over the 2016–2050 period. This corresponds to 27 percent overall growth for the entire period. If priority is given to R&D investment in roots and tubers, however, average projected agricultural TFP growth for this period would increase to 1.29 per year, which is nearly twice as fast as under the BAU scenario.

Table 1–Projected average annual growth of agriculture under different R&D investment scenarios, 2016-2050.

	BAU	Cereals	Roots and tubers	Fruits and vegetables	Cash crops	Livestock	Oil crops
Africa	1.30%	1.37%	1.54%	1.38%	1.49%	1.37%	1.33%
North Africa	0.85%	0.94%	0.85%	1.05%	0.86%	0.97%	0.89%
Central Africa	0.73%	0.75%	0.91%	0.73%	0.81%	0.74%	0.75%
Southern Africa	0.71%	0.74%	1.29%	0.76%	0.82%	0.76%	0.79%
East Africa	1.73%	1.87%	1.87%	1.78%	2.14%	1.88%	1.75%
West Africa	1.67%	1.70%	2.00%	1.74%	1.85%	1.69%	1.71%

Sources: Calculated by authors based on ASTI (various years), FAO (2021), and USDA-ERS (2019).

Notes: The six scenarios, respectively, prioritize investment in (1) cereals, (2) roots and tubers, (3) oil crops, (4) fruits and vegetables, (5) cash crops, and (6) livestock. In all these scenarios, investment in target commodities increases at a yearly rate of 4.8 percent, whereas investment in all other commodities increases at a yearly rate of 2.4 percent.

Box 3. Understanding Total Factor Productivity in the context of long-term growth of the agricultural sector

Increasing the efficiency of agricultural production—that is, getting more output from the same amount of resources—is critical for improving food security. Total Factor Productivity (TFP) is an indicator of how efficiently agricultural land, labor, capital, and other inputs (seed, fertilizer, and so on) are used to produce a country's agricultural outputs (crops, livestock, and so on). TFP is calculated as the ratio of total agricultural outputs to total production inputs, so when more output is produced from a constant amount of resources, TFP increases. R&D activities producing new crop varieties, technologies, and innovations are a crucial driving factor of TFP, but technological spillovers from abroad, higher numbers of skilled workers, investments that favor the development of input and output markets (such as in roads and communications), and government policies and institutions that promote market development and competition are major drivers as well.

It is critical that agricultural TFP growth is sustained into the future because it will positively affect farm incomes and reduce rural poverty. Future growth of agricultural output and productivity will be highly dependent on technical change. Sustained high levels of agricultural R&D investment will play a critical role in driving future innovation. R&D investment decisions that countries make today will have serious repercussions for agricultural productivity growth in the decades to come. It is therefore crucial that countries identify untapped potential in economically important crop and livestock areas.

6. Analysis of R&D Funding Sources

A complete analysis of yearly agricultural research investment levels across countries also requires an examination of how agricultural research is funded (Figure 10). In some countries, the national government funds the bulk of agricultural research activities undertaken by NARIs, whereas other countries are extremely dependent on outside funding from donors and development banks. In certain countries, research agencies generate substantial amounts of funding internally by selling goods (such as seed and vaccinations) and services (such as laboratory tests and technical assistance), while in other countries, the proceeds of such sales are channeled back to the national treasury, discouraging agencies from pursuing this revenue stream. Several countries, including Côte d'Ivoire, Kenya, and Tanzania, have established funding systems that mobilize private-sector resources, either via a tax levy or through subscription dues.

Government funding can reach an agricultural R&D agency through a variety of channels. In some countries, staff salaries are directly disbursed by the Ministry of Finance, while operating and capital costs are disbursed by the Ministry of Agriculture or equivalent. Many countries in the region have a Ministry of Science and Technology that allocates research funding through one or more science funds, either competitively or through direct budget allocations.

Agricultural research in SSA is far more dependent on donor and development bank funding compared with other developing regions around the world, including North Africa (Stads 2015; Stads 2016; Stads et al. 2016; Stads et al. 2020). Overall, during 2009–2016, 57 percent of the funding to the NARIs in SSA (excluding Nigeria, South Africa, and a number of the smaller countries) was provided by national governments, and funding from donors and development banks constituted 28 percent. Dependency on donor funding is particularly high among francophone West African countries. In a large number of countries, the national government funds the salaries of researchers and support staff, but little else, leaving nonsalary-related expenses highly dependent on donors and other funding sources (Figure 11). Although many governments are committed to funding agricultural research in principle, the amounts disbursed are routinely lower than—and in some cases only a fraction of—budgeted allocations. It goes without saying that these funding discrepancies have severe repercussions on the day-to-day operations of agricultural research agencies and their planned activities.

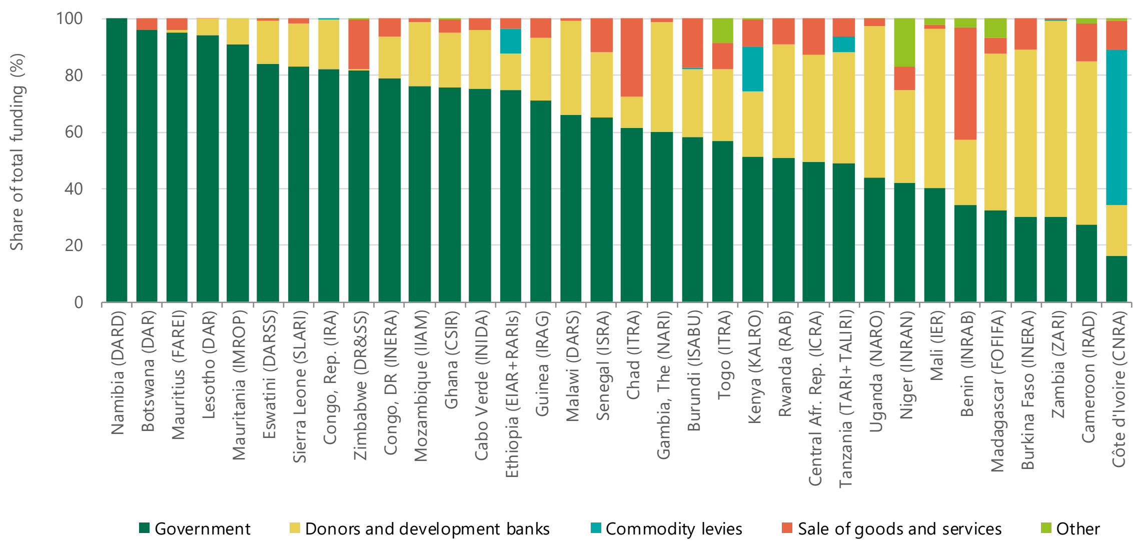
The World Bank has been a major contributor to the institutional development of agricultural research in SSA in the form of country-level projects financed through loans and supplemented by grants. Projects have variously focused purely on agricultural research (the more common approach in the 1980s and 1990s) or on agriculture more generally, while including an agricultural research component (the more common approach in the 2000s). Some projects aimed to reshape the entire NARS, whereas others focused on specific crops, agencies, or general research management and coordination. As of the mid-2000s, the World Bank shifted from a country-level to a regional approach to financing agricultural research in SSA through the model of regional productivity programs,[8] which have injected considerable funding into African NARS. Aside from the World Bank, a large number of other bilateral and multilateral

[8] The East Africa Agricultural Productivity Program (EAAPP), West Africa Agricultural Productivity Program (WAAPP), and Agricultural Productivity Program for Southern Africa (APPSA) focused on enhancing regional cooperation in the generation and dissemination of agricultural technologies, and establishing national centers of excellence to facilitate a more differentiated regional research agenda (Beintema and Stads 2017).

donors, development banks, and private foundations, including the African Development Bank and the International Fund for Agricultural Development fund agricultural research activities in SSA.

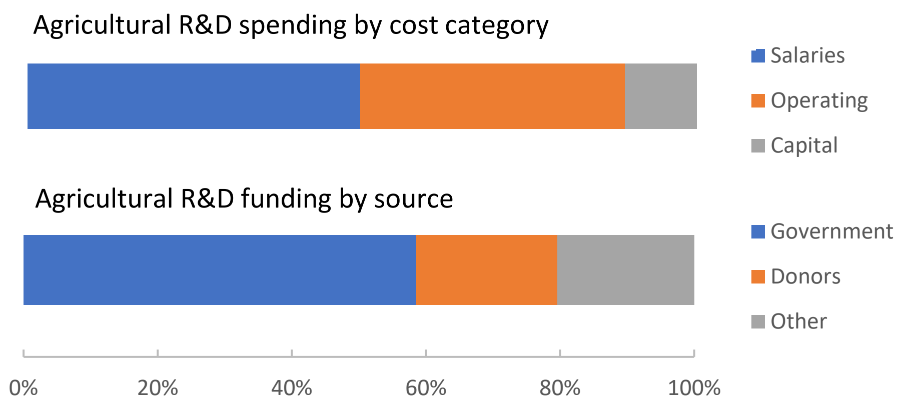
Unlike most African NARIs, which are funded mainly by national governments, donors or resources generated through the sale of goods and services, Côte d'Ivoire's National Center for Agricultural Research (CNRA) stands out in that it is predominantly funded by private producers through the Inter-Professional Fund for Agricultural Research and Extension (FIRCA). FIRCA allocates at least 75 percent of the subscription fees raised by producers in a given subsector to research serving that commodity. The remaining funds are allocated to a solidarity fund to serve sectors (mostly food crops) unable to raise sufficient funding through their own subscription fees. FIRCA is unique and exemplary in Africa in that it promotes demand-driven research.

Figure 10—Funding sources of principal agricultural research agencies in SSA, 2009–2016 averages



Source: Calculated by authors based on ASTI data (various years).
Notes: Data for Botswana, Malawi, Sierra Leone are for 2012–2014 only. Recent data for North Africa, Nigeria, South Africa, and a number of smaller countries were unavailable.

Figure 11—Breakdown of agricultural R&D spending and funding in SSA, 2009–2016 average

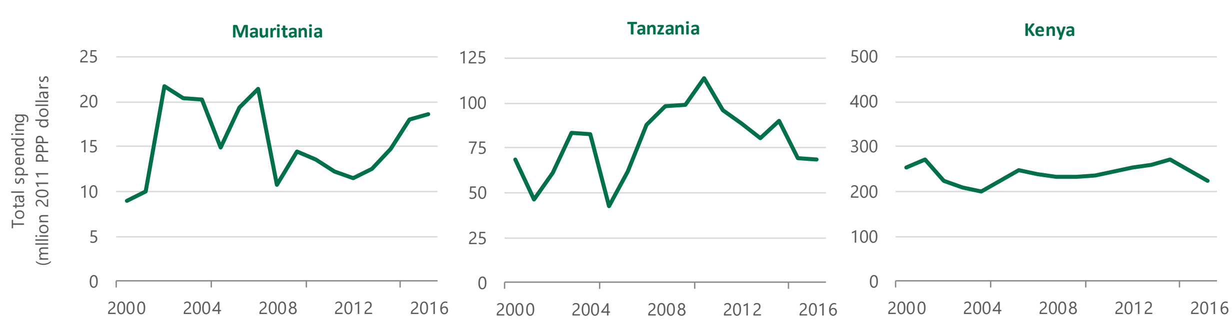


Source: Calculated by authors based on ASTI data (various years).
Note: The category *other* includes commodity levies, the sale of goods and services, and other funding sources.

Volatility of Agricultural Research Funding

Severe fluctuations in yearly agricultural research funding significantly complicate and compromise long-term budget, staffing, and planning decisions, all of which affect the continuity and outcomes of research. Large fluctuations in yearly investment levels thus hinder the advancement of technical change and the release of new varieties and technologies in the long run, in turn negatively affecting agricultural productivity growth and poverty reduction. Long-term spending data reveal that agricultural research funding in many SSA countries has been far from stable over time. For example, agricultural research spending in Mauritania and Tanzania has fluctuated considerably from one year to the next, while expenditure levels in Kenya have been more stable (Figure 12).

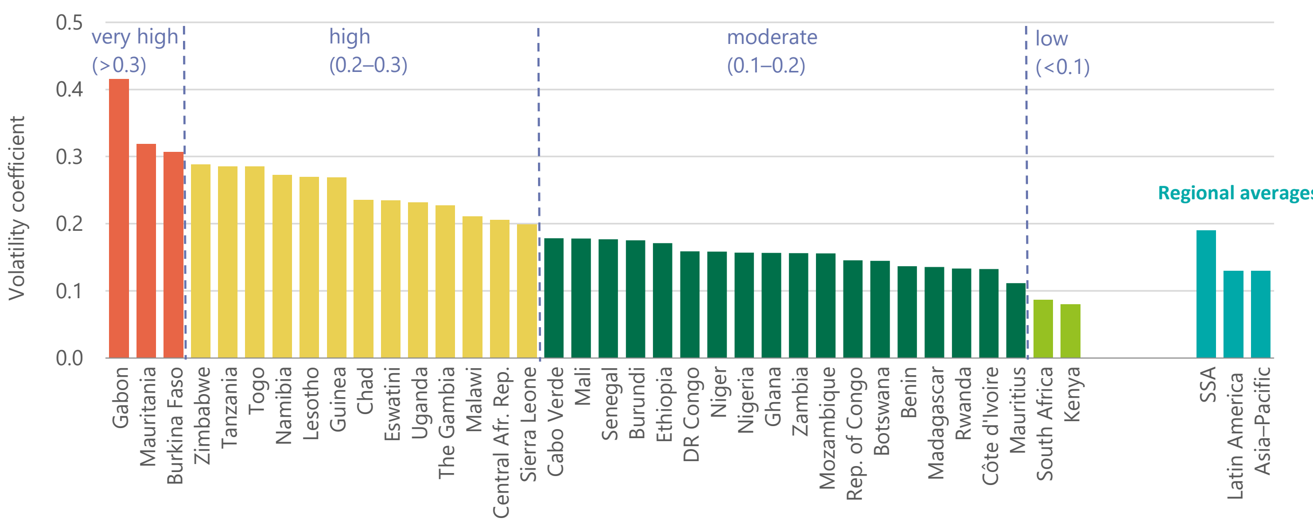
Figure 12—Long-term trends in agricultural research spending for selected countries, 2000–2016



Source: Calculated by authors based on ASTI data (various years).

ASTI developed a measure to quantify funding volatility across countries by applying the standard deviation formula to average yearly logarithmic growth of agricultural research spending over time (see Stads and Beintema 2015). The SSA countries with the highest fluctuation in yearly agricultural research spending during 2000–2016 (in descending order) were Gabon, Mauritania, Burkina Faso, Zimbabwe, Tanzania, and Togo (Figure 13). In contrast, agricultural research spending in countries like Kenya and South Africa was relatively stable during this timeframe. Of most concern, research spending for the region as a whole is significantly more volatile as in other developing regions of the world (Stads and Beintema 2015). Agricultural research agencies in SSA, particularly those in the region's low-income countries, are more dependent on funding from donors and development banks than their counterparts in other developing regions, and this type of funding has shown considerably greater volatility over the past decade compared with government funding. In a large number of SSA countries, donors fund the bulk of nonsalary-related expenditures—that is, program and operating costs and capital investment—(see Figure 11)—and there is extensive evidence of agencies reverting to financial crisis upon the completion of large donor-funded projects, forcing them to scale back their activities. Too much of the critical decision making about research priorities appears to be devolved to donors, with the result that the research agendas of many agricultural research agencies across SSA—particularly in smaller, low-income countries—can be skewed either toward short-term goals that are not necessarily aligned with national and (sub)regional priorities or to commodities of comparatively limited economic importance. A new framework is therefore needed whereby governments establish strategic priorities that donors contribute to. This is already taking place in countries like Nigeria and Tanzania through Project Coordination Units (PCUs) within the Ministry of Agriculture. However, more national governments need to be making critical investments in support of research implementation beyond paying staff salaries.

Figure 13—Volatility of agricultural research spending in SSA, 2000–2016



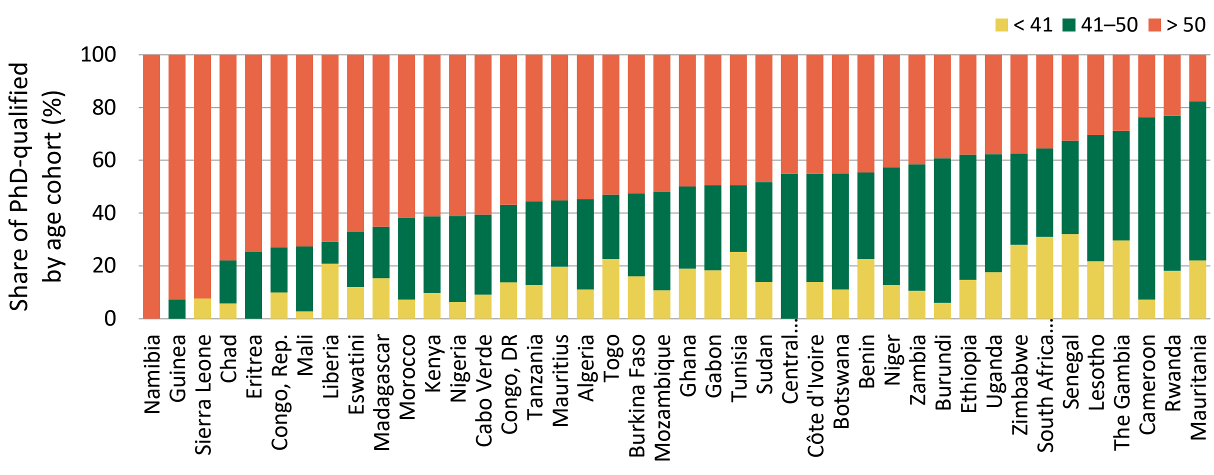
Source: Calculated by authors based on ASTI data (various years).
Note: Volatility in agricultural research spending is quantified by applying the standard deviation formula to average yearly logarithmic growth of agricultural research spending during 2000–2016 (see Stads and Beintema 2015).

7. Brief Overview of Human Capacity Constraints in Africa's Agricultural R&D

African countries have made considerable progress in building their agricultural research capacity since their independence. In the early 1960s, SSA employed about 2,000 agricultural researchers, measured in full-time equivalents (FTEs).[9] This number increased to about 9,000 FTEs in the mid-1990s to more than 16,000 FTEs in 2016. This increase in human capacity has been the main driver behind increased R&D investment in SSA since the turn of the millennium. With the inclusion of North Africa, total FTE agricultural researcher numbers are estimated to reach over 30,000, with Egypt alone accounting for roughly one-third of the continent's agricultural research capacity. Due in most part to substantial donor support for training and capacity strengthening, qualifications of agricultural researchers in SSA improved steadily in the decades leading to 2000. More recently, however, growth in the number of PhD-qualified agricultural researchers in SSA has slowed (Beintema and Stads 2017).

A minimum number of PhD-qualified scientists is generally considered fundamental to the conception, execution, and management of high-quality research; to effective communication with policymakers, donors, and other stakeholders, both locally and through regional and international forums; and for increasing an institute's chances of securing competitive funding. Furthermore, long-term recruitment bans—particularly in francophone Africa—have led to aging pools of senior researchers, many of whom are approaching or have reached the official retirement age. As of 2016, in 21 of the 42 countries for which detailed data were available, at least half of all researchers with PhD degrees were over the age of 50 (Figure 14), while in 8 of these countries, more than 70 percent of the PhD-qualified agricultural researchers were older than 50.

Figure 14—Share of PhD-qualified agricultural researchers by age cohort, 2016



Sources: Calculated by authors based on ASTI data (various years); data on AgGDP are from World Bank (2021).
Notes: Values for Eritrea, and Liberia are based on 2011 data; values for Algeria, Egypt, Morocco, and Tunisia on 2012 data; values for Burkina Faso and Malawi on 2014 data; and values for South Africa on 2015 data. The values for Nigeria, Sierra Leone, and South Africa exclude the higher education sector. Age data for Egypt were unavailable.

The situation is particularly severe in West Africa and a few other SSA countries. Several countries have increased the official retirement age of research staff, but without large-scale recruitment this will only

[9] FTEs take into account the proportion of time researchers spend on R&D activities and not time spend on non-research-related activities, such as teaching, extension, and administration.

provide a temporary solution. Recruitment efforts in more recent years have led to an influx of junior inexperienced staff in need of further training, mentoring, and supervision. Although the arrival of young blood is a positive development, many institutes continue to lack appropriately trained and experienced staff to fill roles left vacant by retiring (and departing) senior staff. At the same time, too few senior staff remain to train and mentor their newly appointed junior colleagues. This issue is even more severe at institutes with numerous disciplines and areas of research focus, or where highly specialized training and experience are needed.

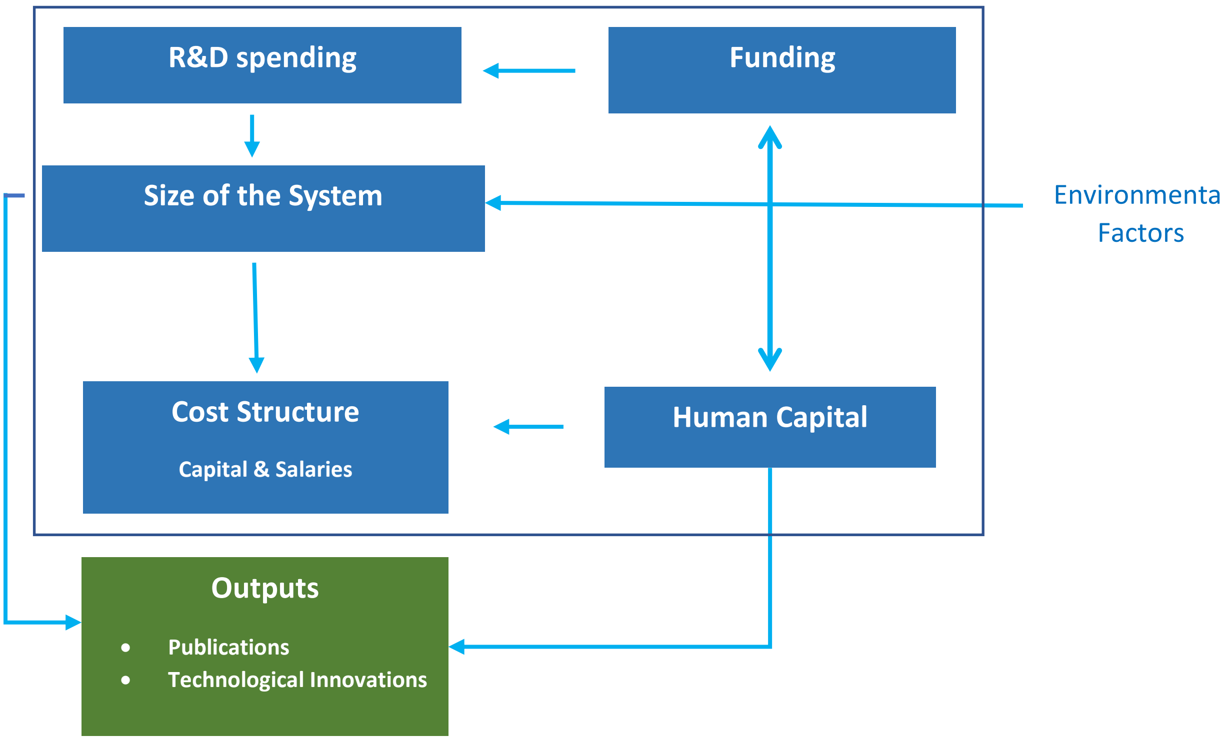
The retirement and departure of large numbers of senior, experienced researchers from agricultural research (and teaching) institutes will exacerbate knowledge gaps in the coming years, raising concerns about the quality of future research outputs. Countries need to develop systematic human resource strategies for agricultural R&D, incorporating existing and anticipated R&D skills gaps and training needs. But their options in addressing the challenges they face in maintaining and developing their human resource capacity are very limited. Financial constraints affect an institute's ability to offer competitive salaries and conditions; to provide training and career opportunities; and to create the necessary incentives to attract, retain, and motivate highly qualified staff over time.

The supply of (high-quality) postgraduates from African and other universities remains limited and underdeveloped. Although increased attention has been given to the expansion and diversification of PhD programs, the majority of agricultural students in Africa are enrolled in undergraduate degree programs and in-country PhD training opportunities are still limited. Besides, the quality of many PhD programs remains subpar. In Egypt, for example, the quality of PhD programs in agricultural sciences is very low compared with international standards. It is encouraging that the Egyptian government has recognized these deficiencies and that is has taken steps to lay the foundation for a new education system through legislative reform, institutional restructuring, and the establishment of independent quality-assurance mechanisms and monitoring systems (Stads et al. 2015). Universities in some of Africa's smaller countries only employ a handful of young professors in agricultural sciences, which further restricts the scope and quality of their higher agricultural education programs. For decades, government funding for education in Africa has prioritized primary and secondary education. Funding for tertiary education has not kept pace with the rapid growth in the number of higher education institutions nor with the strong increase in student enrollments. Government investments in higher education agencies—in particular in agricultural sciences—need to be increased considerably to match growth in undergraduate student enrollments and to scale up and improve postgraduate programs to ensure a greater responsiveness to the needs of a modern, market-oriented agricultural sector (Osiru et al. 2016, Beintema et al 2021).

8. Performance of African Agricultural R&D Systems

As discussed in Section 4, R&D investment intensity ratios have severe limitations and are not the most suitable indicator to compare agricultural research performance across countries. In this section, an alternative is presented that assesses the overall commitment and capacity to invest in agricultural R&D of various African countries. This alternative follows the conceptual framework of Guan and Chen (2012), where an innovation production activity is seen as the process of converting knowledge and ideas into benefit value (See Annex B). Figure 15 shows the main determinants that affect the performance of the R&D system. It also highlights the links of the research system with other components of the innovation system and the external environment given that a significant component of a system's overall performance is determined by structural socio-economic and/or exogenous variables.

Figure 15—Determinants of the performance of agricultural research system



Source: Elaborated by authors.

A short description of each of the elements in Figure 15 is provided below:

R&D spending: This element is a measure of the "research effort" by a country. For comparisons with other countries, investment is measured relative to other variables such as the conventional intensity ratio (see Section 4). Note that investment intensity (at least in the long run) depends on a government's budget constraints, support from donors, legislation facilitating research centers access of alternative sources of funding, and also the size of the economy and of the agricultural sector.

Size of the system: The size of the NARS is one of the most important factors determining its overall performance, affecting costs, productivity, and outputs. Constrained by structural factors, countries have limited options to define the size of their own R&D system.

Human capital: Researchers are at the core of the NARS. Their productivity (i.e. research output per researcher) and their qualifications are major drivers of overall performance of the system. The quality of the research personnel determines research productivity (ceteris paribus) and also affects the structure of the research system.

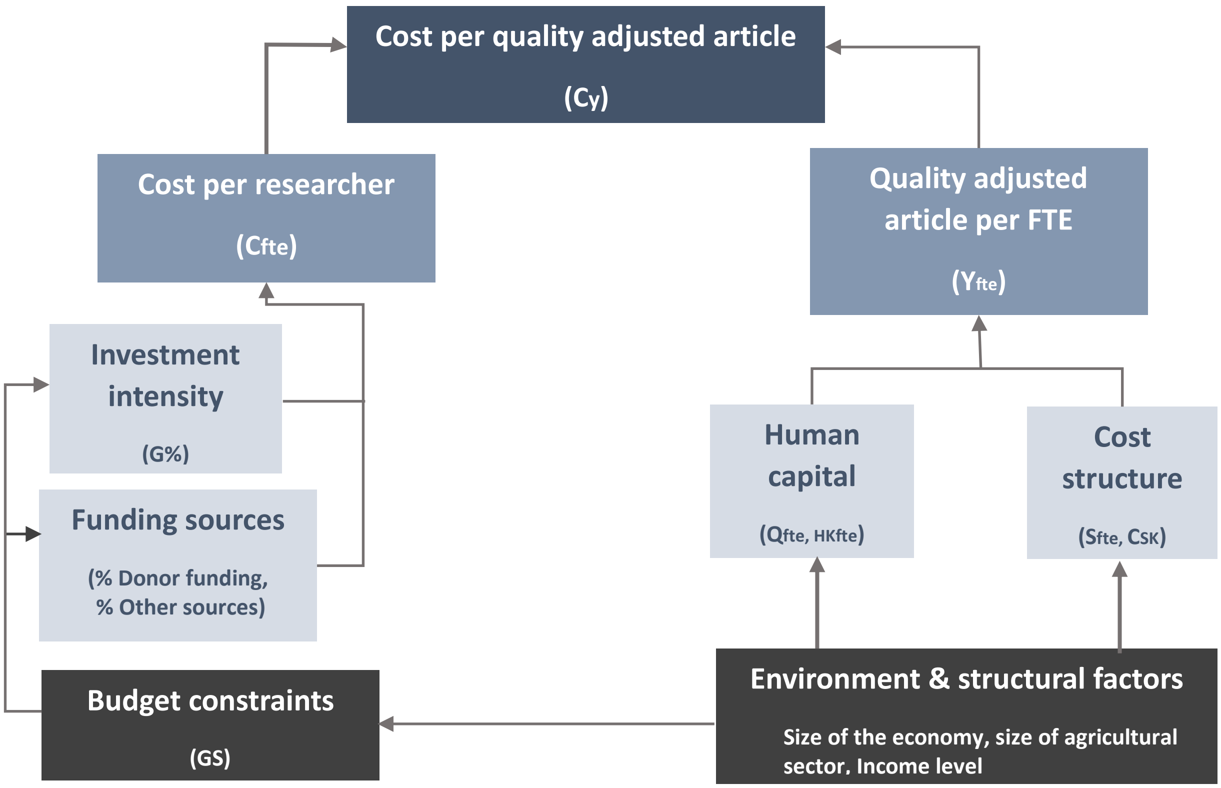
Cost structure: We consider three cost items: (i) salary costs; (ii) operating and program costs; and (iii) capital investments. Previous analyses have shown that relatively high capital costs are mostly associated with inefficient operations, indicating idle infrastructure and high fixed costs. Salaries are typically the main cost item in research operations (see Figure 4 in Section 3), and countries with a higher share of salary costs in total R&D costs are in most cases countries with higher human capital and research productivity. In general, we observe that salaries and operating costs are positively correlated, while they are both negatively correlated with capital costs.

Research outputs: They are the result of the process of creating new knowledge by the NARS and, as shown in Figure B1, they are of two types: scientific and technological innovations. Scientific innovations include the publication of articles in refereed journals, book chapters, and abstracts and articles in proceedings of technical meetings. Technological innovations include new technologies, products, and processes, such as: (i) cultivars, plant varieties, hybrids or clones; (ii) agricultural and livestock processes and practices; (iii) agro-industrial processes, harvest, post-harvest and transformation and preservation of agricultural products; (iv) machinery and equipment developed by a research unit (da Silva et al. 2007).

Performance of the research system: The measure of performance brings together all the system's components shown in Figure 16 and described above, comparing outputs with inputs used in the production of new knowledge. They include measures of productivity and costs per unit of output or per unit of key inputs.

Based on the analytical framework described above, a series of indicators were selected to identify the strengths and weaknesses in the use of research inputs at different levels of the process of producing research outputs. An overview of the set of indicators for the analysis is displayed in Figure 18. More detail on each of the indicators in this figure and the steps taken to derive an overall picture of the performance of the various African NARS is provided in Annex C.

Figure 16—Indicators to measure the overall performance of agricultural research systems



Source: Elaborated by authors.

For each of the elements shown in Figures 15 and 16, that is (i) overall performance; ii) human capital; iii) costs; iv) investment intensity; and v) funding, indicators were applied to rank African countries based on their performance in that particular area. For example, cost per adjusted-quality publication was used to rank countries based on overall performance. Quality of human resources, salary costs per FTE researcher, the gap between actual R&D investment and attainable R&D investment, and total R&D investment were used to rank countries in the areas of human capital, cost structure, investment intensity, and size of the system, respectively. In the case of funding structure, countries were ranked by the importance of non-government and non-donor funding sources (such as internally generated income through the sale of goods and services, commodity levies, and others).

Within each area of performance, all countries were then classified into three groups based on the rankings, with worst performers in each area included in Group 1, average performers in Group 2, and best performers in Group 3. With all countries classified into three groups in each of the five areas of performance, countries were ranked by overall performance by giving the best performing countries in each area a score of 3; the worst performing countries (Group 1) a score of –1; and average performing countries (Group 2) a score of 0. The overall performance score for each country was calculated as the sum of the scores in the five areas of performance. All countries were then ranked according to this overall score and allocated to three groups of equal size: Best performers (top 33 percent of countries); worst performers (bottom 33 percent), and average performers (the remainder).

Table 2 summarizes the key indicators for the best, worst, and average performing groups of countries. These indicators reveal that:

- The cost of agricultural research per unit of output in best performing countries is almost five times smaller than in worst performing countries (despite the cost per researcher in best performing countries being three times larger than in worst performing countries).
- The higher costs per researcher among best performers is compensated by higher productivity per researcher (12 articles per 100 researchers compared to just 4 in the average group and 0.7 among worst performers).
- Differences in productivity of researchers and the cost of research are the result of researcher qualification differences. Higher average degree levels of researchers in the group of best performers make them more productive and at the same time more expensive. However, higher costs per FTE researcher is compensated by their higher productivity.
- The most important research cost item across all three groups is salaries. Salary costs accounted for a higher share of total research costs in the best and average performing groups than in the worst performing group.
- The size of the R&D system seems to play a major role in the performance of the groups. Average spending by the countries in the best performing group was $158 million (in 2011 PPP prices), compared to just $14 million in the group of worst performers.
- The proportion of government funding in total R&D funding is not correlated with performance of the research system. The main difference between best performers and the other two groups is the role of donors in funding the cost of the R&D system. Donors accounted for only 6 percent of total funding in the best performing countries, and 26 and 35 percent in the group of worst and average performing countries, respectively.
- High volatility in R&D funding is associated with poor overall performance of the research system.
- Government spending per capita is five times larger in the best performing group than in the other two groups. This is probably to some extent correlated with a lower dependence of this group on donor funding.
- The difference in gross enrolment in tertiary education between the best and worst performing group is also highly significant. This could be an indication of severe constraints in the supply of researchers in the worst performing countries. Note that countries in the worst performing group need almost twice the number of agricultural researchers per people enrolled in tertiary education than best performing countries (4.6 FTE agricultural researchers per 1000 people compared to 2.7 FTEs in the best performing group).

Table 2—Average performance scores of Africa's best, average, and worst performing national agricultural research systems, 2009–2016

	Groups of performance			
	Worst	Average	Best	Diff. Best-Worst [a]
Overall performance				
Cost per published article (million 2011$)	24.4	5.7	5.0	***
Number of articles per 100 FTE researcher	0.7	4.0	12.1	***
Cost per FTE researchers (1,000s of 2011$)	88.3	151.1	215.6	***
Human capital				
Quality of human resources (Index 1-4 Max)	2.1	2.6	2.6	***
Ratio PhDs/MSc	0.4	0.9	1.2	**
Costs				
Cost of salaries/FTE researcher (1,000s 2011$)	42.9	74.2	133.4	***
Salary-capital cost ratio	9.7	12.2	15.2	-
Agricultural R&D investment Intensity				
Investment gap as % of R&D investment	15%	27%	40%	-
Size of the agricultural R&D system				
Average R&D spending per country (million 2011$)	14	66	158	***
Funding				
Share of direct government funding in total agricultural R&D funding	65%	55%	72%	-
Share of donor funding in total agricultural R&D funding	26%	35%	6%	***
Share of other funding in total agricultural R&D funding	8%	10%	22%	*
Volatility of R&D funding (variance of investment growth rate)	0.21	0.18	0.12	***
Selected environmental variables				
FTE researchers per 1,000 people enrolled in tertiary education	4.6	3.0	2.7	**
Gross enrolment in tertiary education (%)	2.4	5.0	11.4	***
Government spending per capita (million 2011$)	0.3	0.4	1.9	***

Source: Elaborated by authors.
Note: (a) A Welch t-test was performed to determine if there was a statistically significant difference between Best and Worst performers. Number of countries in each group is: Worst=13; Average=14; Best=12. Statistical significance of difference between best and worst groups: (***) sig. at 1%; (**), sig. at 5%; (*) sig. at 10%.

Table 3 shows the overall performance results of the research systems for 39 African countries. The best performing countries are South Africa, Egypt, Botswana, Kenya, Morocco, Tunisia, Algeria, Ghana, Namibia, Côte d'Ivoire, Ethiopia, and Mauritius. The group of worst performers comprises Togo, Lesotho, Zambia, Rwanda, Gambia, DR Congo, Niger, Central African Republic, Mozambique, Chad, Sierra Leone, Guinea, and Mauritania.

Table 3—Performance of agricultural research systems by country, 2009–2016

Country	C_y	Y_{fte}	C_{fte}	Q_{fte}	PhD/MSc	S_{fte}	G%	Size	Donor funding %	Volatility
Best performers										
South Africa	0.5	87.7	0.4	2.7	0.9	0.26	0%	353	1%	0.09
Egypt	2.3	2.7	0.1	3.2	3.1	0.06	42%	534	0%	0.04
Botswana	4.1	4.1	0.2	2.3	0.8	0.11	0%	19	0%	0.14
Kenya	2.3	9.2	0.2	2.6	0.9	0.11	3%	245	23%	0.08
Morocco	5.0	5.6	0.3	2.7	0.8	0.17	56%	157	0%	0.08
Tunisia	0.7	16.8	0.1	3.1	2.6	0.08	109%	63	0%	0.06
Algeria	2.9	5.6	0.2	2.3	0.4	0.12	224%	95	0%	0.11
Ghana	7.0	4.1	0.3	2.8	0.9	0.21	6%	170	20%	0.16
Namibia	7.7	4.0	0.3	1.9	0.3	0.12	0%	31	0%	0.26
Côte d'Ivoire	9.3	3.0	0.3	3.6	3.8	0.17	37%	76	18%	0.13
Ethiopia	3.9	1.0	0.0	1.6	0.2	0.01	0%	117	13%	0.17
Mauritius	14.7	1.6	0.2	2.0	0.3	0.18	0%	34	1%	0.11
Worst performers										
Togo	7.2	1.0	0.1	2.7	0.6	0.02	39%	8	25%	0.29
Lesotho	43.1	0.2	0.1	1.7	0.5	0.07	0%	3	6%	0.27
Zambia	5.4	1.8	0.1	1.9	0.3	0.03	6%	24	69%	0.16
Rwanda	16.7	1.2	0.2	2.4	0.3	0.09	10%	31	40%	0.11
Gambia, The	10.6	0.7	0.1	1.8	0.2	0.04	0%	4	39%	0.23
Congo, Dem. Rep.	46.6	0.1	0.0	1.7	0.8	0.03	0%	26	15%	0.10
Niger	5.2	1.5	0.1	2.7	0.8	0.03	0%	16	33%	0.16
Central African Republic	9.8	0.3	0.0	1.9	0.1	0.01	0%	4	38%	0.14
Mozambique	8.7	0.8	0.1	1.8	0.3	0.04	4%	26	22%	0.13
Chad	72.2	0.2	0.1	2.3	0.2	0.07	50%	12	11%	0.16
Sierra Leone	36.3	0.2	0.1	2.2	0.2	0.06	35%	12	15%	0.39
Guinea	12.6	0.2	0.0	1.7	0.6	0.01	7%	6	22%	0.27
Mauritania	42.7	0.3	0.1	2.1	0.4	0.08	41%	14	9%	0.31

Table 3 (continued)—Performance of agricultural research systems by country, 2009–2016

Country	*Cy*	*Yfte*	*Cfte*	*Qfte*	*PhD/MSc*	*Sfte*	*G%*	*Size*	*Donors funding %*	Volatility
Average performers										
Benin	2.3	5.5	0.1	3.2	1.9	0.05	16%	26	23%	0.14
Congo, Rep.	1.3	6.4	0.1	2.7	0.7	0.03	88%	7	18%	0.15
Senegal	4.3	6.7	0.3	3.5	3.3	0.16	2%	41	23%	0.18
Uganda	6.0	3.6	0.2	2.5	0.8	0.07	0%	121	53%	0.23
Malawi	7.8	2.5	0.2	2.5	0.7	0.10	0%	31	33%	0.20
Zimbabwe	2.3	5.8	0.1	2.1	0.5	0.08	0%	32	0%	0.29
Nigeria	3.4	4.6	0.2	2.1	0.6	n.a.	29%	463	n.a.	0.16
Mali	12.4	1.3	0.2	2.7	0.7	0.05	15%	47	56%	0.18
Madagascar	1.0	4.6	0.0	2.9	0.9	0.02	24%	10	55%	0.14
Cabo Verde	14.1	0.8	0.1	2.0	0.2	0.08	0%	3	21%	0.12
Eswatini	12.1	2.2	0.3	2.6	0.8	0.17	30%	7	15%	0.16
Burkina Faso	4.7	2.6	0.1	3.0	1.1	0.03	0%	37	59%	0.29
Sudan	6.8	0.9	0.1	2.6	0.7	n.a.	122%	54	n.a.	0.18
Cameroon	1.9	7.9	0.2	2.5	0.4	0.04	54%	45	65%	0.11

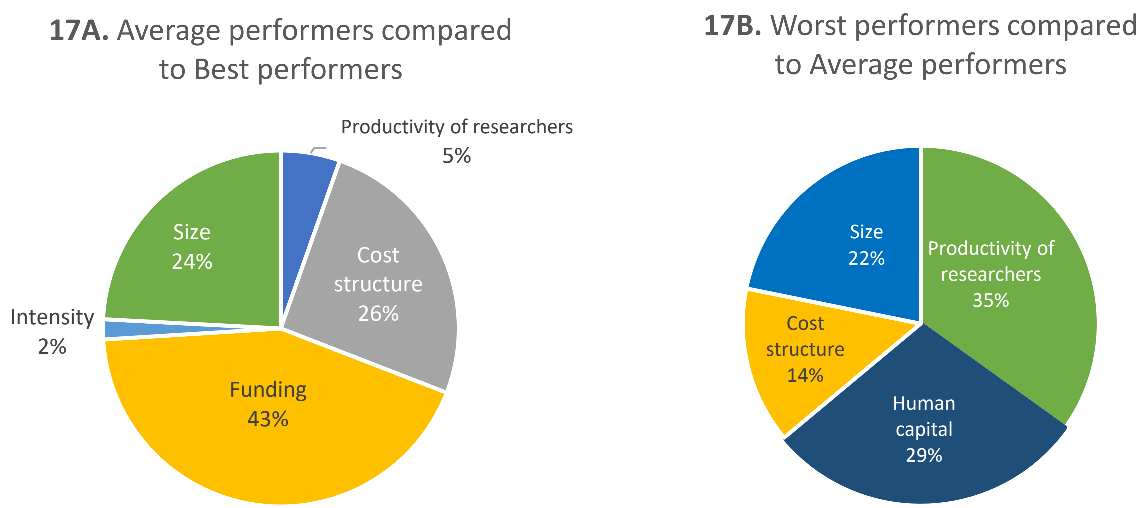
Source: Elaborated by authors.

Note: Cy = Cost per quality-adjusted published article; Yfte = Published articles per 100 FTE researchers; Cfte = Cost per FTE researcher (mill. 2011$); Qfte = Index of qualification of research staff (1-4 max.); PhD/MSc = Ratio of number of FTEs holding a PhD and an MSc degree; Sfte = Salary cost per FTE (million 2011$); G% = Investment gap as % of attainable investment; Size = Million of 2011$ of R&D investment; Donor funding % = Percentage of total research funding funded by donors; Volatility = variance of growth rate of long-term R&D investment. N.a. denotes that data are unavailable.

We now compare the performance of the average group against the best group and the worst group to determine which areas of performance explain differences in NARS performance across country groups. These comparisons are shown in Figure 17. Figure 17A shows that almost half of the difference in performance between the group of best performing countries and the average group can be explained by funding differences (with the average group receiving lower government funding and showing a higher dependence on donor funding). Another large chunk of the performance difference between these two groups is explained by the smaller overall size of research systems and less adequate cost structure of the group of average countries, compared to their counterparts in the best performing group. Performance differences between the groups of average and worst performing countries (Figure 17B) can be explained predominantly by differences in researcher productivity, human capital, and the overall size of the system. It is important to note that the analysis does not consider causalities between areas of performance, but it is likely that the poor overall performance in cost, productivity, and human capital of the group of worst performing countries is correlated to the small size of systems in this group.

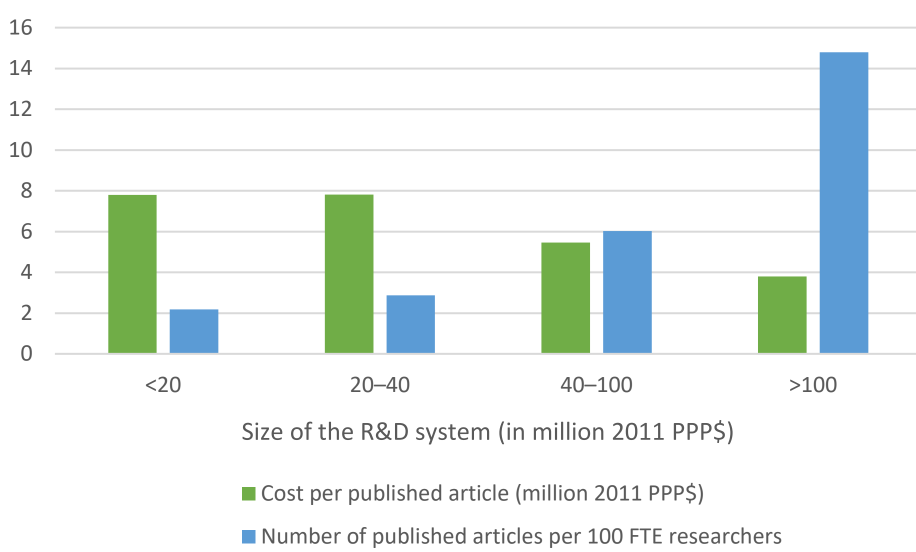
The importance of the size of the research system (measured by annual R&D investment) is shown in Figure 18. The figure indicates that agricultural R&D systems that spend less than $40 million per year (in 2011 PPP prices) are highly inefficient both in terms of cost per unit of output and in productivity of researchers. Productivity (publications per researcher) is more than double in countries spending between $40 and $100 million per year, compared to countries spending less than $40 million per year, while their costs per publication are about 30 percent lower. This is important because only 15 countries in Africa have research systems that spend more than $40 million per year (Egypt, Nigeria, South Africa, Kenya, Ghana, Morocco, Uganda, Ethiopia, Algeria, Tunisia, Côte d'Ivoire, Sudan, Mali, Cameroon, and Senegal). Only the first eight countries have systems that spend more than $100 million per year (in 2011 PPP prices). The numbers thus suggest that economies of scale and scope are critical drivers behind the overall performance of agricultural R&D system, which once again emphasizes the crucial importance of R&D collaboration and coordination among countries.

Figure 17—Factors explaining differences in overall NARS performance between country groups



Source: Elaborated by authors based on ASTI (various years).

Figure 18—Cost per published article and number of published articles per researcher broken down by spending size of the research system, 2009–2016

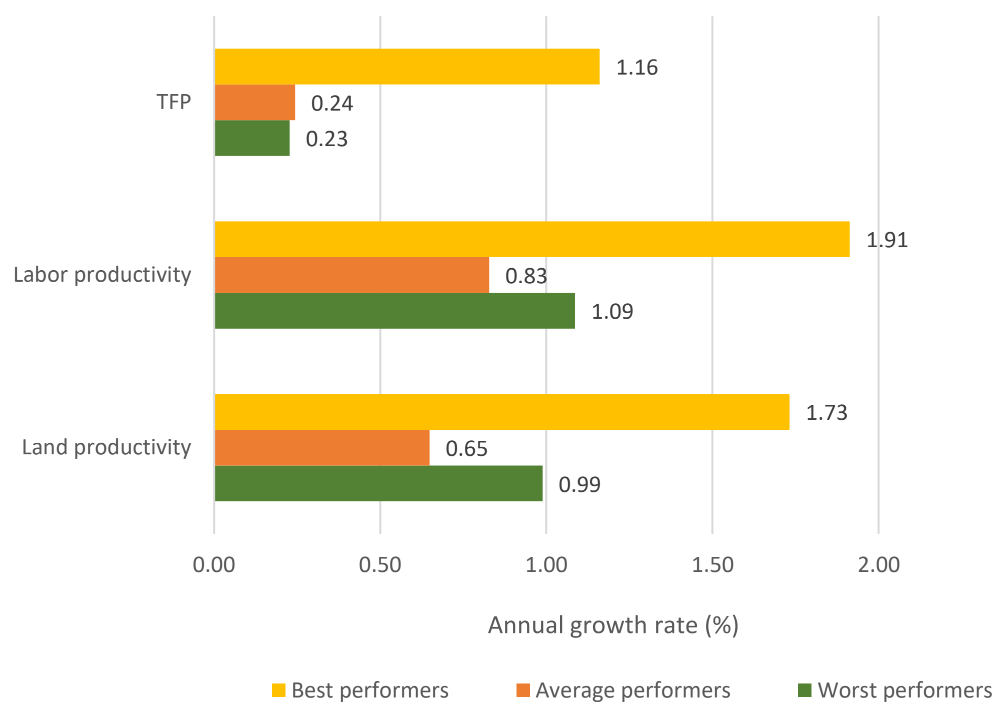


Source: Elaborated by authors based on ASTI (various years).

We end this section by looking at the overall performance of the agricultural sector measured as changes in productivity for the best, average, and worst performing groups. It is important to note that we are not trying to link agricultural performance in recent years to the performance of research systems. This is not only because productivity improvements over time cannot solely be attributed to R&D performance, but most importantly, because of a lagged effect of research on productivity. This means that today's performance of a country's agricultural sector is partly the result of what these countries' research systems produced 10 or 15 years ago. It is, however, likely that the best performing countries today were also among the best performers 15 years ago. Yet, comparisons should be made with caution.

Figure 19 shows the 2000–2016 growth rates of total factor, land, and labor productivity of the agricultural sector for the three groups of countries. Differences in productivity growth between countries with the best performing research systems and the other two groups of countries are large. Cross-country variation in TFP growth is significant. TFP in the best performing group increased at an average rate of 1.16 percent per year during 2000–2016 (still a very modest growth rate if compared to regions outside Africa), while TFP growth in the other groups was very close to 0. Land and labor productivity growth in the best performing group was also considerably higher than in the other two groups.

Figure 19—Agricultural productivity growth by group of agricultural research performance, 2000–2016



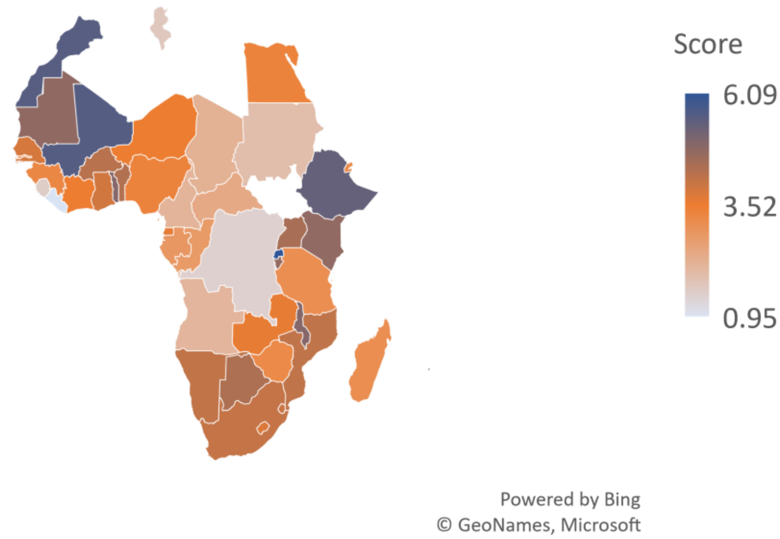
Source: TFP growth data are from USDA-ERS (2020). Land and labor productivity was estimated by authors based on data from USDA-ERS (2020).

9. The Malabo Commitment to End Hunger and Reduce Poverty

At the African Union Summit in Malabo in June 2014, Heads of State and Government adopted a set of new goals to achieve the agricultural vision of prosperity and improved livelihoods for the continent. The Summit affirmed that agriculture should remain high on Africa's development agenda to achieve economic growth and poverty reduction and committed to focus on 7 key areas: 1) A recommitment to CAADP principles and values; 2) Commitment to enhancing investment finance in agriculture; 3) Commitment to ending hunger in Africa by 2025; 4) Commitment to reducing poverty by the year 2025, through inclusive agricultural growth and transformation (agriculture to contribute half of the reduction); 5) Commitment to boosting intra-African trade in agricultural commodities and service; 6) Commitment to enhancing resilience of livelihoods and production systems to climate, variability and other related risks; 7) Commitment to mutual accountability to actions and results.

Under the Commitment on Mutual Accountability, the Heads of State agreed to conduct reviews of their country's agricultural sectors every two years (Biennial Reviews or BRs) to take stock of the progress being made in pursuit of the Malabo agreements. The inaugural BR results were presented at the 30th AU Assembly meeting in Addis Ababa in January 2018. The seven Malabo Commitments were translated into seven thematic areas of performance with 24 performance categories and 47 indicators to evaluate country performance in achieving agricultural growth and transformation goals in Africa. As agreed by the leadership of the AUC, progress made by individual member states would be monitored using balanced scorecard methods. Against the 2017 benchmark, the minimum score for a country to be on track to achieve proposed goals was 3.94 out of 10. Figure 20 provides an overview of the performance of 45 countries. Of these, 19 countries (42%) were on track in 2017. The figure shows that Rwanda, Mali, Morocco, Ethiopia, Mauritius, Togo, Malawi, Mauritania, Kenya and Burundi were the top performing countries in that year. The results of a second BR were launched in early 2020. A total of 49 AU member states (compared with 47 member states in the inaugural report) reported on progress during this second cycle of the biennial review process. Out of these, 36 countries registered positive progress compared with their 2017 scores, which reflects efforts by the member states to address the shortfalls revealed in the inaugural report. However, only 4 member states (Burundi, Cabo Verde, Morocco, and Rwanda) surpassed the minimum score of 6.66 required to be on-track for this round, compared with a minimum score of 3.94 for the previous reporting period (African Union 2019).

Figure 20—Country performance in achieving agricultural growth and transformation goals from the Malabo Commitments, 2017



Source: Matchaya et al. (2018).
Note: In 2017, a benchmark of 3.94 out of 10 was the minimum score for a country to be on track for implementing the Malabo declaration. By 2019, this benchmark had increased to 6.66.

In this section we look at two of the Malabo commitments that relate directly to research and productivity growth in agriculture: Commitments 3 and 4, which focus on ending hunger and reducing poverty in Africa by the year 2025, respectively. To do this we analyze the evolution of two indicators: the poverty headcount ratio (PHR)[10], and prevalence of undernourishment (PoU)[11], both measured as a share of the total population.

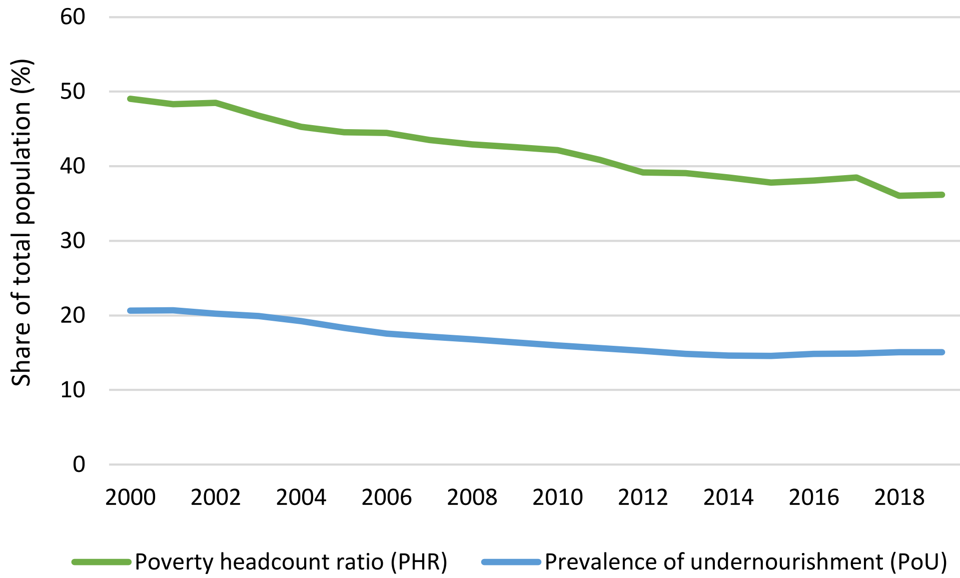
Figure 21 shows the evolution of the PHR and the PoU in Africa between 2000 and 2019. Extreme poverty dropped from almost 50 percent in 2000 to 36 percent in 2019. During the same period, the PoU fell from 20 to 15 percent. Average values in Figure 23 mask a considerable degree of cross-country variation, however. To assess these differences between countries and to identify some of the factors associated with the reduction of poverty and undernourishment, we classify countries in three groups for each of the two indicators (Figure 22). The group of countries showing high poverty reduction, experienced a drop in their PHR of more than 60 percent. The share of people living under extreme poverty in these countries decreased from 32 percent in 2000 to 13 percent in 2018. The average group includes countries with very high levels of extreme poverty in 2000. Although these countries were able to reduce their PHR by 35 percent between 2000 and 2018, the poverty rate was still at a very high 40 percent in 2018, which is in fact higher than 2000 poverty levels in the group of countries that cut

[10] The percentage of the population living on less than $1.90 a day at 2011 PPP prices (World Bank, 2021).
[11] Population below minimum level of dietary energy consumption (also referred to as prevalence of undernourishment) shows the percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously. Data showing as 5 may signify a prevalence of undernourishment below 5% (World Bank, 2021).

poverty the most. The poverty situation in the remaining group (Low) did not change significantly between 2000 and 2018, increasing from 50 percent to 51 percent.

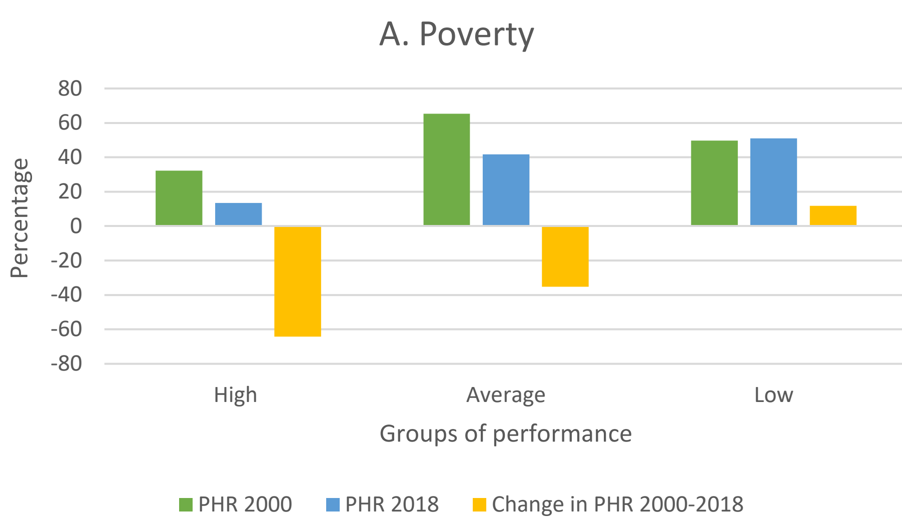
Breaking down countries into groups by hunger reduction over time presents a similar picture. The High group cut its PoU by almost 60 percent, the Average group by 17 percent, and the Low group increased its PoU by 12 percent during 2000–2018.

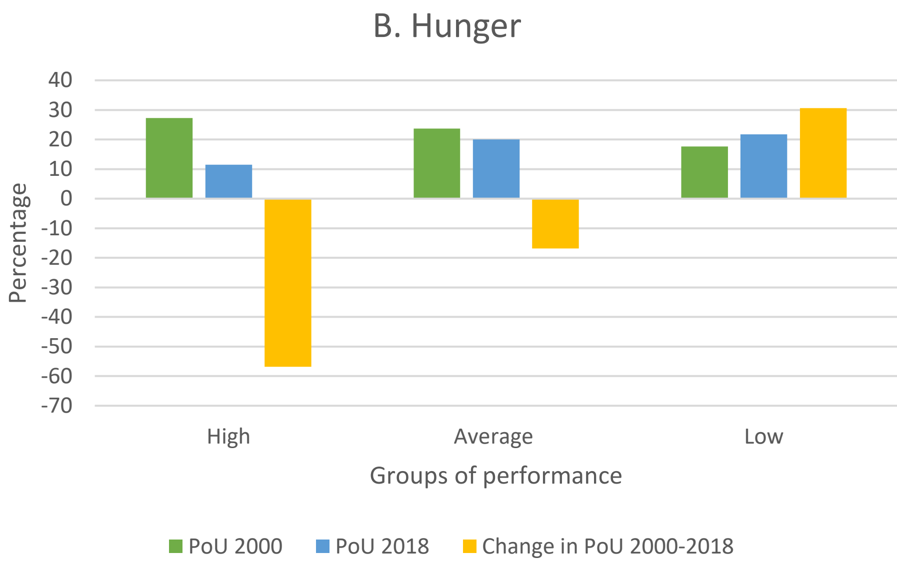
Figure 21—Evolution of the poverty and undernourishment in Africa



Source: World Bank (2021)

Figure 22—Groups of countries achieving high, average, and low levels of poverty and hunger reduction between 2000 and 2018





Source: Authors based on World Bank (2021).
Notes: PHR stands for poverty headcount ratio and measures the percentage of the total population living on less than $1.90/day (2011 PPP prices). PoU is the prevalence of undernourishment as percentage of total population. Please consult Appendix Tables A1 and A2 to see the countries included in each group of performance.

A detailed overview of which countries are classified in which group is provided in Tables D1 and D2 in Annex D. Table D3 presents economic indicators of performance and structural characteristics of countries in each of the three poverty alleviation and hunger reduction groups. We observe significant differences across groups. The group that achieved the highest poverty reduction shows the highest average income among all groups, the highest labor productivity, a lower share of agriculture in GDP and in employment, higher levels of capital formation and foreign direct investment (FDI), and higher growth in GDP per capita, all of which are indicators of more dynamic and better performing economies. In contrast, countries experiencing the highest reduction in PoU over time are characterized by a lower average income than the group of low hunger reduction, lower labor productivity, a higher share of agricultural value added and employment, and higher capital formation and FDI.

Annex D also includes a comparison of agricultural performance between the different groups of countries broken down by their level of poverty alleviation and hunger reduction (Table D4). The table suggests that labor productivity growth is the main factor distinguishing the high and low groups in terms of poverty and hunger reduction. Countries with high poverty reduction increased the use of machinery, fertilizer, animal stock, and land with only a very small increase in the use of labor. Conversely, labor increased at 2.7 percent in the low poverty reduction group with other inputs increasing below this rate, resulting in an overall decrease in labor productivity. In the case of hunger reduction, the transformation of agriculture seems to play a bigger role in the high-reduction group. This group of countries increased output, TFP, and almost all inputs at a higher rate than the low-reduction group. Five countries were in both high poverty and hunger reduction groups: Cameroon, Algeria, Ethiopia, Ghana, and Tunisia.

To conclude, it is important to consider that the analysis in this section does not imply causality relationships between variables. For example, agricultural TFP growth associated to high reduction in the PoU does not mean that agricultural growth was the cause of this reduction. However, these comparisons offer valuable information that allow us to at least propose explanations for the observed performance and the factors behind those changes. A first observation is the great variability of the PHR indicator across countries in 2000. The highest reduction of the PHR occurred in the group of countries with the lowest levels of poverty in 2000. Poverty in other countries is still alarmingly high and seems the result of growing population and agricultural labor, no employment opportunities outside agriculture, and low incorporation of capital and inputs in production. The reduction of the PoU on the other hand, is highly correlated with a strong performance of the agricultural sector (as shown in Table A4 in the Appendix). Growth in agricultural output, total input, labor productivity, and TFP are significantly higher in the group of high performing countries. Finally, the observed trends in Figure 23 show a slowdown in poverty and hunger reduction as the curves plateau after 2011. This could be indicating that poverty and hunger reduction could have been fueled by the favorable period of high growth driven by commodity prices and a group of countries that took advantage of the economic environment. With no low-hanging fruit for poverty and hunger reduction, a less favorable economic environment and the threat of climate change, countries will need to look at medium- and long-term policies and investments to achieve Malabo goals. In this context, strategic investments in R&D for development will be a necessary condition to sustain agricultural growth in the future.

10. Conclusion and Policy Recommendations

Well-developed national agricultural research systems and adequate levels of investment and human resource capacities are prerequisites in the attainment of agricultural development, food security, and poverty reduction. Nonetheless, Africa is still underinvesting considerably in agricultural R&D despite increased political support for the agricultural sector through CAADP. Even though total R&D investment has increased since the turn of the millennium, countries have directed most of the funds toward (much-needed) salary increases for research staff, rather than actual research programs. In a large number of countries, the national government funds the salaries of researchers and support staff, but little else, leaving nonsalary-related expenses highly dependent on donors and other funding sources. Governments urgently need to address underinvestment in agricultural R&D and ensure the full disbursement of approved budgets. They must provide stable and sustainable levels of funding to secure a strategic program of effective research activities that yields increased agricultural productivity. Rather than relying too much on donor contributions and development bank loans to fund critical areas of research, (national and regional) governments need to determine their own long-term national priorities and design relevant, focused, and coherent agricultural R&D programs accordingly. Donor and development bank funding needs to synergistically complement these priorities. Mitigating the effects of any single donor's abrupt change in aid disbursement is crucial, highlighting the need for greater funding diversification—for example, through the sale of goods and services, or by attracting complementary investment from the private sector. The private sector is currently the least developed source of sustainable financing for agricultural R&D in Africa (its funding potential remains largely untapped in most countries). Cultivating private funding requires that national governments provide a more enabling policy environment through tax incentives, protection of intellectual property rights, and regulatory reforms to encourage the spill-in of international technology. More innovative R&D funding mechanisms, such as Côte d'Ivoire's exemplary FIRCA (see Section 6), need to be explored by a greater number of countries.

Governments must also step up their investment in training and capacity building for agricultural research. Few African NARIs have autonomous status in setting their own financial, human resource, or operating policies, which limits their ability to diversify their funding sources, offer competitive salaries and working conditions, and generally maximize efficiency levels. Growing concern exists regarding the lack of human resource capacity in agricultural R&D to respond effectively to the challenges that the African agricultural sector is facing. In a very large number of African countries, especially in West Africa, the majority of PhD-qualified researchers are set to retire in the next few years. NARIs therefore need to develop systematic human resource strategies without delay, incorporating existing and anticipated skills gaps and training needs. The successful implementation of such strategies will require both political and financial support. National governments must expand their investments in agricultural higher education to allow universities to increase the number and size of their MSc and PhD programs—or establish such programs in countries were MSc and PhD programs are still lacking—and to improve the curricula of existing programs. In addition to degree-level training, NARIs should involve present and past tenured researchers in mentoring their younger colleagues. In some countries, this may involve increasing the official retirement age of researchers or instituting some form of flexible working arrangements for retired researchers. Developing incentives to create a more conducive work environment for agricultural researchers is crucial. In a large number of countries, significant discrepancies exist in the remuneration, working conditions, and incentives offered to NARI researchers compared with their university-based colleagues. These inequities need to be removed or overcome to enable the NARIs to attract, retain, and motivate well-qualified researchers.

Agricultural research investment is positively associated with high returns, but these returns take time—often decades—to accrue. Consequently, the inherent lag from the inception of research to the adoption of new varieties or technologies calls for sufficient and sustained agricultural research funding. ASTI evidence in this report demonstrates that Africa's research intensity for the continent as a whole—that is agricultural research spending as a percentage of agricultural output—fell from 0.54 percent in 2000 to 0.39 percent in 2016. Nonetheless, agriculture in Africa continues to be challenged by production inefficiencies resulting from a mostly traditional production systems with a low technology base, natural resource depletion, climate change and variability, and environmental degradation, all of which emphasize the need for considerably higher levels of sustained agricultural research investment in the coming decades. If countries started investing as much in agricultural research as they currently are in defense and security, the livelihoods of millions of marginalized Africans (including women and youth) could be significantly enhanced and job opportunities created.

Repeated calls have been made for increased investments in Africa's agricultural research (and the wider innovation) systems through CAADP, STISA-24, and S3A. AUC actively monitors the advancements towards achieving the CAADP and Malabo goals through its BR process. One of the indicators that AUC actively tracks is "*total agricultural research spending as a share of AgGDP*". The BR scores countries based on whether they invest at least 1 percent of their AgGDP in agricultural research. The data in this report revealed that only a handful of (mostly Southern) African countries have been able to reach this target. Nevertheless, "*total agricultural research spending as a share of AgGDP*" is not the most telling indicator to capture a country's commitment and capacity to invest in agricultural R&D. A *one-size-fits-all* intensity target of 1 percent for all African countries is undesirable, given the widely diverging structural characteristics of each country's economy and agricultural sector. In Section 8 of this report, an alternative is proposed, which the AUC should consider adopting in future BR processes. This alternative takes a range of structural characteristics affecting a country's commitment and capacity to invest in agricultural R&D into account beyond just the size of its agricultural sector.

Regardless of the indicator used to assess agricultural R&D investment, Africa needs to substantially raise its level of agricultural R&D investment to address its agricultural production challenges more effectively. Section 5 of this report presented various future investment scenarios and their projected impact on agricultural productivity growth. Continued underinvestment will constrain long-term agricultural productivity growth and the capacity of countries to develop value chains, achieve self-sufficiency in a broader range of commodities, reduce poverty, and ensure food security, all of which are important CAADP goals. Even though most research systems in the region are severely challenged by low efficiency and high costs, the situation is more severe among Africa's smaller countries. The smallest third of African NARSs spend an average of just $14 million (2011 PPP prices) per year on agricultural R&D (compared to the nearly $160 million spent by the largest third). Challenged by low capacity, funding volatility, and limited ability to take advantage of economies of scale and scope, the scarce research resources of these small NARSs are spread extremely thinly over a wide array of commodities and agro-ecological zones. As a result, small countries generally record much lower returns to R&D compared to their larger counterparts, and their R&D efforts have been less effective in reducing poverty and malnutrition, two principal CAADP goals.

Rather than setting one-size-fits-all national investment targets, it is probably more meaningful to assess investment capacity and allocation for Africa as a whole and set (sub-) regional R&D investment targets. Agricultural R&D investment should not be guided by political boundaries. Instead, agro-ecology needs to be the defining factor. Consequently, a closer integration of agricultural R&D at the subregional and regional level (through joint research programs and regional centers of excellence) is indispensable, as it allows countries with lagging agricultural research systems to benefit from the gains made in countries with similar agro-ecological conditions that have more advanced systems. Continued support to and growth of regional bodies, networks, and mechanisms (including One CGIAR) will help effectively define, implement, and fund regional research agendas targeting issues of common interest, and will ultimately produce higher research impact.

While optimizing the use of agricultural research resources across countries is certainly a sensible strategy, investments in agricultural research undoubtedly need to increase considerably as well. Taking into account where an additional dollar has the largest impact, priority should be given to investment in NARSs in countries with large agricultural sectors, cross-country collaborative research, and the CGIAR. This certainly does not mean that local adaptive research should be deprioritized (it is needed to exploit the benefits of more upstream research), but only that the potential returns to such research are generally lower. To sum up, better coordination and a clear articulation of mandates and responsibilities among national, subregional, regional, and global R&D players are essential to ensuring that scarce financial, human, and infrastructure resources are optimized, duplications minimized, and synergies and complementarities enhanced.

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ANNEX A—ASTI DATA COVERAGE

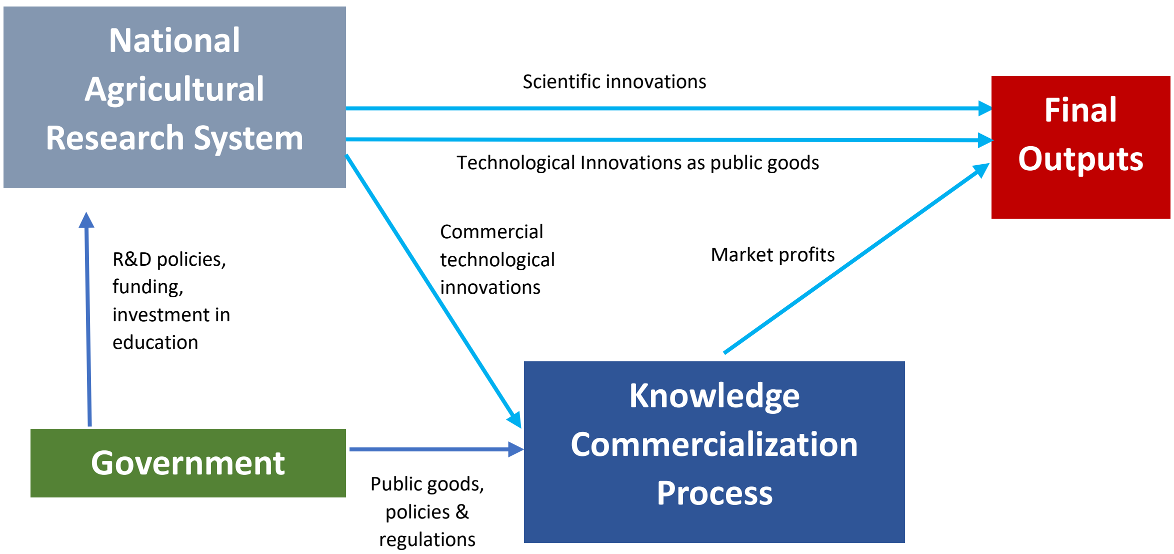
A brief overview of the definitions, coverage, and methodology behind ASTI expenditure datasets and intensity ratios is provided below:

- ASTI datasets cover every single government, higher education, nonprofit agency involved in agricultural R&D in each of the countries.
- From each of these agencies, ASTI collects detailed financial data broken down by salary costs, operating and program costs, and capital investments. Expenditure totals and intensity ratios in this report are inclusive of these three cost categories.
- ASTI collects actual spending data, not budgeted or projected data. This spending data is inclusive of all funding sources (government funding, grants and loans from donors, internally generated resources, allocations derived from commodity levies, etc.).
- ASTI's financial datasets are adjusted for the time an agency spends on agricultural research, as opposed to non-research activities or non-agricultural activities. For instance, the 10 faculty members of a Faculty of Veterinary Medicine who spend 80 percent of their time teaching, and 20 percent on research, collectively count as 2 FTE agricultural researchers. Research expenditures are also assumed to be 20 percent of the faculty's total expenditures.
- ASTI collects all its financial timeseries data in local currency units and converts these into constant prices using official World Bank GDP deflators. In this report, ASTI has expressed all its financial data in 2011 constant prices.
- If the financial year differs from the calendar year, spending is reported in the calendar year that covers most of the financial year in question.
- ASTI follows the FAO definition of agriculture, which includes crops, livestock, forestry, fisheries, and aquaculture. Research investment in agrochemicals, agricultural machinery, or food processing research are not covered in ASTI datasets.
- ASTI intensity ratios are based on official AgGDP data from the World Bank, which can differ from government statistics. The World Bank does not classify agrochemical, agricultural machinery, or food processing industries under the agricultural sector (but under the industry sector instead).
- ASTI expenditure data cover national agricultural research investment only. Data on the contributions of international agricultural research agencies operating in African countries, such as the centers of the CGIAR, have been excluded.

ANNEX B—THE KNOWLEDGE INNOVATION PROCESS IN AGRICULTURE

Figure B1 depicts a simplified version of the process of innovation in agriculture and its components. The agricultural research system, including public and private research, generates new scientific and technological knowledge upstream in the system. This process is linked downstream with the knowledge commercialization process, transforming technological knowledge to profit. These two sub-processes are interdependent and linked by the technological innovation products which are the output of the research system and the input of commercialization sub-process. The government is included as part of the system as it affects the two sub-processes through investments (e.g., R&D, infrastructure, etc.), policies and regulations, and the whole process is depicted as embedded and interdependent with the external innovation environment, which can facilitate or impede the operational efficiency of the innovation process.

Figure B1—Knowledge innovation process in agriculture



Source: Adapted from Guan and Chen (2012).

The outputs of the NARS in Figure B1 are of particular interest for our analysis. Note that there are two distinct outputs: scientific and technological innovations. The scientific innovations are quantified as publications in scientific journals and are different from technological innovations. However, they are by-products of the same research process and as such, linked to each other. Scientific publications in this context could be an indicator of the quality of the research behind the creation of technological innovations and a comparable output to measure research productivity in a system. Also note that the research system produces technological innovations as public goods, knowledge that cannot be converted into profit and that reach final users outside the system through different means, other than the knowledge commercialization process.

The final step of the process of innovation is the use of technical knowledge in the form of new technologies by producers at different levels of the value chain (outputs that go out of the system in Figure B1. These final technological outputs result, if adopted, in benefits for producers in the form of higher productivity, lower costs per unit of output, or higher income. For consumers they lead to lower food prices, increased product variety, or greater product quality. In addition, they help to reach policy targets, including reducing hunger and poverty, increasing resilience of producers, etc. Measuring this impact is a difficult task because there are many factors other than new technologies that determine changes in producer and consumer benefits. Instead, we will analyze the performance of African research systems and link this performance with overall country performance in different policy areas to draw conclusions on the role of agricultural research improving country performance.

ANNEX C—DECOMPOSITION OF NARS PERFORMANCE INDICATORS

- ***Output:*** The major constraint to building an indicator that measures the performance of a research system comes from the research output side. ASTI collected data on releases of new crop varieties, technologies, and publications for countries in SSA, but no such data is available for North Africa. ASTI has some concerns about the comparability across SSA countries of the R&D output data it received from the countries, however. The most reliable information on research outputs available is bibliometric data on scientific publications as they are consistent and comparable across countries. Based on the limited availability of technological output data, we use the number of articles published in agricultural and biological sciences and the H index—an indicator of quantity and quality of publications (SCIMAGO, 2021)—to build a quality-adjusted measure of research output: *quality-adjusted number of published articles in agricultural and biological science*.[12] We expect quantity and quality of publications to be correlated with output of technologies, products, and processes. However, this indicator could be biased in favor of some countries like those with larger and more developed research systems, or those systems with a larger number of researchers in the higher education sector. No information is available to determine the size and direction of possible bias in the comparisons so the results of the analysis should be taken with caution.

- ***Cost per unit of output (Cy):*** This indicator compares research output to research inputs and its value depends on the productivity of researchers and on the cost per researcher. Costs of the research system are obtained from ASTI and used in combination with the output measure described above to calculate the research cost per unit of output for each country. This indicator of overall research system performance is then complemented by different sub-indices that facilitate tracking of differences between countries in different areas of performance.

- ***Cost and output per researcher:*** Cost per unit of research output (*Cy*) can be decomposed into cost per FTE researcher (C_{fte}) and output per researcher (Y_{fte}), a measure of productivity. The more productive researchers are, the smaller *Cy* is. As there is a positive correlation between cost and output per researcher, more spending per researcher increases *Cy* but also results in higher productivity. This means that higher costs per researcher could reduce cost per unit of output if growth in productivity compensates for increases in the cost per researcher.

- ***Quality of human resources (Q_{fte}):*** Productivity of researchers depends mostly on the quality of human resources (degree composition: PhD, MSc, and BSc) and on the cost structure of research (salaries, operating costs, and capital). We calculate human capital of research systems using a simple human resource quality measure based on the number of years of schooling:
    - Q_{fte}= [4×(FTE with a PhD) + 2×(FTE with MSc) + FTE with BSc] /Total FTEs
  - This is an index of human resource quality with values between 1 and 4. An index of 1 indicates that all researchers in the system hold a BSc degree. An index of 4 indicates that all researchers hold PhD degrees. Q_{fte} times the number of FTE researchers gives a measure of the human capital in research (HK_{fte}), as the number of researchers adjusted by degree:
    - HK_{fte} = Qfte × FTE= 4×(FTE with a PhD) + 2×(FTE with MSc) + FTE with BSc
- ***Cost structure:*** We use two indicators to look at the structure of research costs: salary cost per FTE (S_{fte}) and the ratio between salary costs and capital costs (C_{SK}).
    - S_{fte} = Total salary costs of researchers/ FTE
    - C_{SK} = Total salary costs of researchers/Capital costs
- ***Intensity:*** We used the AII to calculate the investment gap as a percentage of actual investment.

[12] The research output is the number of articles in agronomic and biological science published by the country adjusted by the H index, as follows: $AH_i = A_i \times (H_i/H_{max})$, where *AH* is the quality-adjusted number of articles of country *i*; A_i and H_i are the actual number of articles published and the H index of *i*, respectively, and H_{max} is the highest *H* index among all countries in the region. The number of articles by country is transformed in this way into the number of articles of similar quality published by country.

- *G% = Investment gap in $/ R&D investment in $*

- ***Size of the system:*** Calculated as the ratio between total R&D spending of a country and average R&D spending of the sample of countries used in the comparison times 100.
- ***Funding of the research system:*** We distinguish between direct funding from government, funding by donors, and funding by other sources including sales of goods and services by research agencies, and commodity levies. In general, funding by donors is correlated with poor performance of the system while other sources of funding correlate with good performance. Given the importance of exogenous determinants to the level and sources of funding used in research, we introduce an indicator of government budget constraint for the countries:

GS=Government spending/population

Finally, some environmental or exogenous factors affect the efficiency of the process. Structural characteristics like income (e.g. GDP per capita), size of the economy (measured as GDP), size of the agricultural sector (AgGDP), and political factors could affect the relative size of the agricultural research system, investment intensity, R&D funding sources, and budget constraints and could also be determinant of the overall size of the research system, which will affect costs per unit of output.

ANNEX D—BREAKDOWN OF AFRICAN COUNTRIES BY ECONOMIC STRUCTURE, AGRICULTURAL PERFORMANCE, POVERTY AND UNDERNOURISHMENT REDUCTION SCORES

Table D1—Groups of countries achieving high, average, and low levels of poverty reduction between 2000 and 2018

	ISO-code	Country	PHR 2000	PHR 2018	Change (%)
High	TUN	Tunisia	6	0.2	-97
	DZA	Algeria	5.6	0.4	-93
	GMB	Gambia, The	70.8	10.3	-85
	MAR	Morocco	5.8	0.9	-84
	CPV	Cabo Verde	16.6	3.4	-80
	MRT	Mauritania	19.6	6	-69
	GHA	Ghana	35.1	13	-63
	NAM	Namibia	32.6	13.8	-58
	GAB	Gabon	8	3.4	-58
	BWA	Botswana	33.3	14.5	-56
	MUS	Mauritius	0.4	0.2	-50
	CMR	Cameroon	51.2	26	-49
	ETH	Ethiopia	63.4	32.6	-49
	BFA	Burkina Faso	81.6	43.8	-46
	ZAF	South Africa	34.8	18.7	-46
	LSO	Lesotho	50.6	27.8	-45
Average	NER	Niger	81.6	45.4	-44
	TZA	Tanzania	86.2	49.4	-43
	MLI	Mali	85.3	50.3	-41
	SLE	Sierra Leone	72.9	43	-41
	SWZ	Eswatini	48.9	29.2	-40
	NGA	Nigeria	65.3	39.1	-40
	TCD	Chad	62.7	38.1	-39
	UGA	Uganda	66.8	41.5	-38
	LBR	Liberia	71.4	44.4	-38
	SEN	Senegal	57.4	38.5	-33
	COG	Congo, Rep.	55.1	38.2	-31
	RWA	Rwanda	78	56.5	-28
	GIN	Guinea	49.8	36.1	-28
	MOZ	Mozambique	82.1	63.7	-22
	SDN	Sudan	15.7	12.2	-22

Table D1 (continued)—Groups of countries achieving high, average, and low levels of poverty reduction between 2000 and 2018

	ISO-code	Country	PHR 2000	PHR 2018	Change (%)
	CAF	Central African Republic	84.1	65.9	-22
	COD	Congo, Dem. Rep.	94.3	77.2	-18
	DJI	Djibouti	20.2	17	-16
	BDI	Burundi	84.7	72.8	-14
	TGO	Togo	56.5	51.1	-10
	BEN	Benin	48.9	49.6	1
	GNB	Guinea-Bissau	66.6	68.4	3
Low	CIV	Cote d'Ivoire	27	29.8	10
	MWI	Malawi	63.8	70.8	11
	KEN	Kenya	32.2	37.1	15
	MDG	Madagascar	63.9	77.4	21
	ZMB	Zambia	43.8	58.7	34
	AGO	Angola	36.4	51.8	42
	EGY	Egypt	2.4	3.8	58
	ZWE	Zimbabwe	21.4	33.9	58

Source: Author’s based on World Bank (2021).
Note: PHR is Poverty Headcount Ratio measured as the percentage of total population living on less than $1.90/day (2011 PPP prices).

Table D2—Groups of countries achieving high, average, and low levels of PoU reduction between 2000 and 2018

Group	ISO-code	Country	PoU 2000	PoU 2018	Change in PoU
High	AGO	Angola	67.5	18.6	-72
	BEN	Benin	17.4	7.4	-57
	CMR	Cameroon	23.1	6.3	-73
	DZA	Algeria	8	2.8	-65
	ETH	Ethiopia	47.1	19.7	-58
	GHA	Ghana	15	6.5	-57
	MLI	Mali	16.4	5.1	-69
	SDN	Sudan	21.7	12.4	-43
	SEN	Senegal	24.2	9.4	-61
	SLE	Sierra Leone	50.7	26	-49
	TGO	Togo	31.4	20.7	-34
	TUN	Tunisia	4.4	2.5	-43
Average	BFA	Burkina Faso	24.5	19.2	-22
	CIV	Cote d'Ivoire	20.5	19.9	-3
	EGY	Egypt	5.3	4.7	-11
	GMB	Gambia, The	18	11.9	-34
	KEN	Kenya	32.4	23	-29
	MAR	Morocco	6.4	4.3	-33
	MOZ	Mozambique	36.6	32.6	-11
	MUS	Mauritius	5.8	5.3	-9
	MWI	Malawi	23.8	18.8	-21
	RWA	Rwanda	38.5	35.6	-8
	TCD	Chad	39	39.6	2
	TZA	Tanzania	33.1	25	-24
Low	BWA	Botswana	23.2	24.1	4
	COG	Congo, Rep.	27.1	28	3
	CPV	Cabo Verde	14.6	18.5	27
	GAB	Gabon	10.8	16.6	54
	LBR	Liberia	36.7	37.5	2
	LSO	Lesotho	20.2	32.6	61
	MDG	Madagascar	33.9	41.7	23
	MRT	Mauritania	8.4	11.9	42
	NAM	Namibia	13.1	14.7	12
	NGA	Nigeria	9.1	12.6	38
	SWZ	Eswatini	10.7	16.9	58
	ZAF	South Africa	4	5.7	43

Source: Authors based on World Bank (2021).

Note: PoU is prevalence of undernourishment as percentage of total population.

Table D3—Differences between high and low performing countries: Economic structure and performance, 2000–2017

	PHC			PoU		
	Mean value 2001-2017			Mean value 2001-2017		
	High	Low	Welch test (diff. in means)	High	Low	Welch test (diff. in means)
GDP per capita, PPP (constant 2017 international $)	7,416	2,947	***	4,094	6,918	***
Growth in GDP per capita (%)	2.2	1.1	**	2.4	1.32	*
GDP (million $2017)	115,535	91,177	-	103,705	121,564	-
Annual GDP growth 2000-2017	3.9	5.1	-	5.58	4.52	-
Labor productivity (2017 $)	21,179	7,299	***	12,842	19,352	***
Growth in labor productivity (%)	1.6	2.5	-	3	1.93	-
Employment in agriculture (%)	33	58	***	46.2	34.3	***
Annual growth in the share of agricultural employment 2000-2017	-2.4	-0.7	***	-1.68	-1.8	-
Agricultural VA (% GDP)	14	23	***	24	14	***
Agriculture VA (million 2011$)	12,022	13,749	-	17,492	15,674	-
Annual agricultural GDP growth 2000-2017	2.3	3.7	-	4.99	2.6	-
Manufacture VA (% GDP)	13.1	11.2	***	11.5	11.7	-
Manufacture (million 2011$)	21,629	13,099	***	19,651	14,647	-
Annual manufacture growth 2000-2017	3.7	5.0	-	5.12	5.31	-
Gross fixed capital formation (% GDP)	26.3	18.0	***	22.9	26.9	***
Annual capital growth 2000-2017	4.6	6.5	-	7.1	4.63	-
FDI (% GDP)	3.5	2.8	***	3.0	6.5	***
Annual FDI growth 2000-2017	5.2	8.1	-	6.8	4.55	-

Source: Authors' elaboration based on World Bank (2021)

Notes: ***p<0.01, **p<0.05, *p<0.1. Poverty alleviation high performing: Tunisia, Algeria, Gambia, The, Morocco, Cabo Verde, Mauritania, Ghana, Namibia, Gabon, Botswana, Mauritius, Cameroon, Ethiopia, Burkina Faso, South Africa, Lesotho. Poverty alleviation poor performing countries are: Central African Republic, Congo, Dem. Rep., Djibouti, Burundi, Togo, Benin, Guinea-Bissau, Cote d'Ivoire, Malawi, Kenya, Madagascar, Zambia, Angola, Egypt, Zimbabwe. Hunger alleviation high performers: Angola, Benin, Cameroon, Algeria, Ethiopia, Ghana, Mali, Sudan, Senegal, Sierra Leone, Togo, Tunisia. Hunger alleviation poor performers: Botswana, Congo, Rep., Cabo Verde, Gabon, Liberia, Lesotho, Madagascar, Mauritania, Namibia, Nigeria, Eswatini, South Africa

Table D4—Differences between best and worst performing countries: Agricultural production and performance, 2000–2017

	PHR			PoU		
	Mean value 2001-2017			Mean value 2001-2017		
	Best performers	Worst performers	Welch test (diff. in means)	Best performers	Worst performers	Welch test (diff. in means)
Land productivity 2000	696	913	-	571	666	-
Growth in land productivity (%)	1.52	0.67	-	1.63	1.2	-
Labor productivity 2000	2,377	893	**	1,415	2,578	-
Growth in labor productivity (%)	1.53	-0.1	-	3.1	-0.71	***
Land-labor ratio (hectares)	3.87	1.06	***	2.65	3.85	-
Growth in land/worker (%)	0	-0.74	-	1.45	-1.9	***
Tractor eq. per 1000 workers	18.2	2.5	**	12.39	21	-
Growth in machinery/worker (%)	0.4	-0.72	*	0.77	-0.79	*
Output growth (%)	2.05	2.6	-	4.53	1.11	***
TFP growth (%)	1.01	0.04	*	1.7	0.1	***
Total input growth (%)	1.04	2.56	***	2.83	1.01	***
Agricultural land growth (%)	0.52	1.92	*	2.91	-0.08	***
Growth in irrigated area (%)	1.94	0.85	-	1.96	0.54	*
Growth in labor use (%)	0.52	2.67	***	1.45	1.82	-
Growth in animal stock (%)	1.14	2.29	*	2.63	0.94	**
Growth in machinery (%)	0.91	1.95	-	2.22	1.03	-
Growth in fertilizer use (%)	2.92	5.05	*	6.19	3.12	**
Growth in the use of feed (%)	2.51	4.54	-	6.03	0.92	***
Growth in fertilizer per hectare (%)	2.55	3	-	3.02	3.31	-
Growth in feed/cow-equivalent (%)	1.37	2.25	-	3.4	-0.02	**

Source: Authors' elaboration based on World Bank (2021)

Notes: ***p<0.01, **p<0.05, *p<0.1. Poverty alleviation high performing: Tunisia, Algeria, Gambia, The, Morocco, Cabo Verde, Mauritania, Ghana, Namibia, Gabon, Botswana, Mauritius, Cameroon, Ethiopia, Burkina Faso, South Africa, Lesotho. Poverty alleviation poor performing countries are: Central African Republic, Congo, Dem. Rep., Djibouti, Burundi, Togo, Benin, Guinea-Bissau, Cote d'Ivoire, Malawi, Kenya, Madagascar, Zambia, Angola, Egypt, Zimbabwe. Hunger alleviation high performers: Angola, Benin, Cameroon, Algeria, Ethiopia, Ghana, Mali, Sudan, Senegal, Sierra Leone, Togo, Tunisia. Hunger alleviation poor performers: Botswana, Congo, Rep., Cabo Verde, Gabon, Liberia, Lesotho, Madagascar, Mauritania, Namibia, Nigeria, Eswatini, South Africa