Measuring Innovation in Agriculture and Food Systems

Agriculture and food innovation systems are complex and constantly evolving. Today robotics and biotechnological and digital technologies are applied in agriculture and food systems. New actors enter the systems and traditional actors, such as farmers and food companies, grow into commercial farmers, bio/organic producers, and so on.

Agriculture and food systems also vary greatly across countries, reflecting each country's level of development as well as the role that agriculture and food sectors play.

Measuring agricultural innovation is challenging for several reasons:

First, agriculture and food systems span many different sectors, products, and service groups that are not easily grasped and that go far beyond the agriculture sector or agricultural farms alone. As Chapter 1 and the other substantive chapters of this report show, innovations occur along the value chain and involve (1) agricultural inputs such as fertilizers and seeds, at times coming from the chemical or the biotechnology sector; (2) product innovations coming from the capital goods sector; and (3) process or organizational innovations in the fields of payments, logistics, and distribution services coming from the banking, transport, and retail sectors.

Second, key innovation data sources such as the innovation surveys based on the *Oslo Manual* focus on the manufacturing and services sectors, thus excluding agriculture for the most part.[1] Although the agriculture sector is likely to be included in future revisions of the *Oslo Manual,* it is currently unclear whether the coverage of the business sector alone will satisfy the innovation data requirements of the agriculture sector.

Third, in developing countries, agricultural activities and related innovations often take place at the farm or household level (especially in case of subsistence farming), not in private-sector firms as captured by most data collections. Statistically, however, capturing activity in the informal sector or at the grassroots level is challenging.[2]

Clearly, the work of the African Union–New Partnership for Africa's Development (AU-NEPAD) on the African Innovation Outlook,[3] and application of innovation surveys, for example, is ongoing.[4] Yet the focus is currently not on the informal or the agriculture sector.

As a result of the complexities outlined above, and because of a lack of robust metrics (see Chapter 2), measuring innovation in agriculture and food systems is a difficult endeavour. This annex maps agriculture and food systems based on the GII framework.

Although incomplete, this mapping illustrates the above challenge and provides guidance to researchers and policy makers interested in benchmarking their agriculture and food systems. It also shows how the GII framework could be adapted to measuring innovation in specific systems and sectors, thereby laying the foundations for interesting future work.

Potential indicators to benchmark innovation in agriculture and food systems

Table 1 shows how the GII framework could be used to measure the characteristics of agriculture and food innovation systems. The table includes only the indicators that are relevant to measuring innovation in agriculture and food systems and that are available for a large number of economies.[5] The next sections look into some of these indicators and provide snapshots of top performing economies in each selected indicator.

Human capital and research

Education and research and development (R&D) investment are key to boosting productivity; they are also key for advancing the agriculture and food sector.[6,7] Various studies demonstrate that better-educated farmers have the skills to run their farms more efficiently and are more prone to embracing innovation.[8] Education has also proven to spill over, affecting the productivity of family members and neighbours.[9]

In spite of its role in agriculture and food systems, data on farmers' education are limited. This has led researchers to use other proxies, such

Table 1: Adapting the GII framework to agriculture and food systems

GII pillar	GII indicator	Are indicators available for agri-food?	Corresponding indicator in agri-food	Additional indicators
Human capital and research	Expenditure on education	For only a few economies	—	—
	Tertiary enrolment	Yes	Tertiary students in agriculture programmes	—
	Graduates in science & engineering	Yes	ODA for agricultural education/training	—
	Researchers	Yes	Agricultural researchers	—
	Gross expenditures on R&D	Yes	Agricultural R&D expenditures	ODA for agricultural research
	Global R&D companies, average expenditure	No	—	—
	QS university rankings	No	—	—
Market sophistication	Ease of getting credit	For only a few economies	—	—
	Domestic credit to private sector	Yes	Credit to agriculture	—
	Microfinance gross loans	For only a few economies	—	—
	Venture capital deals	No	—	—
	Applied tariff rate	Yes	Applied tariff rate for agriculture and food items	—
	Intensity of local competition	No	—	—
Business sophistication	Knowledge-intensive employment	—	—	—
	Firms offering formal training	Yes	Firms offering formal training in food-processing	—
	GERD performed by business	For only a few economies	—	—
	GERD financed by business	No	—	—
	Females employed w/ advanced degrees	No	—	—
	University/industry research collaborations	No	—	—
	State of cluster development	No	—	—
	GERD financed by abroad	No	—	—
	JV-strategic alliance deals	No	—	—
	Patent families in 2+ offices	Yes	Agri-food patent families in 2+ offices	—
	IP payments	No	—	—
	High-tech imports	Yes	High-tech imports for agri-food sector	Use of fertilizers; Machinery in use
	FDI net inflows	Yes	Agri-food FDI inflows	—
Knowledge and technology outputs	Patents by origin	Yes	Agri-food patents by origin	Plant varieties registered
	PCT patent applications	Yes	Agri-food PCT patent applications	—
	Utility models by origin	Yes	Agri-food utility models by origin	—
	Scientific and technical articles	Yes	Scientific and technical articles in agri-food	—
	Citable documents H index	Yes	Citable documents in agri-food	—
	Growth rate of PPP$ GDP/worker	Yes	Agriculture labour productivity growth	—
	New businesses	No	—	—
	ISO 9001 quality certificates	No	—	—
	IP receipts	No	—	—
	High-tech exports	Yes	Agri-food exports	—
	FDI net outflows	Yes	Agri-food FDI outflows	—
Creative outputs	Trademarks	Yes	Agri-food trademarks	Geographic indications registered
	Industrial designs	Yes	Agri-food industrial designs	—
	ICTs & business model creation	No	—	—
	ICTs & organizational model creation	No	—	—

Notes: The GII pillars Institutions and Infrastructure are not included in this table because the metrics in those pillars already capture the role of institutions and infrastructure in agriculture and food systems. ODA = official development assistance; — = data currently under review.

Table 2: Official development assistance for education and training: Top five economies

Economy	ODA in US$, millions
Afghanistan	8.2
Ethiopia	4.6
China	4.3
Indonesia	4.1
Uganda	3.4

Data source: FAOstats, February 2017. Available at http://www.fao.org/faostat/en/.

Note: Data refer to total disbursements from bilateral and multilateral donors for 2014.

Table 3: Agricultural R&D expenditures: Top five economies

Economy	US$, thousands	Economy	Share of agriculture value added
India	3,857	Singapore	1.48
Korea, Rep.	1,521	Qatar	0.11
China	1,149	Netherlands	0.10
Netherlands	1,145	Trinidad and Tobago	0.10
Australia	842	Denmark	0.06

Data source: UNESCO-UIS Science & Technology Data Center, February 2017. Available at http://data.uis.unesco.org/.

Notes: Where data are not available, data from previous years are used. R&D expenditures are in 2005 PPP$. Data are available for 73 economies. Many Organisation for Economic Co-operation and Development (OECD) economies, including the United States of America (USA), as well as other large economies such as Argentina and Brazil, are excluded because of a lack of data.

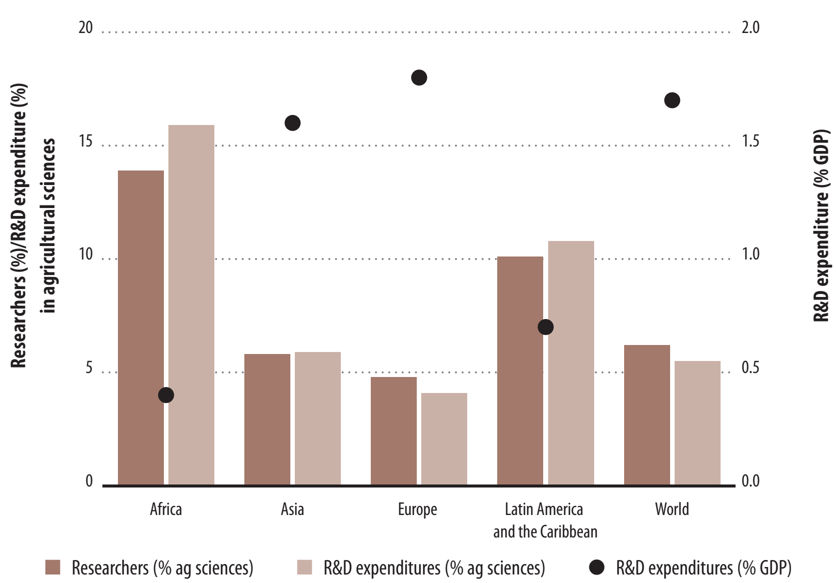
as official development assistance (ODA) for education and training (see Table 2). According to available data, Afghanistan, Ethiopia, China, Indonesia, and Uganda receive the highest amounts of aid in agricultural education and training. Other top recipients include Malawi, Myanmar, and Sierra Leone.

Lagging R&D expenditures in high-, middle-, and low-income economies affect productivity growth and innovation in agriculture. According to the data available, only about 6% of the world's R&D investments and researchers are devoted to agricultural sciences (see Figure 1).[10] Although advanced economies have historically been the leaders in agricultural R&D, research capacity has also reached high standards in several emerging economies—such as China, India, Brazil, Argentina, and South Africa.[11] In agriculture, R&D affects output with a long lag, but the impact lasts for a long time.[12] R&D spillovers tend to be geographically bounded because innovations produced in one part of the world require adaptations to work well in local soil and climate conditions. This makes indigenous R&D efforts essential. Developing countries, especially in Sub-Saharan Africa, have traditionally underspent in agricultural R&D (see Chapter 2). When they undertake R&D, poor (or lacking) extension services generally delay the adoption of innovation.[13] Indeed, research demonstrates that developing countries that invested the most in R&D while simultaneously investing in extension have had the strongest productivity leap.[14]

Overall, the top agricultural R&D spenders are India, the Republic of Korea (Korea), China, the Netherlands, and Australia (see Table 3), with India spending more than double than Korea. Singapore spends the most in relation to the size of its agriculture sector (as measured by value added), investing roughly 150% of its output in R&D. Qatar, the Netherlands, and Trinidad and Tobago follow, with roughly 10% of their agricultural output spent in R&D. Denmark spends 6% of its agricultural output in R&D.

Another way to look at R&D is through ODA disbursements to agricultural research. Nigeria, Argentina, India, Uganda, and Ethiopia are the largest recipients of ODA in this

Figure 1: Researchers and R&D expenditure in agriculture sciences



Data source: UNESCO-UIS Science & Technology Data Center, February 2017. Available at http://data.uis.unesco.org/.

Notes: Data on researchers in agricultural sciences are based on headcount (HC) measurement. Because of a lack of data, Northern America is missing. Data refer to 2014.

Table 4: ODA to agricultural research: Top five economies

Economy	ODA (US$, millions)
Nigeria	30.3
Argentina	28.2
India	24.0
Uganda	16.9
Ethiopia	16.9

Data source: FAOstats, February 2017. Available at http://www.fao.org/faostat/en/.

Note: Data refer to total disbursements from bilateral and multilateral donors for 2014.

Table 5: Tertiary students in agricultural studies: Top five economies

Economy	Share of tertiary students (%)
Ethiopia	8.0
Uzbekistan	7.5
Cambodia	6.8
Viet Nam	6.4
Albania	6.3

Data source: UNESCO-UIS Science & Technology Data Center, February 2017. Available at http://data.uis.unesco.org/.

Notes: When data for 2014 were not available, data points up to 2008 were used.

Table 6: Agricultural credit markets: Top five economies

Economy	US$, millions	Economy	Share of total credit (%)
United States of America	74,951	New Zealand	26
Germany	57,983	Uruguay	17
Australia	54,968	Kyrgyzstan	12
France	54,812	Tajikistan	12
New Zealand	44,903	Bolivia, Plurinational St	11

Data source: FAOstats, February 2017. Available at http://www.fao.org/faostat/en/.

Note: Data for 2014, available for 69 economies.

area. Argentina is the only top ODA recipient among upper-middle-income economies, while the others are mostly low- and lower-middle-income economies. Among the top 10 recipients are Kenya, the United Republic of Tanzania, and Indonesia, which each received more than US$10 million. Finally, ODA to agricultural research reaches much higher values than ODA to agricultural education and training (see Table 4).

Data on the share of tertiary students enrolled in agricultural studies indicate that agricultural studies are particularly relevant in the developing world. The top five highest shares of agricultural students in tertiary students are in Ethiopia, Uzbekistan, Cambodia, Viet Nam, and Albania (see Table 5). Other countries with high shares of agricultural students in total graduates include Malawi, Sierra Leone, Eritrea, and Kenya.

Market sophistication

Financial markets are important components of any innovation system. In agriculture, credit is essential to modernize farms and access high-quality inputs such as seeds and fertilizers. Given the size and nature of most farms, credit constraints can be often severe.[15] According to available data, the countries with the largest credit markets for agriculture are the USA, Germany, Australia, France, and New Zealand (see Table 6). It is worth recalling that these economies have very large credit markets. Indeed, in the GII, New Zealand, the USA, and Australia rank among the top five economies in the Credit sub-pillar. Still, New Zealand is the country that allocated the highest portion of its credit to agriculture (26%). Uruguay, Kyrgyzstan, Tajikistan, and the Plurinational State of Bolivia are the other top economies.

Business sophistication

The adoption of synthetic fertilizers, together with high-yield crop varieties, has been at the basis of the green revolution. Today, despite the growing demand for organic food, less than 1% of agricultural land is farmed using organic methods.[16] Although organic farming has a number of advantages, synthetic fertilizers are still widely used.[17]

Limited access to high-quality fertilizers is still an issue in many countries, most notably in Sub-Saharan Africa (see for example the case of Uganda, described in Chapter 11). Estimates indicate that, from 2009 to 2015, global demand for fertilizers grew by roughly 15%, and will grow at least 1.6% annually from 2015 to 2020. Sub-Saharan Africa will be responsible for most of this growth, reaching an average annual growth rate of 4.4%.[18]

Data on current fertilizer consumption show that global consumption is highly concentrated, with one single economy—China—consuming 31% of total world fertilizers (see Table 7). Although the gap in fertilizer consumption between China and other economies is considerable, according to available data, other top fertilizer consumers are India, the USA, Brazil, and Indonesia. By contrast, Sub-Saharan African countries together account for only 3% of total world consumption. Considered in relation to arable land, Qatar, Malaysia, Hong Kong (China), New Zealand, and Bahrain are the five top consumers; other important consumers include Singapore, Costa Rica, the United Arab Emirates, and Colombia.

Mechanization of agriculture has also contributed greatly to productivity growth in agriculture. Estimates indicate that the economies with the highest number of machines in their agricultural lands

Table 7: Fertilizer consumption: Top five economies

Economy	Share of world consumption (%)	Economy	Tonnes of nutrients per hectare of arable land
China	30.9	Qatar	12,111
India	13.4	Malaysia	2,064
United States of America	11.0	Hong Kong (China)	1,966
Brazil	7.3	New Zealand	1,491
Indonesia	2.6	Bahrain	1,319

Data source: FAOstats, February 2017. Available at http://www.fao.org/faostat/en/.

Notes: Data refer to 2014. Fertilizers include nitrogen, phosphate, and potash.

Table 8: Machinery in use: Top five economies

Economy	Machinery in use (number)
China	10,802,121
India	5,960,636
United States of America	4,351,616
Japan	2,112,822
Poland	1,539,059

Data source: U.S. Department of Agriculture (USDA), International Agricultural Productivity Data, February 2017. Available at https://www.ers.usda.gov/data-products/international-agricultural-productivity/.

Table 9: Agriculture and food FDI net inflows: Top five economies

Economy	Agri-food FDI (US$, millions)	Economy	Agriculture FDI (US$, millions)	Economy	Food FDI (US$, millions)
United Kingdom	19,186.1	China	1,112.1	United Kingdom	19,093.4
Italy	5,728.7	Brazil	426.7	Italy	5,746.7
Brazil	3,211.4	Ghana	348.8	Brazil	2,784.7
China	2,371.0	Argentina	259.4	Sweden	1,962.9
Sweden	1,962.9	Russian Federation	215.8	Turkey	1,700.5

Data source: FAOstats, February 2017. Available at http://www.fao.org/faostat/en/.

Notes: 'Agriculture' includes agriculture, forestry, and fishing. 'Food' includes food, beverages, and tobacco. Data refer to 2012; where data are missing, they refer to 2011, 2010, or 2009. FDI values are expressed in US$, 2005 prices.

are China, India, the USA, Japan, and Poland, with China and India respectively accounting for 25% and 14% of all world agricultural machinery in use (see Table 8). Italy, Thailand, France, Turkey, and Brazil also stand out in the use of machinery in agriculture.

Although these statistics are extremely interesting, in the future, metrics on the use of drones and other autonomous vehicles might also be useful in assessing the innovativeness of agriculture and food innovation systems. According to recent estimates, the market for drone-powered solutions in agriculture is US$32.4 billion—25% of the total drone application market.[19] Drones and robots can be integrated at every stage of the production cycle: they can be used for soil analysis, seed planting, spraying, and weed removal. They are more accurate and efficient than previous technologies such as satellite imagery and traditional tractors, allowing for productivity gains and cost savings.

The last indicator on business sophistication reviewed in this annex is foreign direct investment (FDI) net inflows. Some agricultural and food innovation systems prove to be well integrated in international knowledge networks, receiving considerable FDI. The United Kingdom, Italy, Brazil, China, and Sweden are the top five recipients of FDI inflows in food and agriculture, driven by FDI in food processing (except for China). Ghana, Argentina, and the Russian Federation are among the top five FDI recipients in the agriculture sector, while Turkey is the fifth FDI recipient in food processing (see Table 9).

Knowledge and technology outputs

This section looks at agricultural labour productivity growth, agriculture and food exports, and patents in technological fields related to agriculture and food.[20]

The top five economies in terms of agricultural labour productivity growth are Slovenia, Bahrain, Luxembourg, Armenia, and Belgium (see Table 10). Others that stand out include Bosnia and Herzegovina, Senegal, and Morocco.

Data on agricultural exports are widely available through the UN Comtrade database, which covers almost all economies in the world and allows for a highly disaggregated analysis. According to these data, a mix of high- and middle-income economies are among the top five exporters of agricultural and food products. The USA leads this ranking,

Table 10: Agricultural labour productivity growth: Top five economies

Economy	Growth rate of agriculture value added per worker
Slovenia	34.6
Bahrain	29.2
Luxembourg	19.9
Armenia	16.6
Belgium	15.8

Data source: World Bank's World Development Indicators, February 2017, available at http://data.worldbank.org/data-catalog/world-development-indicators.

Note: Data refer to agriculture value added per worker (constant 2010 US$).

Table 11: Agriculture and food exports: Top five economies

Economy	Share of agriculture and food exports (%)
United States of America	10.2
Netherlands	6.4
Germany	5.8
Brazil	5.4
China	5.0

Data source: UN Comtrade Database, February 2017. Available at https://comtrade.un.org/.

Note: Data refer to 2-digit commodities codes, and include commodities from 01 to 24.

Table 12: PCT applications in agriculture and food: Top five economies

Economy	Total applications
United States of America	4,821
Japan	2,142
China	1,418
Germany	948
Korea, Rep.	798

Data source: WIPO Statistics Database, May 2017.

Note: Data refer to 2016.

Table 13: Plant variety applications: Top five economies

Economy	Total applications
Netherlands	2,720
China	2,100
United States of America	2,027
France	1,038
Germany	942

Data source: WIPO, 2016.

accounting for 10% of total world agri-food exports. The Netherlands, Germany, Brazil, and China follow with shares of between 6% and 5% (see Table 11). Other European economies—namely France, Spain, Italy, and Belgium—follow. Among emerging economies, Argentina, India, and Indonesia stand out.

The top five economies in agri-food patent applications by origin are the USA, Japan, China, Germany, and Korea (see Table 12). Other important players in agri-food PCT patenting are Switzerland, the Netherlands, the United Kingdom, France, and Italy.

Early high-yielding varieties of wheat and rice led to the most significant improvements in crop yields in the 20th century (see Chapters 3 and 10). The green revolution enabled developing economies to import cheaper grains and grow high-yield seed varieties, which were responsive to fertilizers and resistant to diseases and insects. Productivity gains from high-yield varieties are not over. First, new innovations—for example, in genome-editing technologies—are expected to drive the development of ground-breaking crop varieties that could not be obtained by traditional breeding (see Chapter 8). Second, the diffusion of seeds and new plant varieties can still bring considerable advantages, as demonstrated in the case of Bt cotton cultivation in India (see Chapter 5), or in the case of soybeans, corn, and cotton in Latin America and the Caribbean (see Chapter 10).

Yet research shows that the knowledge accumulated in the development of new plant varieties is often tacit and difficult to appropriate.[21] Innovation in plant varieties tends to be cumulative, meaning that prior knowledge is needed to come up with new innovations. The adoption of new plant varieties also depends on the efforts to adapt innovation developed elsewhere to breed locally suitable varieties.[22] These characteristics may make intellectual property protection of new plant varieties a critical issue. The legislation on plant variety protection is increasingly being adopted in low-, middle-, and high-income countries.[23] WIPO data show that, since the early 2000s, plant variety application filings grew rapidly, with middle-income economies—especially in Asia—contributing to global figures more and more frequently.[24]

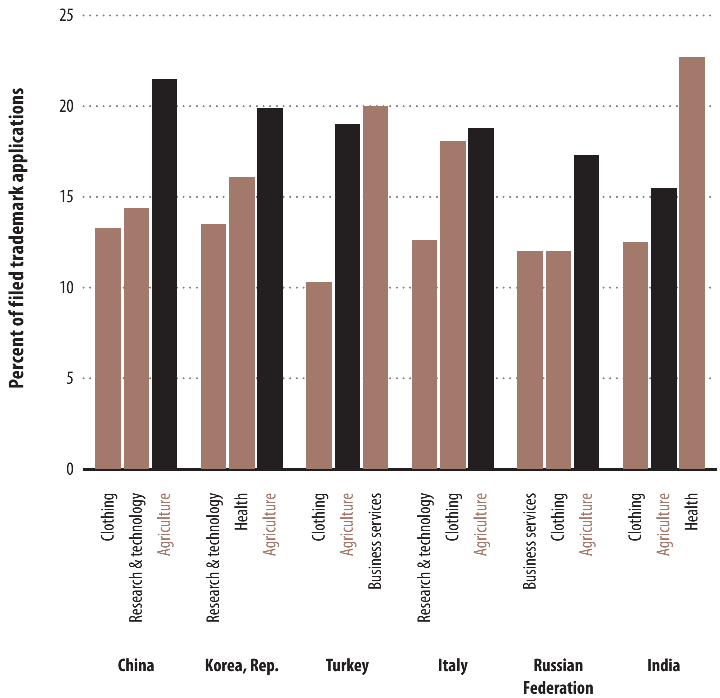
Top filers of plant variety applications are the Netherlands, China, and the USA, followed by France and Germany (see Table 13). Other important applicants are Japan, Korea, the Russian Federation, Ukraine, and Australia.

Creative outputs

The creative outputs of agriculture and food systems can be measured through trademarks and geographic indications.

Looking at trademarks, Nice classes 29, 30, 31, 32, 33, and 43 are typically associated with the agri-food sector.[25] Still, identifying the Nice classes that capture agriculture and food is a complex task because various other Nice classes can potentially contain agriculture- and food-relevant trademarks. For example, Nice class 1 includes genes of seeds for agricultural production and agricultural chemicals; Nice class 7 includes agricultural elevators and machines; and Nice class 44 includes

Figure 2: Trademark applications: Top three sectors by country origin



Data source: WIPO, 2016.

Notes: Data refer to 2015. The top three sectors and top origins were selected based on their 2015 totals.

agriculture, horticulture, and forestry services.

Data on trademark applications indicate that Nice class 30—which collects trademarks in coffee, tea, cocoa, rice, and other food products—is the 6th largest Nice class, comprising 4.6% of all trademark applications filed in 2015. Services for providing food and drink (Nice class 43) ranks 8th, with 3.8%. Finally, Nice class 29 (foodstuffs of animal origin and vegetables) ranks 10th, with 3.7% of all trademark applications. Overall, Nice classes 29, 30, 31, 32, 33, and 43 account for 17.3% of all trademark applications.[26] In China, Korea, Turkey, Italy, the Russian Federation, and India, the agriculture sector is in the top three sectors for trademark applications (see Figure 2).

Notes

1 OECD and Eurostat, 2005.

2 Charmes et al., 2016.

3 AU-NEPAD, 2010; NPCA, 2014.

4 For example, NEPAD's African Science Technology and Innovation Indicators (ASTII) contribute to the development and use of science, technology, and innovation indicators in African countries.

5 Agriculture and food innovation systems rely on nation-wide regulations, infrastructures, and education systems that are common for the economy and are therefore captured by the GII. These indicators are not reported in Table 1.

6 This section has benefited from contributions from our colleagues from the UNESCO Institute for Statistics (UIS) Martin Schaaper, Rohan Pathirage, and Luciana Marins.

7 Alston et al., 2000; Alston, 2010; Hayami and Ruttan, 1970; Kawagoe et al., 1985; Lau and Yotopoulos, 1989; Reimers and Klasen, 2013.

8 Adrian et al., 2005; Knight et al., 2003; Wheeler, 2008.

9 Knight et al., 2003; Weir and Knight, 2004.

10 Africa stands out as the region with the highest proportion of resources committed to agricultural sciences (16% of the region's total R&D expenditure). This is followed by Latin America and the Caribbean (11%), ahead of Asia (6%) and Europe (4%), indicating that middle- and low-income economies allocate more resources to agricultural sciences, whereas high-income focus more on other fields—notably natural sciences and engineering. These figures, however, should be taken with caution because of numerous data gaps.

11 Ruttan, 2002.

12 Alston, 2010.

13 Alston, 2010.

14 Fuglie, 2012. In developing countries, the public sector is still the main source of extension services, although they are plagued by limited funding, insufficient technologies and skills, weak links with research institutes, and limited farmer participation (World Bank, 2005).

15 FAO, 2016.

16 Data from FAOstats, available at http://www.fao.org/faostat/en/.

17 Moreover, modern technologies are optimizing their usage, thus reducing their environmental consequences (see Chapter 4).

18 FAO, 2016.

19 PwC, 2016.

20 Technological fields are selected following Lippoldt (2015).

21 Olmstead and Rhode, 2008.

22 Evenson and Gollin, 2003.

23 Campi and Nuvolari, 2015.

24 WIPO, 2016. See also FAO et al., 2009. On plant variety protection, see http://www.upov.int.

25 WIPO, 2016. The Nice Classification, established by the Nice Agreement (1957), is an international classification of goods and services applied for the registration of trademarks.

26 WIPO, 2016.

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