# The Potential of a Global Diagnostic Tool for Agricultural Innovation Systems

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Eradicating hunger and malnutrition, improving rural livelihoods, and protecting the environment in the context of the global trends and challenges (e.g., population growth, climate change, land degradation) that shape agriculture and food systems worldwide will require creative solutions. Innovative responses to complex issues are needed to accelerate progress towards achieving the UN Sustainable Development Goals (SDGs). Innovation, be it technological, institutional, or social, emerges from collective thinking, iterative learning, and action. It is a process by which multiple actors and stakeholders collectively put knowledge to use.[1] Innovation outcomes—such as poverty reduction, increases in agricultural productivity, and resource use efficiency—are determined by the properties and capacities of the system in which organizations or individuals operate and engage with each other. Effective and dynamic systems are likely to generate more effective and relevant innovation outcomes. In addition to enhanced investments, policies, and technologies, a balanced strategy for sustainable agricultural productivity growth in developing countries involves strengthening agricultural innovation systems (AIS).[2]

## Agricultural innovation systems

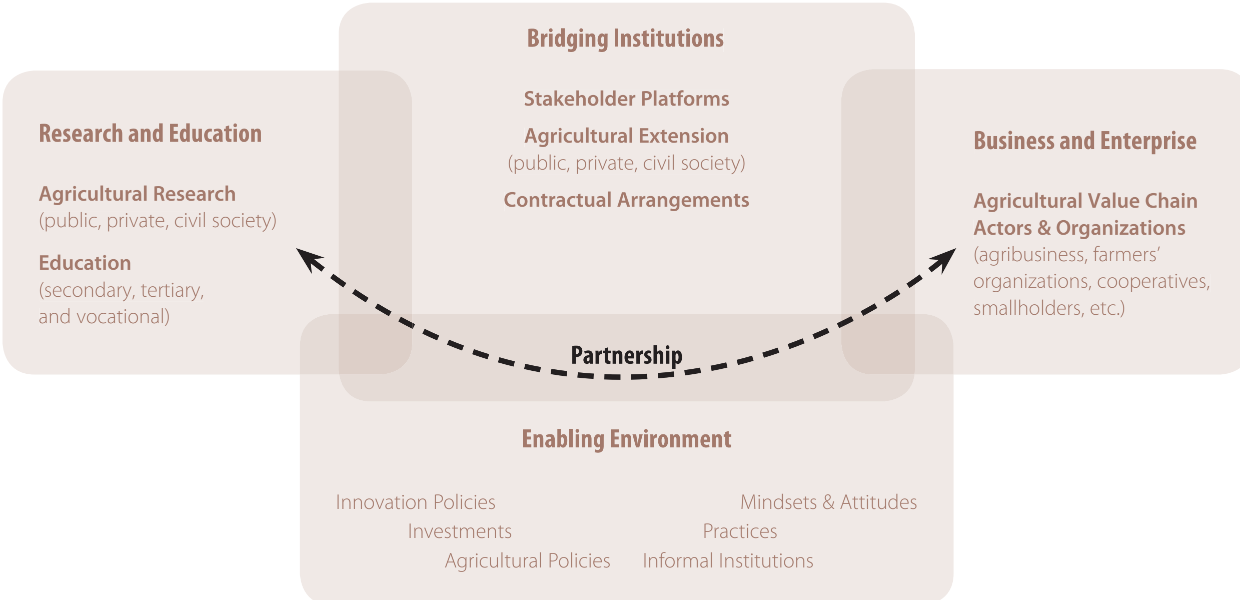
AIS can be understood as a network of actors (organizations and individuals), together with supporting institutions (formal and informal) and policies in the agricultural and related sectors that brings existing or new products, processes, and forms of organization into social and economic use.[3] System thinking is firmly established in the agriculture and rural development disciplines, and the AIS concept is widely recognized among researchers.[4] Adopting an AIS perspective for agricultural development issues is also becoming more commonplace beyond academia in international agencies and fora, donor organizations, and government outfits.[5]

Based on a conceptual model proposed by Arnold and Bell (2001) and further refined by Spielman and Birner (2008) and Spielman and Kelemework (2009), four primary AIS domains comprising public, civil society, and private-sector actors are proposed: (1) research and education, involving research institutes, universities, and vocational training centres; (2) business and enterprise, involving various value chain actors, agribusiness, producers, and consumers; (3) bridging institutions, involving stakeholder platforms, contractual arrangements, and various types of rural advisory services; and (4) an enabling environment, involving governance and policies as well as behaviours, mindsets, and attitudes (Figure 1). The actors in the system engage in collective action at various levels, from local to global, and with various objectives, be it a product, process, or any other type of innovation.

## Requirements for a robust AIS assessment

Assessing agricultural innovation system properties and performance is not a straightforward exercise. Whereas much emphasis has been put on analysing and assessing the overall role of agricultural research and of extension and rural advisory services, relatively little attention has been paid to the system-wide analysis (e.g., understanding AIS actors' linkages and relationships and how these shape AIS performance), or to developing a broader diagnostic tool for assessing national agricultural innovation systems. AIS assessment has the potential to inform decision-makers about strengths, gaps, and opportunities in capacity development and investment. It can also be instrumental in meeting monitoring and evaluation requirements. A transition towards

**Figure 1: Representation of the agricultural innovation system**




Source: Adapted from TAP, 2016, with permission from CAB International 2016.

sustainable growth in the food and agriculture sectors needs evidence on what works and what does not.[6]

In recent years, countries have started to recognize the critical role that innovation plays and will continue to play in achieving the SDGs. During the 25th Session of the Committee on Agriculture (COAG) of the Food and Agriculture Organization of the United Nations (FAO),[7] countries explicitly requested support for the assessment of their innovation systems, in particular through the development of a diagnostic tool.

Data related to different aspects of AIS are available from a wide range of sources. These include FAO, the International Food Policy Research Institute (IFPRI), the Organisation for Economic Co-operation and Development (OECD), the World Bank, the World Economic Forum (WEF), and the World Intellectual Property Organization (WIPO). Existing datasets include information, for example, on public spending and foreign aid for agricultural research and extension, ease of access to loans, and costs associated with agricultural policies. For a more comprehensive assessment, macro-level indicators measuring rather static properties and performance can be complemented by indicators that capture systems dynamics.[8] These can help to understand how far a system is integrated, heterogeneous, and demand-driven.

The AIS concept puts great emphasis on understanding the nature of relationships and interactions between actors and the knowledge, attitudes, and practices that shape these relationships. However, such information is not readily available.

This chapter explores the potential for a diagnostic tool to assess national agricultural innovation systems. Such a diagnostic tool needs to be geared towards identifying enabling and hindering factors that affect the performance of the system, with the aim of improving its overall performance to respond to the needs of its actors and stakeholders. More specifically, the chapter provides insights into data availability and discusses options for additional data gathering and validation.

## Data considerations

Underpinning all these elements is the availability of good and up-to-date data. Good data are both essential and difficult to identify.

### Overview of available information

The complexity of the AIS concept poses challenges in terms of methods and data. The literature on innovation systems in agriculture has been making valuable contributions to the understanding of the role of AIS, mostly through the use of descriptive and case study methods,[9] while usually avoiding the use of more formal models and macro-level analysis.

More systematic assessment approaches are, however, gaining traction.[10] A quantitative diagnostic of AIS at the country level or across a set of countries has been proposed by Spielman and Kelemework (2009) and Mekonnen et al. (2015). For their study of the determinants of technical efficiency in agriculture, Mekonnen et al. (2015) collected a dataset on innovation system properties covering 85 low- and middle-income countries from 2004 to 2011. The results illustrate how a global analysis of AIS can contribute to a better understanding of key agricultural development challenges. At the same time, the study shed light on some of the difficulties related to obtaining meaningful and comprehensive aggregate data on agriculture-specific innovation system properties. In terms of the explained variable, Mekonnen et al. decided to resort to technical efficiency. They point out that the innovation system properties selected for their study are expected to have a positive influence on the efficiency of agricultural production. The quality of institutions and legal systems as well as factors enabling business and enterprise influence the nature and performance of public- and private-sector innovation processes.

Table 1 on page 84 compiles available information that is of potential use for global AIS analysis. These are indicators that have already been used in the literature. As shown in the bottom part of the table, a range of AIS outcome indicators other than technical efficiency are available—for example, eco-efficiency and total factor productivity (TFP)—or simpler metrics, such as the value of agricultural production or agricultural exports. This wide range of indicators demonstrates the need to draw on records from a variety of sources to create a comprehensive database. The compilation reveals that several indicators pertain to innovation at large and are not specific to the agricultural sector. In the absence of more accurate data, these are considered proxies for AIS characteristics. At the same time, they represent spillovers from what shapes innovation in general to the agricultural innovation system, which are important to take into account. Several of the indicators shown in Table 1 have been used in the studies by Spielman and Kelemework (2009) and Mekonnen et al. (2015), while other variables—such as public spending on extension and research-extension collaboration—were not considered previously but have been added here, as deemed relevant. The IFPRI/ASTI database records numbers of researchers and public spending on research in agriculture but falls short of providing any indicators on the relevance and demand-orientation of agricultural research.[11]

Three criteria were applied for selecting variables: (1) the indicator must be a potential parameter to assess innovation processes in agriculture; (2) the data must be openly accessible; (3) the level of data coverage across countries and years must be high (for most countries less than 20% of data are missing between 2000 and 2014). For any assessment of AIS on the basis of the data presented here, it is crucial to take into account issues regarding the quality and informative value of the data. Rather than focusing the analysis on single years or averages, data trends as well as variability, especially in the case of financial flows, should be at the core of an innovation system diagnostic.

### AIS properties

Although a range of useful indicators has been identified, it becomes clear that many gaps exist—for example, gaps in data on rural advisory services and farmer organizations. Some indicators capture generic innovation system properties but lack precision in the context of analysing AIS. In Table 2 on page 85, additional indicators are proposed that would be desirable for a more accurate and in-depth diagnosis of AIS. The indicators listed here by no means present an exhaustive list but serve to draw attention to how some important gaps could potentially be filled. Data on these indicators exist but are available only for a limited number of countries. Furthermore, data from national sources or surveys exist for selected countries but require considerable effort to make them comparable cross-country.

In Tables 1 and 2, the AIS properties variables were attributed to one of the four AIS domains to reflect how they capture the education and research levels, business and enterprise development, bridging institutions, and enabling environment aspects of the assessment. This categorization, however, falls short of making an important distinction that is of great relevance for any AIS analysis. Indicators can represent either more actor-oriented and static AIS characteristics or more system- and action-oriented properties. In addition, a distinction can be made in terms of specificity. While some indicators can be considered more generic, applying to innovation systems in general, others are more specific to innovation systems in the agricultural sector.

The following indicators can be classified as representing mostly static and generic properties: health expenditures, foreign aid received, total tax rate, patent applications, scientific and technical journal articles, domestic credit to the private sector, and the credit information index.

A range of indicators can be classified as representing mostly static but fairly agriculture-specific properties: farmer organization membership, extension service providers, extension

### Table 1: Selected easily accessible variables of relevance for global AIS analysis

| Domain | Indicators | Analytical focus | Unit | Sources |
|---|---|---|---|---|
| **AIS PROPERTIES** | | | | |
| **Research and education** | Quality of the education system | Trend | 1 (low) to 7 (high) | WEF, GCR data |
| | Foreign aid for agricultural education/ training | Trend, variability | % of agriculture GDP | OECD, DAC data |
| | Quality of scientific research institutions | Trend | 1 (low) to 7 (high) | WEF, GCR data |
| | Agricultural researchers | Trend | FTEs per 100,000 farmers | IFPRI, ASTI data |
| | Agricultural research spending | Trend, variability | % of agriculture GDP | IFPRI, ASTI data |
| | Foreign aid for agricultural research | Trend, variability | % of agriculture GDP | OECD, DAC data |
| | Patent applications | Trend | Number per 1,000,000 people | WIPO data |
| | Scientific and technical journal articles | Trend, variability | Number per 100 researchers | WB, WDI data |
| **Bridging institutions** | University-industry collaboration in R&D | Trend, variability | 1 (minimal) to 7 (intensive) | WEF, GCR data |
| | Foreign aid for extension | Trend, variability | % of agriculture GDP | OECD, DAC data |
| **Business and enterprise** | Start-up procedures to register a business | Trend | Number | WB, WDI data |
| | Time required to start a business | Trend | Days | WB, WDI data |
| | Total tax rate | Trend | % of commercial profits | WB, WDI data |
| | Ease of accessing loans | Trend | 1 (low) to 7 (high) | WEF, GCR data |
| | Domestic credit to private sectors | Trend, variability | % of GDP | WB, WDI data |
| **Enabling environment** | Credit information index | Trend | 0 (low) to 8 (high) | WB, WDI data |
| | Credit to agriculture | Trend, variability | % of total credit | FAOSTAT data |
| | Government expenditure on agriculture | Trend, variability | % of total outlays | FAOSTAT data |
| | Agricultural policy costs | Trend | 1 (low) to 7 (high) | WEF, GCR data |
| | Foreign aid received | Trend, variability | Current international US$ per capita | OECD, DAC data |
| | Foreign aid for agriculture | Trend, variability | % of agriculture GDP | OECD, DAC data |
| | Gross capital formation | Trend | % of GDP | WB, WDI data |
| | Health expenditures | Trend, variability | % of GDP | WB, WDI data |
| **AIS OUTCOMES** | | | | |
| Domain | Indicators | Analytical focus | Unit | Sources |
| **Results** | Agricultural output | Level, growth | Tons per hectare / % | FAOSTAT data |
| | Value of agricultural output | Level, growth | Current international US$ per hectare / % | FAOSTAT data |
| | Value of agricultural exports | Level, growth | % of agricultural output | FAOSTAT data |
| | Total factor productivity[a] | Growth | Index | FAOSTAT data (calculation required); USDA, ERS |
| | Eco-efficiency | Level, growth | 0 (low) to (1high) / % | FAOSTAT data (calculation required) |
| | Rural poverty | Trend | % of rural population | WB, WDI data |

Note: FAOSTAT data = FAO Statistical Databases, available at http://www.fao.org/faostat/en/#home; IFPRI, ASTI data = International Food Policy Research Institute, Agriculture Science and Technology Indicators, available at https://www.asti.cgiar.org/; OECD, DAC data = Organisation for Economic Co-operation and Development, Development Assistance Committee, available at http://www.oecd.org/development/stats/idsonline.htm; USDA, ERS = United States Department of Agriculture, Economic Research Service, available at https://www.ers.usda.gov/data-products/international-agricultural-productivity/; WB, WDI data = World Bank, World Development Indicators, available at http://data.worldbank.org/data-catalog/world-development-indicators; WEF, GCR = World Economic Forum, Global Competitiveness Report 2016–2017, available at https://www.weforum.org/reports/the-global-competitiveness-report-2016-2017-1; and World Intellectual Property Organization (WIPO), Global Brand Database, available at http://www.wipo.int/branddb/en/.

a Environmentally adjusted total factor productivity has been suggested as an alternative measure by the OECD.

### Table 2: Proposed indicators for in-depth diagnosis of AIS

| AIS PROPERTIES | | | | |
|---|---|---|---|---|
| Domain | Indicators | Analytical focus | Unit | Possible sources |
| **Research and education** | Vocational training graduates | Trend | Number per 100,000 farmers | National data |
| | Quality of university education in agriculture | Trend | 1 (low) to 10 (high) | Survey data |
| | Quality of vocational training in agriculture | Trend | 1 (low) to 10 (high) | Survey data |
| | Demand-orientation of agricultural Research | Trend | 1 (low) to 10 (high) | Survey data |
| | Research-extension collaborations | | 1 (low) to 10 (high) | Survey data |
| **Bridging institutions** | Extension service providers | Trend | Number | National data |
| | Extension agents | Trend | Number per 100,000 farmers | National data |
| | Public spending on extension | Trend, variability | % of agriculture GDP | National data |
| | Demand-orientation of extension | Trend | 1 (low) to 10 (high) | Survey data |
| **Business and enterprise** | Farmer organization membership | Trend | % of total farmers | National data |
| | Adoption of certification standards | Trend | 1 (low) to 10 (high) | Survey data |
| | Seed regulation | Trend | 0 (poor) to 100 (good practice) | WB, EBA data |
| | Fertiliser regulation | Trend | 0 (poor) to 100 (good practice) | WB, EBA data |
| | Access to finance in agriculture | Trend | 0 (poor) to 100 (good practice) | WB, EBA data |
| **Enabling environment** | Market regulation in agriculture | Trend | 0 (poor) to 100 (good practice) | WB, EBA data |
| | Transport regulation in agriculture | Trend | 0 (poor) to 100 (good practice) | WB, EBA data |
| | Research-policy collaborations | Trend | 1 (low) to 10 (high) | Survey data |

Note: WB, EBA data = World Bank, Enabling the Business of Agriculture, available at http://eba.worldbank.org/; national data = national government statistical data; survey data = data collected through key informant/expert opinion interviews.

agents, agricultural researchers, credit to agriculture, government expenditure on agriculture, public spending on agricultural research, public spending on extension, foreign aid for agriculture, foreign aid for agricultural education/training, foreign aid for extension, and foreign aid for agricultural research.

Several of the indicators can be classified as representing mostly dynamic and generic properties: quality of the education system, quality of scientific research institutions, university-industry collaboration in R&D, start-up procedures to register a business, time required to start a business, ease of accessing loans, and gross capital formation.

The remaining indicators can be classified as representing mostly dynamic and agriculture-specific properties: quality of university education in agriculture, quality of vocational training in agriculture, demand-orientation of agricultural research, research-extension collaborations, demand-orientation of extension, research-policy collaborations, agricultural policy costs, adoption of certification standards, seed regulation, fertilizer regulation, access to finance in agriculture, market regulation in agriculture, and transport regulation in agriculture.

It should be noted that the above classification is not conceived of as a clear-cut typology, but rather an aid for reflection.

### AIS outcomes

For the AIS outcome indicators shown at the bottom of Table 1, data on agricultural output for all major crops and the value of agricultural production are readily available through FAOSTAT. Outcomes measured through TFP growth or eco-efficiency entail calculations that can be performed using existing FAOSTAT data but require knowledge of appropriate methods.

TFP denotes the ratio between total outputs and total inputs. It has been used to broaden the focus on land or labour productivity, improving understanding of technical change in agriculture. Growth in TFP is interpreted as increased efficiency of input use.[12] Fuglie (2015) explains the use of growth accounting to construct TFP indices for agriculture worldwide.[13] Using FAO data and the growth accounting methodology, internationally consistent and comparable agricultural TFP growth rates can be computed, for which a complete dataset is accessible through the USDA website.[14] TFP rarely accounts for quality improvements in inputs or changes in natural resource stocks.

'Eco-efficiency' is defined as the ratio between economic value added and a composite variable of environmental pressures.[15] It must be stressed that measures used for computing eco-efficiency scores do not attempt to represent the environmental impact of agricultural production but rather the environmental pressures associated with it. Following the eco-efficiency definition, a country can be considered eco-efficient if it is impossible to decrease any environmental pressure without simultaneously increasing another pressure or decreasing the economic value added. For calculation purposes, data envelopment analysis is commonly used,[16] solving linear programming problems to trace a global eco-efficiency frontier and determine the distance of countries from that frontier. Data on environmental pressures from agriculture are available through FAOSTAT to a steadily increasing extent.

## Conclusions

The precise representation of AIS properties constitutes the most important constraint in any attempt of a diagnostic and/or assessment, where agriculture-specific data are by and large missing. As this chapter shows, some key data for characterizing and assessing national AIS covering a wide range of countries and periods are available and accessible from various sources. These include *inter-alia* data from FAO, IFPRI, the International Fund for Agricultural Development (IFAD), World Bank, OECD, WEF, WIPO, and so on. However, other crucial data are missing or are not readily available. These include data on extension and civil society (non-governmental organizations and farmers' organizations), public spending on extension services, the responsiveness of research to the needs of producers, and regulatory procedures in agriculture. A lack of structured data at the country level is particularly apparent for extension and other institutional arrangements that fulfil the bridging function between education and research actors and value chain actors. For these reasons, any AIS diagnostic tool remains exploratory rather than one that allows for precise analysis and definite answers. Despite limitations arising from the nature and scope of the data used, interesting results can emerge from AIS measurements and assessments. The information and knowledge generated can provide pointers to policy and investment gaps and innovation opportunities.

There is potential for a comprehensive diagnostic tool for AIS assessment, but data availability and accessibility at the county level remain a daunting challenge. For a thorough analysis of national AIS, it is important to identify available and accessible data and then fill gaps through additional data gathering. Equally important is to focus on trends and to rely on additional qualitative data sources and validation to interpret results. A sizeable set of indicators has been presented in Table 2. Selecting key indicators characterizing actors and actions/interactions, linkages, and relationships in the AIS will allow for a meaningful analysis of the system in terms of strengths and weaknesses. A multi-criteria AIS diagnosis can thus generate the sound evidence required to formulate global, regional, and national agricultural innovation strategies. In order to draw meaningful results from the diagnosis, it is of paramount importance to define upstream its purpose and the information expected to be generated through the analysis of the diagnostic outputs. This requires the definition of information and knowledge needs by national actors and stakeholders that will guide data collection processes and the diagnostic process. Once the specific context is known, the selection of core indicators from the original set can then facilitate the data collection. The involvement of key AIS actors and stakeholders from the outset is therefore critical to ensure that the diagnosis responds to their information and knowledge requirements and needs.

## Notes

1 TAP, 2016.

2 World Bank, 2012; FAO, 2014.

3 TAP, 2016.

4 Klerkx et al., 2012.

5 OECD, 2010; OECD, 2012; World Bank, 2012; FAO, 2014.

6 OECD, 2011.

7 FAO, 2016.

8 For example, public researchers per $100 million of agricultural GDP (ASTI indicator); university-industry research collaboration (WEF indicator); and external assistance to agriculture (FAO indicator). See Spielman and Kelemework, 2009.

9 For example, Hall and Clark, 1995; Klerkx et al., 2010.

10 Schut et al., 2015.

11 IFPRI, 2015.

12 Fuglie and Wang, 2012.

13 Fuglie, 2015.

14 USDA, 2016.

15 Kuosmanen and Kortelainen, 2005.

16 Kuosmanen and Kortelainen, 2005.

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