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Measurement of Agricultural Productivity in Africa South of the Sahara

A Spatial Typology Application

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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ABSTRACT

The great diversity of agricultural activities and practices across the African continent has significant implications for technology transfer and productivity growth. This paper compiles diverse spatial data on biophysical conditions, farming systems, demographics, and infrastructure to spatially disaggregate country targets into subsystem units, namely agricultural production zones. The resulting typologies highlight the limitations of simple national aggregates and reveal remarkable heterogeneity in the subsystems within the country. The typologies provide a natural linkage between national-level analysis and localized production information and can help policymakers in refining national agricultural strategies through location- and subsystem-oriented policies based on local comparative advantages and constraints. The classification is useful in identifying commonalities beyond a country's borders and hence encourages cross learning and joint efforts in scaling up policies.

Keywords: typology, Africa south of the Sahara, SSA, productivity, population density, market access, NDVI, farming system

JEL code: O13, O47, Q16, Q18

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1. INTRODUCTION

Agricultural activities and practices are much more diverse across the African continent than in any other region in the world. Even within a given country, biophysical conditions, productivity levels, and farmer behaviors are hardly homogeneously distributed. In recent years, the remarkable benefits of a greater understanding of the spatial dimensions of productivity and productivity growth have increasingly drawn the attention of development researchers and practitioners. The spatial variations of agricultural production has been observed in production, land use, climate, and foreign direct investment (Thornton et al. 2009; Denninger and Byerlee 2011; Dixon, Gulliver, and Gibbon 2001).

In the case of technology adoption pathways, biophysical conditions, political factors, human capital, risk aversion, and social factors are identified as the key underlying drivers of technology adoption at the household level (Foster and Rosenzweig 1995; Koundouri, Nauges, and Tzouvelekas 2006). These factors explain the heterogeneity in adoption decisions across population densities and farming systems. Although an examination of the political and social factors is beyond the aims and scope of this study, it is important to bear in mind the multifaceted nature of technology adoption and productivity growth.

Naturally, biophysical measurements are the most-studied aspects of spatial heterogeneity, and their values vary substantially over distance. Precipitation patterns could be similar across hundreds of square kilometers in a flat area, but the soil attributes may change dramatically within a few meters. Social, historical, and cultural differences across space that could be easily neglected also play a key role in shaping agricultural development in Africa. Socioeconomic factors often shape the agricultural development options in a region because the selection of crops to grow, farm management practices to adopt, and food consumption preference is usually influenced by cultural and/or religious background (Nkamleu 2007; Nkamleu, Nyemeck, and Sanogo 2006).

The biophysical and socioeconomic differences interact and must be considered holistically. Agroclimatic conditions determine the suitability of crops and the feasibility of farming practices, while socioeconomic conditions modify predetermined constraints, leading to shifts in regional inequality over time. A good example of the spatial interaction between biophysical and socioeconomic conditions is the Green Revolution. It is widely recognized that the flat performance of African agricultural productivity is largely due to the greater spatial heterogeneity in cropping systems and cultural and social behaviors. Huge spatial diversity makes development, delivery, diffusion, and use of agricultural innovations across large numbers of farms and geographic expanses considerably more complex and costly in Africa. Greater spatial diversity makes the development and diffusion of agricultural innovations more expensive due to the high cost of local adaptation, limiting the transferability of local successes and the ability to scale up to larger spatial units or other locations (Wood and Anderson 2009; Evenson and Gollin 2003).

Stock (2012) points out that different agricultural pathways across Africa have been conditioned by spatial constraints in agroecological conditions and socioeconomic development. The spatial heterogeneity has led to varying development outcomes within and across countries, contributing to vast regional inequalities that can lead to potential social instability. Hence, knowledge of the spatial dynamics in Africa can help policymakers achieve more effective and efficient impact through improved design, targeting, and implementation of agricultural policies and services (Dorosh et al. 2010).

The remarkable spatial heterogeneity across the countries and regions of Africa and the dynamics in agricultural productivity over time have been widely observed (Dixon, Gulliver, and Gibbon 2001; Foster and Rosenzweig 1995; Landmann and Dubovyk 2013). At the system level, spatial heterogeneity is characterized by the inherent variations in climate, land suitability for agriculture, human and animal populations, expanding transportation networks, and other rural infrastructure. The production agents, typically farm households, face various resource constraints in technology adoption, including human, physical, financial, and social factors. The co-evolution of these characteristics contributes to a dynamic context in which the nature and performance of agriculture manifests itself through different spatial patterns of production portfolios and productivity. In most countries, there are important subregional

differences in both biophysical and socioeconomic factors that shape agricultural productivity and opportunities for growth, which can increasingly be recognized and addressed by explicit targeting and formulation of agriculture policies for farmers and service providers at the subnational level.

Over the past 20 years, geo-referenced data and analytical tools have expanded substantially, making it easier and less expensive to incorporate the spatial perspective into agricultural productivity research. The rapid evolution of new technologies, data management systems, and tools includes big low-cost spatial data, high-frequency observation of the land surface using satellite and unmanned aerial vehicle imagery, improved spatial resolutions to less than 1 meter, and sophisticated spatial models. These technical advances have made the collection, management, and application of spatial data much easier and more affordable, allowing researchers to integrate the spatial dimension into traditional studies of agricultural development and growth using geographic information system (GIS) tools.

Building on the farming systems developed by Dixon, Gulliver, and Gibbon (2001), this paper first quantifies factors affecting productivity in the biophysical and socioeconomic dimensions of agricultural production in each local production unit, or agricultural productivity zone (APZ). An APZ is defined as a geographic region, or a set of noncontiguous geographic areas, nested within farming systems, national borders, and agricultural conditions. The APZ exhibits broadly homogeneous characteristics with regard to the potential productivity of agricultural agents, providing a fine-grained system based measurement.

Next, typology analysis combines a finite set of medium-resolution attributes of APZs to spatially group them based on similarities in resource bases, economic activities, demographics, and market access. The objective of the grouping is to identify APZs that share similar production patterns and socioeconomic constraints, as these APZs are more likely to follow a similar technology adoption pathway. The resulting typologies offer a useful instrument for identifying possible pathways of technology adoption and agricultural productivity growth based on local biophysical and socioeconomic conditions, thus assisting in the design of a tailored agricultural development strategy and policy interventions at the subnational level that take into account local comparative advantages. This approach pays special attention to the nuances within farming systems, serving as a bridge between macro analysis at the regional and national levels and micro analysis at the household and pixel levels. In general, locally specific measures of the composition of and comparative advantages in agricultural production provide a more accurate description of food security than broad national and regional indicators.

In addition, despite tremendous spatial heterogeneity there are common themes in the structure of agricultural production and development challenges that offer opportunities for designing and implementing strategies that cut across national boundaries and agroecological conditions. By revealing similarities beyond administrative borders and farming systems, this typology analysis can help regional organizations and national governments identify common constraints and comparative advantages in agricultural production in different parts of the country or region, thus encouraging the search for common solutions to similar issues that impede agricultural production. Instead of simply promoting the scaling up or replication of other countries' experiences, analysis at the subnational level also promotes mutual learning, regional cooperation, and dialogue to share knowledge and practical lessons for production areas that face similar development challenges, either in different parts of a single country or across national borders, which will contribute to the ultimate development goals of increasing food security and reducing poverty in Africa.

The paper is organized as follows. Section 2 describes the data compiled from various sources and the calibration process, followed by a review of spatial patterns in Section 3. Typology analysis results are presented in Section 4, and Section 5 provides within-country applications of the typology analysis. The paper concludes with a discussion of policy implications in last Section 6.

2. DATA

While standard agricultural-performance measures such as crop yields are useful, we can gain a more nuanced and powerful picture by using a broad array of indicators, because the conventional measures focus primarily on certain commodities but ignore economic and natural resource conditions and the composition of agricultural production. In the Sahel region, for instance, it is generally not feasible to produce crops without irrigation, and local climatic and demographic conditions are more favorable to livestock herding.

The literature indicates that a number of variables correlate with agricultural performance, including agricultural potential, demographics, infrastructure, and cropland use (Dixon, Gulliver, and Gibbon 2001; Conradie, Piesse, and Thirtle 2009a). Three unique datasets for the African continent are used in the analysis and need to be highlighted here. The first is the farming system as outlined by Dixon, Gulliver, and Gibbon (2001), which captures farm practices, livelihoods, environment, and access to services. The second is the Normalized Difference Vegetation Index (NDVI), which is a biophysical measurement of vegetation and agricultural land production potential. The third dataset involves socioeconomic attributes, namely, travel time to major towns or market accessibility. The data for the variables chosen for the study are obtained via expert classification and surface observation from space.

Farming System

The concept of a farming system encompasses the interdependent elements of natural resource endowment, human activities, and the socioeconomic environment. According to Dixon, Gulliver, and Gibbon (2001), a farming system is “a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihood and constraints.” In other words, farming systems are largely defined by similarities in biophysical endowments and climate, science and technology, trade and market access, policies and institutions, and human capital. Farming systems can also cut across political boundaries; hence, a country can have multiple farming systems and one farming system may contain more than one country. Farming systems reflect similarities in biophysical endowments, demographics, farm practices, infrastructure, and livelihood choices.

Dixon, Gulliver, and Gibbon (2001) identify 15 farming systems for Africa south of the Sahara (SSA) (Figure 2.1), of which the major ones are forest-based, root crop, cereal/root crop mixed, maize mixed, highland perennial, highland temperate mixed, agropastoral millet/sorghum, and pastoral systems. Each farming system has its own unique features in terms of principal livelihoods and poverty prevalence. For example, the highland perennial farming system exists in Ethiopia, Uganda, Rwanda, and Burundi in areas with favorable natural resources and climate. The major crops for rural livelihood are perennial crops such as banana/plantain and coffee, supplemented by roots (cassava and sweet potato), beans, and cereals. This farming system is characterized by high population density, small landholding size, and intensive use of land. The highland temperate mixed farming system is quite similar to the highland perennial farming system in its geographic location, mild climate, high population density, and small farm size. Major crops are wheat, barley, teff, pulses, and potatoes. Both systems have a considerable livestock component for fieldwork, fuel, and saving.

Figure 2.1 Farming systems in Africa

Source: Dixon, Gulliver, and Gibbon (2001).

The farming systems delineated above are quite general, as each farming system covers tens of millions of hectares and usually extends across national boundaries. This lack of fine-grain definition makes it impossible to provide targeted policy recommendations for improving agricultural productivity based merely on the broad farming systems across the continent. Unlike national statistics, disaggregation within farming systems reveals the heterogeneous patterns of agricultural productivity within a country, allowing researchers to carefully examine the spatial variations at the subnational level (Conradie, Piesse, and Thirtle 2009a, 2009b).

Normalized Difference Vegetation Index

Technologies have been developed to assist with many aspects of natural resource management, including distinguishing land cover types, detecting land use changes, monitoring natural resource management, and estimating crop yields. Remote sensing science, combined with GIS, has become a critical and universal tool for natural resource management. One or more instruments mounted on a satellite or airplane scan the Earth's surface through multispectral or hyper-spectral bandwidth cameras, which collect information and record features across the electromagnetic spectrum that are not visible to the human eye. Remote sensing distinguishes different surfaces by processing the images based on unique fingerprints across the spectrum. For example, live vegetation strongly absorbs visible light for photosynthesis but strongly reflects near infrared light, while bare soil reflects most of the light in both bands. By looking at the characteristics of light reflectance using a vast portion of the electromagnetic spectrum, researchers can detect different features and measure the density magnitude.

Remote sensing has several unique advantages over other technologies used in natural resource management. First, observation from space allows users to gather information over a large land area, usually crossing many countries in a continent. The technology can be applied to objects across a wide range of observation scales, from farm household, to local landscape, to regional agricultural development. Second, remote sensing provides a broad view of landscapes and allows consistent measurement of land use over time by scanning the same geographic location periodically (for example, daily or weekly) to produce images of the Earth's surface, making it a natural tool for tracking natural resource use, evaluating productivity, and characterizing land. In addition, long-term land monitoring results can provide insight into the stressors and drivers of natural resource changes, potentially allowing for the development of management strategies that target the causes of these changes rather than simply addressing the symptoms. Third, GIS technology combines remote sensing data with other information, for example, physical, biological, and socioeconomic indicators, to analyze the status of and changes in the system and to assess the potential impacts associated with these changes. The increasing focus on integrating socioeconomic and biological information with remote sensing and GIS technology can expand our understanding of and capacity to manage natural resources in a more sustainable way by facilitating comprehensive research into farming systems. Finally, the cost of using remote sensing technology is relatively low compared to the traditional approach of field visits.

Information related to natural resource management, such as land use information, is inadequate to meet the growing data needs for management and policy purposes. It is quite common that data are collected at different scales over different time periods, and that the time series are incomplete or do not produce enough baseline data. Additionally, information available to researchers is usually poorly coordinated with little comparability, which further hinders the wide adoption and application of this type of data. In recent years, as the temporal frequency and spatial resolution of data have improved dramatically, remotely sensed data have been widely used in land characterization and crop yield estimation and predictions.

Quantitative assessments of vegetation activity, density, and conditions are key applications of satellite imagery; these assessments usually involve the computation of vegetation indexes as ratios or linear combinations of light reflectance ratios of red, green, and infrared spectral bands. Vegetation indexes are more sensitive than light reflectance of individual bands to vegetation parameters such as biomass and percentage of vegetation cover, thus facilitating the classification and monitoring of agricultural crops (Asrar et al. 1984).

NDVI, derived from satellite images of moderate resolution, has been in use since the 1980s to measure and monitor plant growth (vigor), vegetation cover, and biomass production based on multispectral satellite data. It is one of the widely used vegetation indexes to identify vegetated areas and detect their conditions based on live green plant canopies in multispectral remote sensing data (Running et al. 1995; Doraiswamy et al. 2005). NDVI summarizes the effects of soil characteristics, rainfall, temperature, length of growing period, and irrigation (Dixon, Gulliver, and Gibbon 2001; NASA 2011; Sanchez, Palm, and Buol 2003; Hijmans et al. 2005; Fischer et al. 2007).

Although NDVI could be affected by soil background and atmospheric scattering and can be relatively insensitive to high biomass levels, it is still used by many researchers due to its stability in capturing vegetation growth status and conditions and vegetation phenology. The time-series satellite images also capture the seasonal and interannual changes in the medium term and thus help researchers characterize the general vegetation behavior within its spatial footprint. NDVI series are often used to monitor agriculture productivity, natural resources, and food security because they provide repeated observations of the same location, allowing frequent updating of the vegetation status. For example, NDVI time series have been applied in several African countries to successfully produce early warnings of potential food production problems.

NDVI can capture vegetation status because the visible band in the red-light region of the electromagnetic spectrum is considerably absorbed for photosynthesis, whereas the near infrared band is mostly reflected. It is calculated as

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)},$$

where *NIR* is the spectral reflectance measurement in the near-infrared region, and *VIS* is the spectral reflectance measurement in the visible (red) region. NDVI falls in the range between -1 and 1 but is always positive for Earth-surface observations. Generally speaking, a high positive NDVI (0.5–1) is associated with areas under dense vegetation. Exposed soil is characterized by a small positive value (0.1–0.2), while open water has a value close to zero. NDVI is straightforward to calculate and enables users to distinguish vegetated areas from other surface types and to identify vigorously growing vegetation (high NDVI).

In this study, NDVI is calculated within the farming system using monthly NDVI observations from 2000 to 2008 from remotely sensed satellite images at the pixel level, and the data are resampled to a 5-arc-minute (about 10-kilometer [km]) grid cell. Three NDVI attributes or layers are calculated: minimum, maximum, and mean of NDVI over the period 2000–2008. Agricultural potential, measured in NDVI, is calculated by adopting a rule based classification approach using the three long term NDVI attributes. The NDVI value is always positive because land under vegetation can never take a negative value. A high NDVI value means highly favorable vegetation conditions on the ground. NDVI is then classified into a qualitative measurement coded as very low, low, medium, and high potential.

Market Access

Socioeconomic attributes, which are usually obtained from household surveys and census data, can provide detailed information on the population in the country. Usually, household surveys are conducted on a national basis, with the administrative units varying across the country spatially (regions, districts, wards, and so on). The survey time is not the same across countries, depending on the implementation year. Data from surveys and censuses were not used to measure spatial heterogeneity in the socioeconomic dimension because the objective of this study requires both spatial and temporal consistency at the continental level.

Improved market access for the poorest countries is widely regarded as necessary to support agricultural and rural development (Calderón 2009). In Africa, trade in agricultural products is largely constrained by ineffective agricultural policies and poor transportation networks. Challenging road conditions, long distances, and inadequate road infrastructure add to travel times and transportation costs and therefore limit opportunities for farmers to participate in market transactions. Poor market access can also negatively impact farm production because access to critical agricultural inputs such as fertilizer, pesticides, and seed is also limited. Compared to urban households and those with easy access to markets, rural farm households without market access typically rely on their own production for most of their calorie intake. Inadequate market access, therefore, puts these households at greater risk of food insecurity. The more accessible markets are, the greater the population's ability to remain economically self-sufficient and maintain food security.

The travel time to a major market is introduced as a proxy for market access and infrastructure in the analysis. It captures how likely farming households are to be physically integrated with or isolated from markets and can thus help policymakers and development practitioners better understand factors that influence or constrain farm performance. For instance, a simple cost-benefit analysis reveals whether it is more profitable to travel a longer distance to a larger market or travel a shorter distance to reach the nearest market.

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

The travel times to the nearest cities with a population greater than 50,000 persons are used in the analysis. Data are taken from You and Guo (2011), and each pixel is measured at 5-arc-minute (about 10-km) grid cell resolution. Most Africans do not have easy access to markets, and accessibility is unevenly distributed in Africa. For example, to reach a city or town of 50,000 people, a farmer in western Africa may need travel 1 to 2 hours, whereas farmers in less densely populated areas such as eastern Angola may need to travel 8 hours or more. Travel time is influenced not only by distance but also by infrastructure quality and road conditions. For example, it would take a typical South African farmer less time than a farmer in the Democratic Republic of the Congo to travel the same distance, because South Africa has better infrastructure and more well-maintained roads than the Democratic Republic of the Congo. Another factor in determining market accessibility is the distribution and density of large cities in a country. A country with many large cities scattered around the country, such as Nigeria, has highly accessible markets for most farmers.

Production and Other Variables

Many other indicators are considered to enable a comprehensive evaluation of agricultural potential, current production patterns, and socioeconomic conditions from multiple angles. These indicators correlate with agricultural productivity and include the following:

- Production information for 20 major crops: Area (in hectares) and production (in tons) of wheat, rice, maize, barley, millet, sorghum, potato, sweet potato, cassava, banana, soybean, beans, other pulses, sugarcane, coffee, cotton, other fibers, groundnut, other oil crops, and other crops. Data are taken from SPAM (Spatial Production Allocation Model) (You, Wood, and Wood-Sichra 2009), and each pixel is measured at 5-arc-minute (about 10-km) grid cell resolution.
- Production information for two cash crops: Area (in hectares) and production (in tons) of cocoa and tobacco. Data are from the authors’ own calculations based on national statistics as reported by FAO (2011), and each pixel is measured at 5-arc-minute (about 10-km) grid cell resolution.
- Production information for five types of livestock: Number of live cattle, sheep, goats, chickens, and pigs. Data are taken from Wint and Robinson (2007), and each pixel is measured at 5-arc-minute (about 10-km) grid cell resolution.

- International prices for crops and livestock: Data are obtained from FAO (2011), measured in the 2004–2006 average of constant dollars per ton.
- Agricultural value of production: Data are obtained from FAO (2011), measured in 2004–2006 constant thousand dollars per ton.
- Land indicator: Total and cropland area in hectares. Data are taken from Fischer et al. (2007), and each pixel is measured at 5-arc-minute (about 10-km) grid cell resolution. The share of cropland in total land area is calculated at the pixel level.
- Demographic indicators: Total, rural, and urban population. Data are from the joint project by CIESIN, Columbia University, IFPRI, the World Bank, and CIAT (2011), and each pixel is measured at 5-arc-minute (about 10-km) grid cell resolution. Population density is calculated by dividing total population headcounts by land area and is measured in the number of persons per square kilometer (km²) in each pixel.

NDVI and land area data from remote sensing are generally viewed as reliable and are widely used by many researchers. These indicators are subject to small differences in vegetation types on the ground, but they can be greatly improved if combined with farming systems to identify dominant agricultural activities. In terms of demographic indicators, CIESIN et al. (2011) follow procedures to ensure that data disseminated are of reasonable quality, and population estimates are comparable to national population statistics reported by the United Nations (UN 2011). To avoid price fluctuation, prices of crops and livestock are smoothed by averaging over 2004–2006. Production data are scaled up to national statistics as reported in FAOSTAT in SPAM. We recognize that these data could misrepresent the current state of the African economy due to historical and political factors, as pointed out by Jerven (2013), and we made every effort to ensure the comparability of data with national sources if possible.

Data Standardization

Given the different sources, ranges, and measurement units in the indicators of productivity correlates, the data are first compiled and harmonized based on pixel-level data. This involves several steps, including the simplification of farming systems and the determination of analytic units.

The Food and Agriculture Organization of the United Nations (FAO) definition of a farming system is simplified somewhat, as some closely related farming systems are combined. For example, agropastoral millet/sorghum, pastoral, and sparse systems in the FAO definitions are grouped together to form a new farming system called “pastoral/agropastoral.” FAO defines the pastoral, agropastoral millet/sorghum, and sparse farming systems as areas with a harsh agricultural environment, limited cultivated land, low population density, high dependence on livestock, and vulnerability to drought. These systems stretch through the arid and semiarid zones of the Sahel, the Horn of Africa, and the western part of southern Africa. Since the three farming systems are not very distinguishable in terms of livelihood or agricultural activities, they are referred to as the pastoral/agropastoral farming system in this study.

Similarly, highland perennial and highland temperate mixed farming systems under the FAO definitions are combined into one system labeled “highlands,” for several reasons. First, these systems are found in close geographical proximity to each other and share similar agroclimatic conditions in the subhumid and humid agroecological zones in the Horn of Africa. Second, the two systems share similar agronomic and socioeconomic features in FAO definition, such as high population density, small farm size, dependence on livestock, poor infrastructure, and vulnerability to climate risk.

In the same logic, the tree crop and root crop systems are grouped together as “tree/root crop” because they are largely located in the humid agroecological zones in West and Central Africa, enjoying desirable natural resources, and substantial portion of agricultural land is allocated to industrial tree crops in both systems. Thus, the 14 farming systems originally defined by FAO are simplified to 10 new farming systems, as listed in Table 2.1.

Table 2.1 Comparison of simplified and FAO-defined farming systems

Simplified farming system	Farming system defined by FAO
Tree/root crop	Tree crop
	Root crop
Forest based	Forest based
Highlands	Highland perennial
	Highland temperate mixed
Cereal/root crop	Cereal/root crop mixed
Maize mixed	Maize mixed
Pastoral/agropastoral	Agropastoral millet/sorghum
	Pastoral
	Sparse (arid)
Irrigated	Irrigated
Rice/tree crop	Rice/tree crop
Coastal	Coastal artisanal fishing
Large commercial & smallholder	Large commercial & smallholder

Source: Authors' adaptation of Dixon, Gulliver, and Gibbon (2001).

Note: FAO = Food and Agriculture Organization of the United Nations.

Next, in order to assess the relative importance of field crops and livestock in each agricultural productivity zone, 2004–2006 average price and output values are used to obtain the value shares of 22 crops and five types of livestock in the data. Table 2.2 summarizes the characteristics of agricultural production across the ten simplified farming systems. The majority of the population manages and is sustained by five farming systems (in order of total population): tree/root crop (118 million), pastoral/agropastoral (99 million), maize mixed (96 million), highlands (87 million), and cereal/root crop (84 million). These five major systems account for 87 percent of the cropland in SSA and produce more than 80 percent of the area's agricultural output. Although cereal and root systems dominate the human and land resources, secondary food staples, especially legumes/pulses and oil crops, as well as livestock, are also important.

We determine the qualitative definition of population density and market access based on the group average of the farming system. If the group average falls below the 33rd percentile of the sample of 539 APZs it is defined as low, and if the average is above the 67th percentile of the sample it is defined as high; values between the 33rd and 67th percentiles of the sample are defined as medium. Low population density refers to a group average below 0.12 persons per km², high population density is above 0.47 persons per km², and medium population density falls between 0.12 and 0.47 persons per km². In the case of market access, the cutoff points are set at 4.27 and 7.53 hours to the nearest town of more than 50,000 people. High agricultural potential is defined as an NDVI value above 3, and low potential is below 2.

Among the five major farming systems, the tree/root crop system features high vegetation density, high population density, and medium-level road access to markets. This farming system is located primarily in Central and West Africa, in countries such as Nigeria, Ghana, Côte d'Ivoire, and the Democratic Republic of the Congo. It is also found in part of Tanzania. The pastoral/agropastoral system is in many ways the opposite of the tree/root crop system, with less favorable biophysical conditions, low population density, and difficult access to markets. It is found in the Horn of Africa, the Sahel, and southwest Africa. The maize mixed farming system stretches across eastern and southern Africa. The staple crop maize is cultivated under a moderately humid climate with moderately high population density and quite low market access. The highlands system is located in Ethiopia, Uganda, Rwanda, and Burundi. It supports high population density and a large population of livestock, while access to markets and the agricultural potential of most farms are about the African average. The cereal/root crop system is found in

two belts, one in West Africa and the other in central and southern Africa. It is characterized by a predominantly dry climate, high dependence on livestock breeding, and a wide range of crops.

The main commodities of agricultural production differ significantly across farming systems. For example, rice is produced mainly in the tree/root crop, cereal/root crop, and rice/tree crop farming systems, while tobacco is produced almost exclusively in the maize mixed system. The pastoral/agropastoral system is the major producer of sorghum, millet, soybeans, and groundnuts. In the case of cattle herding, although 27 percent of cattle production comes from the pastoral/agropastoral system, the highlands, cereal/root crop, and maize mixed farming systems together account for more than half of total cattle production in the subcontinent.

Table 2.2 Share in SSA agricultural production (%) and average by farming system

Share (%)	Tree/ root crop	Forest based	Highlands	Cereal/ root crop	Maize mixed	Pastoral/ agropastoral	Irrigated	Rice/ tree crop	Coastal	Large commercial & smallholder
No. of APZs	94	19	56	76	53	141	28	4	49	19
Share of total in farming system (%)										
Population	19.1	7.0	14.2	13.6	15.7	16.1	1.9	1.8	5.2	5.4
Crop area	20.9	3.3	7.4	19.9	11.5	27.2	2.9	0.9	2.3	3.8
Value share in SSA (%)										
Agriculture	23.9	3.2	10.6	18.1	14.0	18.2	2.4	1.3	2.5	5.8
Crop	28.2	3.7	9.6	17.6	13.7	14.9	1.9	1.2	2.9	6.2
Wheat	0.4	0.1	20.2	0.3	15.9	15.1	2.6	0.1	0.0	45.3
Rice	33.7	5.6	1.7	22.8	5.2	8.0	3.0	13.7	6.1	0.0
Maize	14.5	2.4	8.2	10.7	24.5	5.5	0.6	0.1	1.5	31.9
Sorghum/millet	6.6	0.2	4.0	27.8	6.0	46.7	7.8	0.0	0.4	0.6
Potato	4.7	3.3	23.0	7.3	49.5	9.9	1.1	0.5	0.7	0.1
Sweet potato	49.3	1.2	7.2	22.9	8.3	4.0	0.2	0.3	6.4	0.3
Cassava	48.3	11.9	5.9	12.3	10.5	3.4	0.1	1.3	6.3	0.0
Banana	22.9	6.4	44.8	6.1	12.2	3.8	0.2	0.6	2.6	0.4
Soybean	10.8	0.6	4.9	13.5	16.4	39.2	2.4	0.0	0.3	11.9
Pulses	8.4	1.3	14.9	34.0	13.2	24.3	1.6	0.4	1.3	0.7
Sugarcane	7.0	4.4	4.0	5.1	30.3	8.7	2.8	2.6	1.1	34.0
Coffee	43.2	4.2	16.7	3.8	19.9	6.3	0.0	4.4	1.5	0.0
Cotton	26.5	0.5	1.6	32.2	13.2	17.9	3.1	0.6	1.6	2.8
Groundnut	17.0	4.0	1.4	27.2	7.2	35.0	4.9	0.2	1.2	2.0
Cocoa	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Livestock	11.1	1.9	13.3	19.4	14.8	28.4	3.9	1.3	1.1	4.8
Cattle	9.4	1.6	15.5	19.2	16.5	27.4	3.6	1.6	0.8	4.4
Sheep/goat	13.3	1.5	8.4	18.3	10.1	36.1	5.5	0.1	1.3	5.5
Chicken/pig	23.9	7.9	7.2	26.9	15.1	5.9	0.1	3.1	3.8	6.2
Average										
NDVI	high	high	medium	medium	medium	medium	medium	medium	high	medium
Population density	1.3	0.5	1.0	0.7	0.8	0.3	0.5	0.2	5.7	0.5
Market access	6.6	10.2	5.1	6.3	7.2	9.4	4.8	8.1	4.5	6.0

Source: Authors' calculations based on version 3.05 SPAM results. (December 2011).

Notes: APZ = agricultural productivity zone; NDVI = Normalized Difference Vegetation Index. The shares are based on output values, and each row adds up to 100 percent.

To understand the spatial patterns of agricultural productivity, the appropriate units of measurement for productivity must be determined. First, since the majority of productivity analysis is based on administrative boundaries (Conradie, Piesse, and Thirtle 2009a, 2009b), the unit of analysis, agricultural productivity zone (APZ), is defined by dissecting the dominant farming systems with NDVI classes within each country. Next, the nature of this study implies that the size of the appropriate measurement unit should be small enough to capture local production conditions within national borders and farming systems. The APZ is determined as an area larger than the pixel (around 100 km²) but smaller than the farming system (about 1.7 million km²). The final APZs groups of pixels nested within the country border and farming systems, with an average APZ area of 5,381 km². The attributes of each APZ are calculated to capture agricultural potential, demographics, and economic development that are unique to the local natural endowment and development status. This provides a linkage between national-level analysis and household-level production information, thus allowing researchers to obtain detailed agricultural production and socioeconomic characteristics (attributes) at the subnational level without compromising the overall regional structure or distracting from the interpretation of results.

There are 543 APZs distributed in 43 countries, and the number of distinctive APZs varies substantially across countries (Table 2.3). There are many variations in the combination of vegetation and farming patterns in Tanzania, Nigeria, Kenya, and Sudan (each boasts more than 24 APZs), while Djibouti and Equatorial Guinea exhibit little diversity. Although countries with smaller land areas tend to have fewer APZs, this is not always the case, as APZs are designed to measure the spatial variation of each country. Hence Sahel countries such as Niger, Chad, and Mauritania have less than a dozen APZs, but each APZ covers a large area of more than 50,000 km² due to low spatial variation. In contrast, a medium-size country can be divided into many APZs, suggesting complex biophysical conditions in terms of land vegetation coverage, surface temperature, and farming practices. Tanzania, for example, contains 29 APZs that fall into eight farming systems, and all four classes of NDVI potential, from very low to high, co-exist.

Table 2.3 Number of APZs by country

Country	Number of APZs	Total APZ size (sq. km)	Average APZ size (sq. km)
Angola	24	1,240,087	51,670
Benin	9	115,108	12,790
Botswana	14	578,741	41,339
Burkina Faso	8	275,063	34,383
Burundi	7	26,880	3,840
Cameroon	23	463,948	20,172
Central African Republic	9	620,270	68,919
Chad	13	1,259,542	96,888
Côte d'Ivoire	7	316,304	45,186
Democratic Republic of Congo	20	2,327,139	116,357
Djibouti	2	19,679	9,839
Equatorial Guinea	5	24,440	4,888
Eritrea	9	113,304	12,589
Ethiopia	21	1,131,650	53,888
Gabon	7	255,418	36,488
Gambia	5	8,402	1,680
Ghana	13	234,609	18,047
Guinea	10	241,743	24,174
Guinea-Bissau	5	26,857	5,371

Table 2.3 Continued

Country	Number of APZs	Total APZ size (sq. km)	Average APZ size (sq. km)
Kenya	25	578,681	23,147
Lesotho	6	30,802	5,134
Liberia	5	92,159	18,432
Madagascar	15	567,498	37,833
Malawi	9	117,769	13,085
Mali	13	1,236,707	95,131
Mauritania	6	1,026,828	171,138
Mozambique	19	770,688	40,563
Namibia	14	815,022	58,216
Niger	11	1,169,758	106,342
Nigeria	25	899,113	35,965
Republic of Congo	9	341,100	37,900
Rwanda	6	25,372	4,229
Senegal	13	190,715	14,670
Sierra Leone	5	68,985	13,797
Somalia	15	614,756	40,984
South Africa	14	1,203,945	85,996
Sudan	25	2,478,093	99,124
Swaziland	5	17,400	3,480
Tanzania	30	934,170	31,139
Togo	11	57,147	5,195
Uganda	12	240,915	20,076
Zambia	19	751,390	39,547
Zimbabwe	20	390,612	19,531
Total	543	23,898,806	44,013

Source: Authors' calculations.

Note: APZ = agricultural productivity zone.

3. SPATIAL PATTERNS OF PRODUCTION FACTORS

NDVI provides a crude estimate of vegetation health and thickness and can serve as a tool for tracking changes in vegetation over time (see Figure 3.1(a)). One noticeable feature is the concentration of areas with high NDVI in Central and West Africa, especially north of the equator, as well as along the coast of Madagascar. The lowest NDVI is located in areas with low precipitation and high evaporation, mainly along the Sahara Desert in the north and the Namib Desert in the southwest of the continent, as well as in the arid area in the Horn of Africa. On average, central and eastern African countries enjoy a crop-friendly climate and have an above average NDVI value (Table A.1). Agriculture faces an extremely harsh environment in the arid part of the pastoral/agropastoral farming system, while area with a high NDVI value is located in the forest-based, tree/root farming systems and along the coast line.

On average, cropland accounts for around 10 percent of land area in SSA (FAO 2011). Half of SSA's cropland is located in West Africa (Table A.2), where more than 40–50 percent of land is dedicated to agricultural production. There are also pockets of high cropland allocation in East African countries such as Ethiopia, Rwanda, and Uganda, and in the central and northeast parts of South Africa (Figure 3.1(b)). The top three farming systems, measured by cropland size, are the pastoral/agropastoral, tree/root crop, and cereal/root farming systems (Table A.2). The maize mixed system is also important, accounting for more than 10 percent of total crop area in the subcontinent.

Infrastructure is represented by market access, defined as travel time to the nearest regional center of population with more than 50,000 inhabitants. It links infrastructure development with agricultural productivity potential because road connectivity facilitates the transfer of a full range of agricultural services such as inputs, markets, extension, credit, veterinary services, and health and other related services (Dorosh et al. 2010). The average travel time to the nearest city with a population above 50,000 is 12.8 hours in SSA (Table A.3). Road access is relatively more advanced in the coastal and large commercial & smallholder farming systems. It usually takes less than 8 hours to visit the nearest city in five farming systems, including highlands, rice/tree crop and cereal/root crop systems. However, forest-based and pastoral/agropastoral systems face the greatest challenge in accessing markets and other services, where average travel time is more than 10 hours. Eastern Africa has the best access, at 9.2 hours, while travel time in West Africa is almost double that (Figure 3.1(c)). Road access could be a constraint in central Africa as well.

Eastern Africa is home to about half of the population in SSA and also has high population density. The average population density in western Africa reaches 33.9 persons per km², followed by eastern Africa at 30.9 persons per km², which is about twice as high as the level of central and southern Africa (Table A.4). What is more revealing is land pressure for agricultural production, as measured by the density of rural population per hectare of cropland (Figure 3.1(d)). In eastern Africa each hectare of cropland supports 4 rural people, in West Africa 1.8, and in southern Africa 2 (although this does not account for the greater importance of livestock in West Africa, nor the higher share of urban population in southern and western Africa). The highest rural population densities, by a significant margin, are those of the highland systems of eastern Africa (average 122 persons per km²), which are far above those of the second-most-crowded farming system, the coastal system (about 92 persons per km²). Population is more dispersed in the pastoral/agropastoral and forest-based farming systems. Extremely low rural population density is found in the pastoral/agropastoral system in central and southern Africa (below 5 persons per km²), whereas the typical range for most other crop-based systems is 20–50 persons per km².

Figure 3.1 Spatial patterns of key factors influencing agricultural production and productivity at the system level

(a) Annual average (NDVI)

(b) Cropland intensity (c. 2000)

(c) Travel time to markets (>50,000 population)

(d) Rural population density (c. 2000)

Source: (a) MODIS vegetation indexes (2001–2008) and NASA Land Processes Distributed Active Archive Center (LP DAAC) data; (b) Global Rural-Urban Mapping Project (GRUMP) data for 2005; (c) You and Guo (2011); and (d) Ramankutty (2008).

Note: NDVI = Normalized Difference Vegetation Index.

The region's road network has been shaped by patterns of land suitability, demographics, and cropland and in turn has influenced their co-evolution. It is generally expected that cropland closer to markets will be more productive due to easier access to a wide range of services, lower transaction costs on purchased inputs, and higher effective farmgate prices for outputs. The spatial correspondence between biophysical and socioeconomic factors—population density, market access, and the conduct of agriculture (cropland intensity)—is clearly revealed by comparing the panels in Figure 3.1(a)–(d), and Tables A.1–A.4 show high spatial correlation at the farming system level. The intensity of cropland is closely associated with the spatial distribution of an adequate supply of rainfall (represented by a high NDVI), population density, and market access. In West Africa, high agricultural potential is exploited and supported by high cropland intensity, (relatively) easy access to markets, and high population density. In eastern and southern Africa, high population density overlaps with improved market access, and hence there is a high reliance on crop production despite less than optimal agroecological conditions. In Central Africa, fertile land and a tropical climate do not translate into crop-oriented agriculture, partly because of insufficient road coverage, poor travel conditions, and below-average rural population density.

The spatial distribution of APZs, differentiated by their numeric NDVI codes, is illustrated in Figure 3.2. Compared to the map of farming systems based on Dixon, Gulliver, and Gibbon (2001), the current APZ map provides a finer distinction across the continent by further disaggregating the farming systems according to NDVI level and non-vegetation-covered area, data that are obtained through surface observation of vegetation conditions from satellite images. The map highlights considerable variations in biophysical conditions within country borders and agroecological zones. Some countries exhibit substantial heterogeneity in agricultural production and productivity potential. For example, in Cameroon, there are six types of farming systems in the country, including tree-root crop, highlands, and dryland-related systems such as pastoral/agropastoral. Agricultural potential also ranges from high to very low. However, there are also countries that have quite homogeneous natural endowments. In Chad, for example, there are only three farming systems within a vast area of arid land.

When overlaid with the simplified farming systems, a high NDVI corresponds to subsistence-farming livelihood options such as tree/root crop and maize mixed farming systems. A high NDVI is also found in the highlands system of Ethiopia, Kenya, and Uganda, with the highest NDVI areas being associated with forest-based systems. Low rainfall makes rainfed agriculture a challenge in the pastoral/agropastoral system. The north-south gradients in NDVI measurements in high-humidity areas are mainly driven by forest-based and tree/root crop farming systems. Also, it is notable that there are large commercial and smallholder zones in South Africa with generally low NDVI values, while elsewhere in SSA areas with such low NDVI are almost exclusively pastoral.

In summary, although cropland use intensity does not completely overlap with the concentration of population, road networks, or agricultural potential, there are interrelations among the variables that promote agricultural productivity. Generally speaking, areas of high crop intensity tend to exhibit high population density and improved road access and vice versa. High population concentration, coupled with favorable biophysical conditions, makes the highlands system the most market accessible. The predominant geographical areas of cropland and population concentration are the Savannah areas in West Africa and the highland arc in East Africa. In West Africa this area includes northern Nigeria, southern Niger, and Burkina Faso, with a more southerly and more extensive belt running west from Cameroon across the southern and coastal regions of Nigeria, Benin, Togo, Ghana, and Côte d'Ivoire. In East Africa it covers the highlands in Ethiopia, western Kenya, Uganda, Rwanda, and the central and northeastern provinces of South Africa. The most remote farming systems are forest-based systems and pastoral-related systems, where population density is low and the cropping structure is the least developed. The tree crop, irrigated, and large commercial and smallholder systems are typically related to higher levels of crop intensification and/or the production of cash crops.

Figure 3.2 Distribution of agricultural productivity zones

Source: Authors' calculations.

4. TYPOLOGY ANALYSIS

The simplified farming systems demarcation and the spatial pattern of factors related to agricultural productivity provide a useful framework for typology analysis based on local conditions and major agricultural activities. The typology analysis involves statistical and econometric methods, namely spatial and cluster techniques, to group subnational agricultural production regions according to similarities in their agricultural potential, existing production arrangements, and spatial attributes. Spatial attributes of different dimensions of agricultural potential and socioeconomic development will feed into the cluster analysis to detect similarities among APZs and break the observations into a distinct number of nonoverlapping groups, significantly reducing the number of observations in the study. This approach not only assists in discovering similar patterns in data across different regions but also acts as a powerful tool to extract representative information from similar APZs.

K-median cluster analysis is used to group APZs based on major agricultural activities (cropland shares), soil and climatic conditions (NDVI), infrastructure (market access), and population density in each farming system. The *k*-median cluster is a partition clustering method to break the observations into a *k* of groups, or a cluster, based on the differences in the data (Everitt et al. 2011). The resulting groups should be distinct and nonoverlapping, each with its own unique characteristics. The procedure involves the following steps:

1. Assume a set *X* of *n* observations (APZs) in a *d*-dimensional space, with all variables standardized to zero means and unit standard deviations to prevent any variables from distorting the results due to measurement units.
2. It is assumed that the APZs can be grouped into *k* (*k* is predetermined) initial separate clusters, and each APZ is assigned to one of the clusters. The first cluster contains the 1st, (1 + *k*)th, (1 + 2*k*)th, ..., APZs, and the second cluster contains the 2nd, (2 + *k*)th, (2 + 2*k*)th, ..., APZs, and so on.
3. For cluster *k*, the median m_k is computed by taking the sum of the absolute values of the differences in each dimension. This approach minimizes error over all clusters because the cluster median is the point with the smallest sum of the distances from each observation in the cluster to the nearest median. In mathematical terms, define the distance of observation *i* to the median point of cluster *k* as $d_{ik} = \|x_i - m_k\|$, where $\|$ is the sum of the absolute values of all dimensions.
4. Calculate the sum of distance $\sum_k \sum_i d_{ik}$ for all observations *i*.
5. Assign each observation to the nearest cluster with the closest median.
6. Repeat step 3.
7. Stop when there is no change in the cluster median, or no observations change groups. That is, the *k* clusters formed from the data have the minimal sum of distance.

The number of clusters *k* is specified by the user in the iterative process, and there is no preset optimal number of clusters. The first goal is to find *k* clusters such that these clusters are the most compact and distinct. Instead of predetermining a fixed number of clusters, this analysis computes and compares several *k*-median solutions with different numbers of clusters *k* for each farming system. The optimal number of distinct clusters is determined by the large values of the Calinski-Harabasz pseudo-F index and the Duda-Hart $Je(2)/Je(1)$ index (Milligan and Cooper 1985). A small pseudo-T-squared value confirms the distinctness of the clusters. In addition, we also plot several statistics against the number of clusters to visually identify the kink point in the curve. These statistics including the within sum of squares (WSS), the logarithm of WSS, the η^2 coefficient, and the proportional reduction of errors (PRE) coefficient (Makles 2012).

The resulting clusters can help us recognize the common characteristics shared by APZs in the same cluster and thus create typologies to summarize the comparative advantages and constraints in each unique cluster. This typology will not be confined by administrative borders, allowing great flexibility in capturing the binding factors in multiple countries. The final typology table will report typology by dominant field crop and livestock pattern, and one country can be included in more than one typology. For example, the cassava- and banana-dominated typology within the forest-based farming system can be found in Angola and the Democratic Republic of Congo, but development potential is limited by low population density in Angola.

The *k*-median clustering is performed for each farming system. For the 94 APZs within the tree/root crop system, both the Calinski-Harabasz pseudo-F index and the Duda-Hart index indicate that the three-group solution generates the most distinct classification when compared with the two-group and four-group solutions in the tree/root crop system (Table 4.1). The pseudo-T-squared value is the smallest for the three-cluster case, although Figure 4.1 does not give a clear kink point for optimal size. Hence the *k*-median clustering with three clusters will be our final classification for the tree/root crop farming system based on the statistical tests. These clusters are called subsystems in this analysis.

Table 4.1 Statistics by different number of clusters

Number of cluster	Calinski-Harabasz pseudo-F	Duda-Hart	
		Je(2)/Je(1)	Pseudo T-squared
1		0.9282	7.12
2	7.12	0.9605	3.70
3	5.50	0.9612	3.59
4	4.96	0.7949	22.70
5	10.22	0.0000	11.67
6	8.67	0.9005	9.06
7	9.43	0.9708	2.34
8	8.55	0.9468	4.33
9	8.33	0.4013	5.97
10	7.80	0.9575	3.33
11	7.57	0.8658	11.31
12	8.86	0.1266	13.80
13	8.53	0.9295	4.70
14	8.65	0.4370	11.59
15	9.05	0.8894	7.34

Source: Authors' calculations.

Figure 4.1 Statistics by number of clusters

Source: Authors' calculations.

Note: PRE = proportional reduction of errors; WSS = within sum of squares.

Table 4.2 shows major agricultural activities for the three subsystems within the tree/root crop system. The first panel presents the relative importance of each subsystem by comparing their shares of population, crop area, and output value, calculated over the total values of 94 APZs in the tree/root farming system. The contribution of each agricultural commodity within the subsystem is presented in the second panel. The last panel shows the average values of population density, market access, and agricultural potential, weighted by land size. This farming system enjoys an auspicious climate and fertile land, as represented by a high NDVI.

Table 4.2 Description of major agricultural activities in the tree/root crop farming system

Subsystem	Roots	Cocoa + cassava + banana	Livestock
Share in the farming system (%)			
Population	85.3	14.0	0.7
Crop area	75.9	23.9	0.1
Output value	74.9	24.7	0.3
Value share in the subsystem (%)			
Wheat	0.0	0.0	0.0
Rice	6.7	1.4	0.1
Maize	5.4	3.4	1.0
Barley	0.0	0.0	0.0
Sorghum/millet	2.9	0.3	7.7
Potato	0.3	0.3	0.0
Sweet potato	20.1	7.4	0.2
Cassava	22.9	14.9	0.5
Banana	4.6	11.4	0.2
Soybean	0.3	0.0	0.0
Pulses	2.2	0.7	0.4
Sugarcane	0.6	0.4	0.8
Coffee	2.9	1.0	0.0
Cotton	2.5	0.3	0.0
Groundnut	5.5	0.5	1.8
Cocoa	2.7	51.0	0.0
Tobacco	0.0	0.0	0.0
Cattle	8.5	1.2	52.6
Chicken/pig	1.5	0.5	0.1
Sheep/goat	3.9	1.4	34.4
Other	6.3	3.8	0.2
Total	100	100	100
Average			
Population density	medium	high	low
NDVI	high	high	high
Market access	low	medium	medium
Dominant in country:	Central African Republic, Liberia, Guinea, Sierra Leone	Ghana	

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

One subsystem accounts for more than three-quarters of agricultural production and crop area and supports 85 percent of the population. Because this subsystem is predominately root crops (cassava and sweet potato), it is simply labeled “roots.” This subsystem can be found in many West African countries and in Sudan, and it is the dominant subsystem in several countries in the region, such as the Central African Republic, Liberia, Guinea, and Sierra Leone (Table 4.3). This subsystem typically features medium population density and limited market access. The second subsystem is characterized by the tree crop of cocoa, along with root crops and banana, so it is named “cocoa + cassava + banana.” Almost all of SSA’s cocoa is produced in this subsystem, which is located in West Africa, including Ghana, Côte

d'Ivoire, Cameroon, and Togo, and it contributes almost three-quarters of the agricultural crop production value in Ghana. The cocoa-producing subsystem accounts for less than a quarter of crop area and value in the tree/root crop farming system and generally is found in areas of high population density and medium access to markets. The third subsystem is called "livestock" for its overwhelming focus on production of cattle and sheep or goats. It is very marginal and contributes less than 1 percent of agricultural production. Population density in this group is low and market access is at an average level. In addition to cocoa, the tree/root crop system is essential for domestic food security and foreign exchange earnings because nearly half of SSA's root crops and coffee are produced by this system.

Table 4.3 Typology of major subsystems in Africa south of the Sahara

Farming system	Subsystem	Population density	NDVI	Market access	Country	Area (million ha.)	Population (million)	Share in national agricultural production (%)
Tree/root crop	cocoa + cassava + banana	low	high	medium	Equatorial Guinea	0.1	0.4	13.5
		medium	high	medium	Cameroon	2.9	14.6	37.5
		high	medium	high	Côte d'Ivoire	6.1	14.3	38.4
		high	high	medium	Ghana	5.0	17.2	73.2
		high	high	medium	Togo	1.3	4.1	35.8
		high	high	high	Sierra Leone	0.4	3.3	11.7
	roots	low	medium	low	Sudan	11.3	30.8	5.6
		low	high	low	Angola	2.0	12.2	11.1
		low	high	low	Central African Republic	0.7	3.7	54.8
		low	high	low	Gabon	0.2	0.9	21.3
		low	high	low	Mozambique	4.9	16.4	11.1
		low	high	low	Republic of Congo	0.2	2.4	5.1
		low	high	low	Zambia	1.2	10.6	7.8
		medium	medium	medium	Ghana	5.0	17.2	5.9
		medium	high	low	Democratic Republic of Congo	5.9	50.8	19.4
		medium	high	low	Tanzania	6.5	32.9	38.8
		medium	high	medium	Cameroon	2.9	14.6	24.2
		medium	high	medium	Côte d'Ivoire	6.1	14.3	56.4
		medium	high	medium	Liberia	0.3	2.1	64.0
		medium	high	high	Guinea	1.6	7.6	76.5
		medium	high	high	Sierra Leone	0.4	3.3	80.5
		high	high	medium	Burundi	1.0	6.3	19.3
		high	high	high	Benin	1.9	5.8	47.4
		high	high	high	Nigeria	39.6	107.9	36.0
		high	high	high	Togo	1.3	4.1	39.9

Table 4.3 Continued

Farming system	Sub-system	Population density	NDVI	Market access	Country	Area (million ha.)	Population (million)	Share in national agricultural production (%)
Forest based	banana + cassava	low	high	low	Gabon	0.2	0.9	51.5
		medium	high	low	Cameroon	2.9	14.6	10.7
		medium	high	medium	Equatorial Guinea	0.1	0.4	54.5
	cassava + banana	low	high	low	Republic of Congo	0.2	2.4	88.3
		medium	high	low	Democratic Republic of Congo	5.9	50.8	61.4
	cattle + rice + cassava	low	high	low	Central African Republic	0.7	3.7	39.3
		medium	high	low	Madagascar	2.4	14.8	20.9
Highlands	banana + roots	high	high	medium	Democratic Republic of Congo	5.9	50.8	9.6
		high	high	medium	Rwanda	1.4	7.8	99.6
		high	high	high	Burundi	1.0	6.3	80.6
		high	high	high	Kenya	3.9	29.8	8.8
		high	high	high	Uganda	6.2	23.1	57.0
	cattle + maize	high	low	high	Eritrea	0.4	3.5	33.8
		high	medium	low	Ethiopia	6.5	63.0	55.6
		high	medium	low	Lesotho	0.2	2.0	91.4
		high	high	low	Ethiopia	6.5	63.0	8.3
		high	high	medium	Zimbabwe	2.7	12.6	5.0
Cereal/ root crop	cassava + coarse grain + ground-nuts	low	medium	low	Central African Republic	0.7	3.7	5.9
		medium	medium	medium	Benin	1.9	5.8	34.1
		medium	medium	high	Ghana	5.0	17.2	16.2
		medium	high	low	Mozambique	4.9	16.4	36.3
		medium	high	medium	Guinea	1.6	7.6	17.3
		medium	high	medium	Guinea-Bissau	0.2	0.7	75.3
		high	medium	high	Nigeria	39.6	107.9	36.3
		high	high	high	Malawi	3.0	11.2	14.0
	cattle + cassava	low	high	low	Angola	2.0	12.2	26.6
		low	high	low	Zambia	1.2	10.6	11.7
		medium	medium	medium	Madagascar	2.4	14.8	13.6
		medium	high	low	Sudan	11.3	30.8	6.1
		high	low	high	Togo	1.3	4.1	13.2
	cattle + pulses + coarse grain	low	low	low	Sudan	11.3	30.8	19.3
		medium	medium	medium	Burkina Faso	4.2	11.5	76.0
		medium	medium	medium	Chad	2.8	7.7	47.7
		medium	medium	medium	Mali	3.4	11.2	27.6
		medium	medium	medium	Senegal	2.4	6.3	18.8
		high	medium	high	Cameroon	2.9	14.6	16.7
		high	medium	high	Gambia	0.2	0.6	33.9

Table 4.3 Continued

Farming system	Subsystem	Population density	NDVI	Market access	Country	Area (million ha.)	Population (million)	Share in national agricultural production (%)
Maize mixed	cattle + maize	medium	medium	low	Tanzania	6.5	32.9	53.5
		medium	medium	medium	Zimbabwe	2.7	12.6	69.4
		medium	high	low	Ethiopia	6.5	63.0	17.2
		high	high	medium	Kenya	3.9	29.8	29.3
		high	high	medium	Uganda	6.2	23.1	42.2
	roots + maize + tobacco	medium	low	medium	Zimbabwe	2.7	12.6	10.7
		high	medium	medium	Kenya	3.9	29.8	35.1
		high	medium	medium	Malawi	3.0	11.2	74.8
	sugarcane + cattle	high	medium	medium	South Africa	5.9	40.3	5.1
		high	high	medium	Swaziland	0.1	0.9	98.9
	tobacco + maize	medium	high	low	Malawi	3.0	11.2	11.1
		medium	high	low	Mozambique	4.9	16.4	31.1
		medium	high	low	Zambia	1.2	10.6	67.5
Pastoral/ agro-pastoral	cattle dominated	low	low	low	Kenya	3.9	29.8	6.3
		low	low	low	Namibia	0.3	1.4	56.4
		low	low	low	Somalia	1.0	7.3	51.6
		low	low	medium	Botswana	0.2	1.6	35.1
		low	low	medium	Djibouti	0.0	0.2	100.0
		low	low	medium	Mauritania	0.3	1.1	74.2
		medium	low	low	Eritrea	0.4	3.5	39.0
		medium	low	medium	Sudan	11.3	30.8	18.1
	cattle + cassava + maize	low	medium	low	Angola	2.0	12.2	50.5
		low	medium	low	Kenya	3.9	29.8	16.8
		low	medium	medium	Zambia	1.2	10.6	9.8
		medium	medium	medium	Zimbabwe	2.7	12.6	11.1
		high	medium	low	Ethiopia	6.5	63.0	12.3
	coarse grain + cattle + groundnuts	low	low	low	Sudan	11.3	30.8	29.3
		low	low	medium	Chad	2.8	7.7	32.9
		low	medium	low	Namibia	0.3	1.4	7.4
		medium	low	low	Niger	11.6	10.8	93.5
		medium	low	medium	Burkina Faso	4.2	11.5	23.0
		medium	low	medium	Eritrea	0.4	3.5	27.0
		medium	low	medium	Mali	3.4	11.2	60.7
		medium	low	high	Senegal	2.4	6.3	70.4
		high	low	high	Nigeria	39.6	107.9	20.3
	livestock	low	low	low	Chad	2.8	7.7	18.2
		low	medium	low	Botswana	0.2	1.6	57.7
		low	medium	low	Namibia	0.3	1.4	13.4
		medium	low	low	Angola	2.0	12.2	6.6
		medium	high	low	Somalia	1.0	7.3	11.3
	sheep	low	low	low	Mauritania	0.3	1.1	10.6
		low	low	low	Somalia	1.0	7.3	18.6

Table 4.3 Continued

Farming system	Subsystem	Population density	NDVI	Market access	Country	Area (million ha.)	Population (million)	Share in national agricultural production (%)
Irrigated	coarse grain + groundnuts + livestock	medium	low	medium	Sudan	11.3	30.8	7.2
	groundnuts + coarse grain + cattle	high	medium	high	Gambia	0.2	0.6	64.6
		high	medium	high	Senegal	2.4	6.3	5.6
	livestock + coarse grain	medium	low	medium	Sudan	11.3	30.8	9.9
		medium	medium	medium	Somalia	1.0	7.3	18.4
	rice + livestock	medium	low	high	Mauritania	0.3	1.1	11.0
Rice/tree crop	rice + cattle + cassava	medium	high	medium	Madagascar	2.4	14.8	53.7
Coastal	rice + cattle	low	high	medium	Madagascar	2.4	14.8	11.8
		medium	high	high	Guinea-Bissau	0.2	0.7	24.5
		high	high	high	Sierra Leone	0.4	3.3	7.8
	roots	low	high	low	Gabon	0.2	0.9	27.2
		medium	high	medium	Liberia	0.3	2.1	36.0
		medium	high	medium	Mozambique	4.9	16.4	17.1
		medium	high	high	Equatorial Guinea	0.1	0.4	32.0
		high	medium	high	Togo	1.3	4.1	7.7
		high	high	high	Benin	1.9	5.8	18.5
Large commercial & small-holder	livestock	low	low	low	Botswana	0.2	1.6	7.2
		low	low	low	Namibia	0.3	1.4	15.5
	maize + cattle + sugarcane + wheat	medium	low	medium	South Africa	5.9	40.3	88.3
		high	low	high	Lesotho	0.2	2.0	8.6

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

Similarly, three distinctive subsystems are found within the forest-based farming system, all registering high agricultural potential (see Table 4.4). More than 80 percent of the population lives under the first subsystem and depends heavily on cassava and banana production, with more than half of agricultural income derived from cassava. This subsystem is hence labeled “cassava + banana.” It is located in central African countries such as the Democratic Republic of the Congo and the Republic of the Congo, contributing 61 and 88 percent of national agricultural production, respectively (Table 4.3). The second subsystem, mainly found in Madagascar, predominantly focuses on cattle breeding and the cultivation of rice and root crops. Although it accounts for less than 10 percent of the population of the forest-based farming system, this subsystem is found on more than 15 percent of cropland and contributes 24 percent of output value. Banana plays an essential role in the third subsystem, with about one-third of agricultural production coming from the banana harvest. Unlike the cassava + banana subsystem, in this subsystem households supplement their food and income from banana and cassava by raising chickens and pigs, along with sweet potato. This subsystem is found in Cameroon, but it is the major system in Gabon. In terms of socioeconomic dimensions, the rural population living under the forest-based farming system usually has inadequate access to roads and markets, which is due in part to the prevailing low population density.

Table 4.4 Description of major agricultural activities in the forest-based farming system

Subsystem	Cassava + banana	Cattle + rice + cassava	Banana + cassava
Share in the farming system (%)			
Population	81.7	8.9	9.4
Crop area	77.8	15.8	6.3
Output value	65.8	23.7	10.5
Value share in the subsystem (%)			
Wheat	0.0	0.1	0.0
Rice	3.8	17.4	0.0
Maize	7.5	2.3	3.1
Barley	0.0	0.0	0.0
Sorghum/millet	0.5	0.2	0.1
Potato	0.1	6.3	0.1
Sweet potato	1.4	5.6	6.8
Cassava	51.2	10.2	18.8
Banana	13.1	4.0	32.3
Soybean	0.1	0.0	0.1
Pulses	1.8	3.1	1.2
Sugarcane	2.9	1.6	4.4
Coffee	1.3	3.2	1.3
Cotton	0.3	0.3	0.3
Groundnut	8.3	5.7	5.4
Cocoa	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0
Cattle	1.4	30.4	6.6
Chicken/pig	1.6	4.4	10.0
Sheep/goat	2.0	2.7	8.2
Other	2.7	2.7	1.2
Total	100	100	100
Average			
Population density	medium	medium	low
NDVI	high	high	high
Market access	low	low	low
Dominant in country:	Republic of Congo, Democratic Republic of Congo		Equatorial Guinea

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

Livestock plays an important role in the highlands farming system, contributing more than half of agricultural output in three out of the four distinctive subsystems. The majority of the population lives in two subsystems: banana + roots and cattle + maize + coarse grain (Table 4.5). The banana + roots subsystem is mostly observed in several East African countries and is the most important subsystem in Burundi, Rwanda, and Uganda. This subsystem provides nearly half of the subcontinent's banana harvest. More than half of agricultural production originates from cattle herding in the cattle + maize + coarse grain subsystem, which can be found on the Horn of Africa, in Ethiopia and Eritrea, and lower on the continent, in Zimbabwe and Lesotho. It is the dominant agricultural system in Ethiopia and Lesotho (Table 4.3). The other subsystems also rely heavily on livestock, supplemented with maize and cassava. These subsystems are not included in Table 4.3, as they do not make a substantial contribution to agricultural value addition in any sub-Saharan countries. Highlands are usually densely populated, with insufficient access to markets for inputs and knowledge. However, agricultural potential varies considerably within this system. High soil fertility and a helpful climate encourages field crop cultivation in the crop and livestock mix subsystems, whereas harsh biophysical conditions can prevent any significant crop production and hence livestock becomes the major contributor to the agricultural sector in livestock-dominated subsystems.

Table 4.5 Description of major agricultural activities in the highlands farming system

Subsystem	Banana + roots	Cattle + maize + coarse grain	Cattle + maize	Livestock + cassava
Share in the farming system (%)				
Population	44.6	43.8	11.3	0.3
Crop area	59.7	32.6	7.7	0.0
Output value	60.1	31.2	8.6	0.0
Value share in the subsystem (%)				
Wheat	0.1	7.9	2.9	0.6
Rice	1.0	0.0	0.1	1.5
Maize	2.9	9.5	17.7	0.9
Barley	0.0	3.2	0.7	0.0
Sorghum/millet	1.8	5.8	2.8	1.1
Potato	4.4	1.7	3.2	0.7
Sweet potato	8.4	1.2	2.1	3.3
Cassava	9.5	0.0	0.5	9.0
Banana	46.2	0.0	0.7	0.9
Soybean	0.3	0.1	0.2	0.1
Pulses	8.5	6.6	3.3	5.9
Sugarcane	0.8	0.4	1.7	0.1
Coffee	2.4	1.5	2.8	1.8
Cotton	0.1	0.2	1.3	0.1
Groundnut	1.1	0.1	1.5	4.7
Cocoa	0.0	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0	0.0
Cattle	8.5	52.2	48.2	10.5
Chicken/pig	1.2	0.1	1.1	41.5
Sheep/goat	2.3	8.9	8.6	17.3
Other	0.6	0.7	0.5	0.0
Total	100	100	100	100
Average				
Population density	high	high	high	medium
NDVI	high	medium	high	low
Market access	medium	low	low	high
Dominant in country:	Rwanda, Burundi, Uganda	Ethiopia, Lesotho		

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

Crop production is important, but the livestock sector cannot be ignored even in the cereal/root crop farming system, as livestock accounts for 15–49 percent of agricultural value. More than half of the cropland is devoted to the subsystem called “cassava + coarse grain + groundnuts,” located in Central and West Africa, including the Central African Republic, Benin, Ghana, Guinea, Guinea-Bissau, and Nigeria. It is also an important agricultural system in Mozambique and Malawi. The second subsystem is more diversified, and its major agricultural commodities include cattle, pulses, sorghum, millet, and groundnuts. This subsystem can be found in parts of Sahel countries such as Sudan, Chad, Mali, Burkina Faso, Cameroon, and the Gambia. The third subsystem, cattle + cassava, combines cattle and cassava

production, with cattle and cassava accounting for 38 and 20 percent of total agricultural value, respectively (Table 4.6). This system is found in parts of the southern African countries of Angola, Zambia, and Madagascar and also in Sudan. The cereal/root crop farming system can be described as generally having medium population density with medium to high agricultural potential. Road construction is still inadequate to reduce travel time to the nearest town of 50,000 persons to below 4.3 hours.

Table 4.6 Description of major agricultural activities in the cereal/root crop farming system

Subsystem	Cassava + coarse grain + groundnuts	Cattle + pulses + coarse grain	Cattle + cassava
Share in the farming system (%)			
Population	52.9	29.7	17.3
Crop area	67.7	26.8	5.5
Output value	60.1	30.9	9.0
Value share in the subsystem (%)			
Wheat	0.0	0.0	0.1
Rice	6.4	2.3	3.5
Maize	5.9	2.7	3.9
Barley	0.0	0.0	0.1
Sorghum/millet	14.8	11.5	3.6
Potato	0.9	0.2	0.5
Sweet potato	16.4	0.9	2.6
Cassava	8.5	0.6	19.6
Banana	3.0	0.1	4.1
Soybean	0.6	0.1	0.0
Pulses	5.5	20.5	3.2
Sugarcane	0.5	0.4	1.5
Coffee	0.1	0.4	1.2
Cotton	1.9	6.1	1.0
Groundnut	9.7	9.7	2.6
Cocoa	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0
Cattle	9.1	31.1	38.3
Chicken/pig	1.9	2.2	1.2
Sheep/goat	3.9	9.9	9.3
Other	11.1	1.4	3.7
Total	100	100	100
Average			
Population density	medium	medium	medium
NDVI	medium	medium	high
Market access	medium	medium	low
Dominant in country:	Guinea-Bissau	Burkina Faso	

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

The maize mixed farming system spans the whole of eastern and southern Africa, and about half of the maize in SSA is produced within this system. Although the farming system is called "maize mixed," maize contributes less than 30 percent of total agricultural production in this system (Table 2.2). More than 60 percent of the population lives in a livestock-dominant subsystem called "cattle + maize," where population density is medium but market access is far from ideal despite favorable climate and soil conditions (Table 4.7). Countries along the east and south coast, including Tanzania, Kenya, Zimbabwe, Ethiopia, and Uganda, are home to this system, and it is the dominant system in Tanzania and Zimbabwe (Table 4.3). The second subsystem, roots + maize + tobacco, dominates agricultural production in Malawi

but is also key to the livelihood of 42 million people in Zimbabwe and Kenya. The main agricultural activity in this subsystem is maize growing combined with roots and tubers and tobacco. This subsystem supports 16 percent of the population within the maize mixed farming system on less than a quarter of the land and produces 23 percent of output. High population density is observed in this subsystem, along with medium agricultural potential and road access. Highly beneficial climate and soil conditions help the cultivation of tobacco and maize in parts of Malawi, Mozambique, and Zambia in the third subsystem. The fourth subsystem is specialized in the production of sugarcane combined with livestock breeding and is mainly found in areas with agricultural and development conditions of medium favorability in South Africa and Swaziland. Production of cash crops is essential in the agricultural sector in Malawi, Zambia, and Swaziland due to the dominance of specific subsystems. The great potential in agricultural production and labor supply is constrained by a less developed road network in the maize mixed system. In sub-Saharan Africa, tobacco is produced exclusively in the maize mixed farming system, in the roots + maize + tobacco, cattle + maize, and tobacco + maize subsystems.

Table 4.7 Description of major agricultural activities in the maize mixed farming system

Subsystem	Cattle + maize	Roots + maize + tobacco	Tobacco + maize	Sugarcane + cattle
<i>Share in the farming system (%)</i>				
Population	68.0	16.3	10.0	5.7
Crop area	64.2	22.2	11.2	2.3
Output value	61.5	23.4	9.8	5.3
<i>Value share in the subsystem (%)</i>				
Wheat	1.9	1.1	0.6	2.7
Rice	2.1	0.4	0.7	0.1
Maize	12.5	19.5	14.9	6.9
Barley	0.2	0.2	0.0	0.0
Sorghum/millet	5.1	0.8	1.7	1.2
Potato	1.7	17.7	3.7	0.2
Sweet potato	4.2	7.3	5.5	0.4
Cassava	8.9	7.3	6.3	0.5
Banana	7.6	4.2	0.4	0.5
Soybean	0.8	0.2	0.5	0.7
Pulses	5.3	5.7	4.3	0.6
Sugarcane	3.0	1.4	4.3	35.8
Coffee	2.5	1.5	0.4	0.0
Cotton	1.6	0.8	3.9	1.4
Groundnut	3.1	3.0	4.0	1.8
Cocoa	0.0	0.0	0.0	0.0
Tobacco	5.6	13.2	33.8	6.0
Cattle	25.3	10.5	9.8	28.9
Chicken/pig	1.5	0.9	2.2	0.9
Sheep/goat	4.6	3.7	2.5	9.1
Other	2.4	0.6	0.5	2.2
Total	100	100	100	100
<i>Average</i>				
Population density	medium	high	medium	medium
NDVI	high	medium	high	medium
Market access	low	medium	low	medium
Dominant in country:	Tanzania, Zimbabwe	Malawi	Zambia	Swaziland

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

Areas under the pastoral/agropastoral farming system tend to be sparsely populated, and vegetation coverage is low in most cases due to infrequent precipitation and a shortage of irrigation facilities. Livestock is the main activity in this farming system, either as the prevailing source of

employment, income, and food, or combined with crop cultivation. More than 60 percent of the population relies on the first subsystem, coarse grain + cattle + groundnuts, which accounts for two-thirds of agricultural output in this farming system (Table 4.8). Cattle raising is combined with the production of drought-resistant sorghum, millet, and groundnuts as the main agricultural activities, and about half of SSA's total coarse grain production comes from this subsystem. It is widely observed in the Sahel zone parallel to the equator in several countries and contributes more than half of the agricultural value added in Niger, Mali, and Senegal. Cattle represent more than half of the agricultural production value in the cattle-dominated subsystem, which is the dominant system in several countries, largely under arid climate. Cattle production is accompanied by cassava and maize cultivation in areas with medium agricultural potential and population density. This subsystem is found in several clusters in southern and East Africa: Ethiopia and Kenya, Zambia and Zimbabwe, and Angola. In the livestock subsystem, about 70 percent of agricultural value is derived from cattle and small ruminants (sheep and goats). Market access can be very limited in many subsystems. For example, average travel time to the nearest urban market can be more than 20 hours in the sheep/goat-dominated livestock subsystem.

Table 4.8 Description of major agricultural activities in the pastoral/agropastoral farming system

Subsystem	Coarse grain + cattle + groundnuts	Cattle dominated	Cattle + cassava + maize	Livestock	Sheep
Share in the farming system (%)					
Population	61.7	17.8	14.0	4.5	2.0
Crop area	80.5	8.8	8.4	2.2	0.1
Output value	67.0	15.2	12.6	3.9	1.3
Value share in the subsystem (%)					
Wheat	1.0	0.5	3.1	0.3	1.6
Rice	2.2	0.5	0.5	1.5	0.6
Maize	1.0	1.2	12.0	1.7	0.7
Barley	0.0	0.1	0.8	0.0	0.0
Sorghum/millet	29.3	6.6	3.0	6.4	0.4
Potato	0.6	0.9	2.3	0.4	0.0
Sweet potato	1.9	0.5	2.8	2.1	0.0
Cassava	0.3	0.3	12.1	3.9	0.4
Banana	1.4	0.2	3.2	0.6	0.5
Soybean	1.6	0.0	0.4	0.0	0.1
Pulses	8.1	3.3	8.2	2.3	0.9
Sugarcane	0.8	1.3	1.8	0.7	0.7
Coffee	0.0	0.4	3.1	0.0	0.0
Cotton	2.0	1.1	1.0	1.4	0.0
Groundnut	15.5	4.2	2.3	7.7	0.1
Cocoa	0.0	0.0	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0	0.0	0.0
Cattle	18.2	52.6	30.6	49.6	11.0
Chicken/pig	0.3	0.1	1.5	0.7	0.1
Sheep/goat	8.7	24.0	6.8	19.6	82.7
Other	7.2	2.1	4.5	0.9	0.0
Total	100	100	100	100	100
Average					
Population density	medium	low	medium	low	low
NDVI	low	low	medium	low	low
Market access	low	low	low	low	low
Dominant in country:	Niger, Mali, Senegal	Namibia, Somalia, Djibouti, Mauritania	Angola	Botswana	

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

Although the irrigated farming system is relatively small in terms of population and area, it is very diverse, with five distinctive subsystems (Table 4.9). Because this farming system comprises large-scale irrigation schemes, it is mainly found scattered in countries with complex irrigated cropping patterns: the Gambia, Senegal, Somalia, and Sudan. The two major subsystems involve livestock breeding and growing sorghum and/or millet, sometimes combined with groundnut production. Areas with large coarse-grain production (coarse grain + groundnuts + livestock) feature high population density and reasonable access to markets. More than 70 percent of agricultural value added is derived from livestock production in the livestock + coarse grain subsystem, located on the Horn of Africa. Agricultural production is not diversified, and most farms produce groundnuts, coarse grain, and cattle in the third subsystem. The fourth subsystem is also focused on rice, livestock, and coarse grain. Biophysical conditions in these subsystems can be challenging, with difficult climate and soil conditions for agricultural production without irrigation.

Table 4.9 Description of major agricultural activities in the irrigated farming system

Subsystem	Coarse grain + groundnuts + livestock	Livestock + coarse grain	Groundnuts + coarse grain + cattle	Rice + livestock	Cattle
Share in the farming system (%)					
Population	56.5	31.7	4.4	7.3	0.0
Crop area	63.6	24.8	6.5	5.1	0.0
Output value	47.4	37.0	8.3	7.2	0.0
Value share in the subsystem (%)					
Wheat	2.5	0.9	0.0	0.5	0.1
Rice	2.0	0.8	4.2	45.0	0.0
Maize	1.4	3.3	1.8	0.2	2.2
Barley	0.0	0.0	0.0	0.0	0.3
Sorghum/millet	44.1	9.8	18.7	9.4	5.5
Potato	1.1	0.6	0.0	0.0	0.3
Sweet potato	1.4	0.1	0.0	0.0	0.4
Cassava	0.1	0.4	0.3	0.1	2.1
Banana	0.7	0.2	0.0	0.0	0.2
Soybean	1.1	0.0	0.0	0.0	0.2
Pulses	5.5	1.6	0.3	3.9	1.0
Sugarcane	2.5	1.7	0.5	7.1	0.0
Coffee	0.0	0.0	0.0	0.0	0.7
Cotton	2.0	3.4	0.2	0.1	0.0
Groundnut	12.3	3.8	59.3	0.3	0.4
Cocoa	0.0	0.0	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0	0.0	0.0
Cattle	11.1	49.7	10.8	15.3	83.9
Chicken/pig	0.0	0.0	0.5	0.1	0.0
Sheep/goat	8.8	22.4	2.5	17.8	2.8
Other	3.5	1.2	0.7	0.1	0.0
Total	100	100	100	100	100
Average					
Population density	high	medium	high	low	low
NDVI	low	medium	medium	low	high
Market access	medium	medium	high	medium	low
Dominant in country:			Gambia		

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

The rice/tree crop farming system exists only in Madagascar and is relatively simple (Table 4.3). The coastal farming system spans coasts on both east and west sides of SSA. In East Africa, this system is found in Mozambique and Madagascar. It lines the coastal area of West Africa in Gabon, Benin, Togo, Guinea-Bissau, Sierra Leone, and Liberia. There are three subsystems within the coastal farming system, and each registers a unique combination of commodities (Table 4.10). The first subsystem depends on root crops (cassava and sweet potato), while the combination of rice and cattle is another important subsystem. The coastal system can be generalized as densely populated, with fair to favorable agricultural potential and a relatively widespread road network.

Table 4.10 Description of major agricultural activities in the coastal farming system

Subsystem	Roots	Rice + cattle	Groundnuts + sheep + coarse grain + rice
Share in the farming system (%)			
Population	87.8	6.8	5.4
Crop area	87.7	11.7	0.7
Output value	83.5	15.9	0.6
Value share in the subsystem (%)			
Wheat	0.0	0.0	0.0
Rice	3.6	40.0	14.5
Maize	5.8	0.9	1.8
Barley	0.0	0.0	0.0
Sorghum/millet	1.3	0.4	16.7
Potato	0.2	1.7	0.1
Sweet potato	24.8	2.6	0.1
Cassava	30.2	7.4	1.0
Banana	7.7	2.5	0.1
Soybean	0.1	0.0	0.0
Pulses	2.8	2.8	2.7
Sugarcane	0.9	1.4	0.0
Coffee	0.5	2.3	0.0
Cotton	1.3	0.4	0.5
Groundnut	3.0	2.3	31.8
Cocoa	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0
Cattle	1.8	25.3	6.7
Chicken/pig	1.7	3.3	0.5
Sheep/goat	3.4	1.4	21.3
Other	11.1	5.1	2.0
Total	100	100	100
Average			
Population density	high	medium	high
NDVI	high	high	medium
Market access	medium	medium	high

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

The final farming system is called the large commercial and smallholder system, which exists mainly in southern Africa (Table 4.3). This system is dominated by a single subsystem specialized in producing maize, wheat, and sugarcane (Table 4.11). This system is quite commonly observed in South Africa, supporting 40 million people on 6 million hectares of land. Although nearly half of the continent's wheat is produced in this farming system, wheat itself accounts for only about 5 percent of the total agricultural sector output.

Table 4.11 Description of major agricultural activities in the large commercial and smallholder farming system

Subsystem	Maize + cattle + sugarcane + wheat	Livestock
<i>Share in the farming system (%)</i>		
Population	99.3	0.7
Crop area	99.5	0.5
Output value	98.9	1.1
<i>Value share in the subsystem (%)</i>		
Wheat	11.2	0.3
Rice	0.0	0.0
Maize	44.2	0.1
Barley	0.4	0.0
Sorghum/millet	0.8	0.7
Potato	0.0	0.0
Sweet potato	0.4	0.0
Cassava	0.0	0.0
Banana	0.5	0.0
Soybean	1.1	0.0
Pulses	0.6	1.4
Sugarcane	12.1	0.4
Coffee	0.0	0.0
Cotton	0.8	3.5
Groundnut	2.1	0.1
Cocoa	0.0	0.0
Tobacco	0.0	0.0
Cattle	12.7	45.9
Chicken/pig	1.4	0.3
Sheep/goat	5.3	45.9
Other	6.5	1.3
Total	100	100
<i>Average</i>		
Population density	medium	low
NDVI	low	low
Market access	medium	low

Source: Authors' calculations based on cluster analysis.

Note: NDVI = Normalized Difference Vegetation Index.

Table 4.3 summarizes the major farming systems and subsystems in SSA, characterized by demographics (population density), agricultural potential (NDVI), and infrastructure (market access). The land area and population of each subsystem are presented. The last column presents the importance of the subsystem in national agricultural production. This table provides an overview of common challenges or advantages that go beyond country borders. For example, the cocoa + cassava + banana subsystem within the tree/root crop system is dominated by cocoa cultivation, along with cassava and banana, while featuring high population density and lush vegetation, with relatively easy access to markets. This subsystem is observed in several western African countries, including Ghana, Togo, and Sierra Leone, which suggests that these countries may be able to benefit from each other's experiences in poverty reduction and agricultural development. If a policy intervention that focuses on poverty reduction by exploiting comparative advantage (say, encouraging cocoa production to increase farm income) is proven effective in Ghana, the lessons learned from Ghana's experience may be relevant and able to help shape similar interventions in certain regions of Togo and Sierra Leone where the same subsystems are found. This could enable development goals to be achieved more efficiently, after policies are adjusted to reflect local political and socioeconomic conditions.

5. WITHIN-COUNTRY TYPOLOGY APPLICATION

The APZs can also be reorganized by country and then split according to different dimensions of development, such as demographic distribution (population density), agricultural potential (NDVI), and infrastructure (market access). The differentiated patterns of agricultural production structures and external conditions within each country are summarized in Table 5.1, 5.2 and A.5. Table 5.1 reports the typology for major subsystems (contributing more than 20 percent of national agricultural output) and Table 5.2 for minor subsystems (contributing less than 20 percent but more than 5 percent of national agricultural output). Minor subsystems play a small role in the country's economy (less than 5 percent of agricultural output) but not necessarily in terms of poverty reduction or agricultural transformation for populations living under these subsystems. Marginal subsystems (contributing less than 5 percent of national agricultural output) are summarized in Table A.5.

Table 5.1 Typology of major subsystems by country in Africa south of the Sahara

Country	Population density	NDVI	Market access		
			Low	Medium	High
Angola	low	medium	cattle + cassava + maize (pastoral/agropastoral)		
	medium	medium	cattle + cassava (cereal/root crop)		
Benin	medium	medium		cassava + coarse grain + groundnuts (cereal/root crop)	
	high	high			roots (tree/root crop)
Botswana	low	low		cattle dominated (pastoral/agropastoral)	
	low	medium	livestock (pastoral/agropastoral)		
Burkina Faso	medium	low		coarse grain + cattle + groundnuts (pastoral/agropastoral)	
	high	low			cattle + pulses + coarse grain (cereal/root crop)
Burundi	high	high			banana + roots (highlands)
Cameroon	medium	medium		roots (tree/root crop)	
	medium	high		cocoa + cassava + banana (tree/root crop)	
Central African Republic	low	high	roots (tree/root crop)		
	medium	high	cattle + rice + cassava (forest based)		
Chad	medium	low		cattle + pulses + coarse grain (cereal/root crop)	
	high	low		coarse grain + cattle + groundnuts (pastoral/agropastoral)	

Table 5.1 Continued

Country	Population density	NDVI	Market access		
			Low	Medium	High
Côte d'Ivoire	medium	high		roots (tree/root crop)	
	high	medium			cocoa + cassava + banana (tree/root crop)
Democratic Republic of Congo	high	high	cassava + banana (forest based)		
Djibouti	low	low		cattle dominated (pastoral/ agropastoral)	
Equatorial Guinea	medium	high		banana + cassava (forest based)	
	medium	high			roots (coastal)
Eritrea	medium	low		coarse grain + cattle + groundnuts (pastoral/ agropastoral)	
	medium	low	cattle dominated (pastoral/ agropastoral)		
	high	low			cattle + maize (highlands)
Ethiopia	high	medium	cattle + maize (highlands)		
Gabon	low	high	roots (tree/root crop)		
	low	high	banana + cassava (forest based)		
	low	high	roots (coastal)		
Gambia	high	medium			cattle + pulses + coarse grain (cereal/root crop)
	high	medium			groundnuts + coarse grain + cattle (irrigated)
Ghana	high	high		cocoa + cassava + banana (tree/root crop)	
Guinea	medium	medium			roots (tree/root crop)
Guinea-Bissau	medium	high		cassava + coarse grain + groundnuts (cereal/root crop)	
	medium	high			rice + cattle (coastal)
Kenya	medium	low		roots + maize + tobacco (maize mixed)	
	high	high		cattle + maize (maize mixed)	
Lesotho	high	low	cattle + maize (highlands)		
Liberia	medium	high	roots (coastal)		
	medium	high		roots (tree/root crop)	

Table 5.1 Continued

Country	Population density	NDVI	Market access		
			Low	Medium	High
Madagascar	medium	medium	cattle + rice + cassava (forest based)		
	medium	medium	rice + cattle + cassava (rice/tree crop)		
Malawi	high	medium		roots + maize + tobacco (maize mixed)	
Mali	medium	low			cattle + pulses + coarse grain (cereal/root crop)
	medium	low		coarse grain + cattle + groundnuts (pastoral/agropastoral)	
Mauritania	low	low		cattle dominated (pastoral/agropastoral)	
Mozambique	low	high	tobacco + maize (maize mixed)		
	medium	high	cassava + coarse grain + groundnuts (cereal/root crop)		
Namibia	low	low	cattle dominated (pastoral/agropastoral)		
Niger	medium	low		coarse grain + cattle + groundnuts (pastoral/agropastoral)	
Nigeria	high	low			coarse grain + cattle + groundnuts (pastoral/agropastoral)
	high	medium		cassava + coarse grain + groundnuts (cereal/root crop)	
	high	medium			roots (tree/root crop)
Republic of Congo	medium	high	cassava + banana (forest based)		
Rwanda	high	high		banana + roots (highlands)	
Senegal	medium	low			coarse grain + cattle + groundnuts (pastoral/agropastoral)
Sierra Leone	high	high			roots (tree/root crop)
Somalia	medium	low	cattle dominated (pastoral/agropastoral)		
South Africa	medium	medium		maize + cattle + sugarcane + wheat (large commercial & smallholder)	

Table 5.1 Continued

Country	Population density	NDVI	Market access		
			Low	Medium	High
Sudan	high	medium		coarse grain + cattle + groundnuts (pastoral/agropastoral)	
Swaziland	high	medium			sugarcane + cattle (maize mixed)
Tanzania	medium	medium	cattle + maize (maize mixed)		
	high	medium		roots (tree/root crop)	
Togo	high	medium			roots (tree/root crop)
	high	high			cocoa + cassava + banana (tree/root crop)
Uganda	high	medium		cattle + maize (maize mixed)	
	high	high			banana + roots (highlands)
Zambia	medium	high	tobacco + maize (maize mixed)		
Zimbabwe	medium	medium		cattle + maize (maize mixed)	

Source: Authors' calculations.

Note: NDVI = Normalized Difference Vegetation Index.

The differentiated patterns of agricultural structures and external conditions underscore the complicated agricultural systems in SSA. The remarkable heterogeneity in farming systems within a single country necessitates different policy interventions for operations in different agroclimatic and socioeconomic settings. Given the diversity in productivity performance, the results underscore the limitations of using simple aggregates within national borders or agroecological zones because they mask wide regional variations in productivity, as shown by the subnational analysis by Conradie, Pesse, and Thirtle (2009a, 2009b). For example, there are two major farming subsystems in Chad: cattle + pulses + coarse grain (within the cereal/root crop farming system) and coarse grain + cattle + groundnuts (within the pastoral/agropastoral system). The two systems interact with the market in quite different ways due to different infrastructure within each subsystem, with the latter suffering from low labor supply caused by low population density, an inhospitable climate, unpredictable water supply, and limited market access. This implies that agricultural development policies should not be a standard package for the whole nation; instead, policies and target populations should be differentiated based on local demographic and biophysical conditions to achieve maximal impact.

Table 5.2 Typology of minor subsystems by country in Africa south of the Sahara

Country	Population density	NDVI	Market access		
			Low	Medium	High
Angola	low	high	roots (tree/root crop)		
	medium	low	livestock (pastoral/agropastoral)		
Benin	high	high			roots (coastal)
Botswana	medium	low	livestock (large commercial & smallholder)		
Burundi	high	medium		roots (tree/root crop)	
Cameroon	medium	low			cattle + pulses + coarse grain (cereal/root crop)
	high	high		banana + cassava (forest based)	
Central African Republic	low	medium	cassava + coarse grain + groundnuts (cereal/root crop)		
Chad	low	low	livestock (pastoral/agropastoral)		
Democratic Republic of Congo	medium	high	roots (tree/root crop)		
	high	high			banana + roots (highlands)
Equatorial Guinea	low	high		cocoa + cassava + banana (tree/root crop)	
Ethiopia	medium	medium	cattle + maize (maize mixed)		
	high	medium	cattle + cassava + maize (pastoral/agropastoral)		
Ghana	medium	medium			cassava + coarse grain + groundnuts (cereal/root crop)
	medium	medium		roots (tree/root crop)	
Guinea	medium	high		cassava + coarse grain + groundnuts (cereal/root crop)	
Kenya	low	low	cattle dominated (pastoral/agropastoral)		
	low	medium	cattle + cassava + maize (pastoral/agropastoral)		
	high	high			banana + roots (highlands)
Lesotho	high	low			maize + cattle + sugarcane + wheat (large commercial & smallholder)
Madagascar	low	medium		rice + cattle (coastal)	
	low	medium		cattle + cassava (cereal/root crop)	

Table 5.2 Continued

Country	Population density	NDVI	Market access		
Malawi	medium	high	tobacco + maize (maize mixed)		
	high	medium		cassava + coarse grain + groundnuts (cereal/root crop)	
Mauritania	low	low	sheep (pastoral/agropastoral)		
	medium	low			rice + livestock (irrigated)
Mozambique	low	medium	roots (tree/root crop)		
	medium	high		roots (coastal)	
Namibia	low	low	livestock (large commercial & smallholder)		
	low	medium	coarse grain + cattle + groundnuts (pastoral/agropastoral)		
	low	medium	livestock (pastoral/agropastoral)		
Republic of Congo	low	high	roots (tree/root crop)		
Senegal	medium	low		cattle + pulses + coarse grain (cereal/root crop)	
	medium	medium			groundnuts + coarse grain + cattle (irrigated)
Sierra Leone	high	high			rice + cattle (coastal)
	high	high			cocoa + cassava + banana (tree/root crop)
Somalia	low	low	sheep (pastoral/agropastoral)		
	medium	high	livestock (pastoral/agropastoral)		
	high	medium		livestock + coarse grain (irrigated)	
South Africa	high	medium		sugarcane + cattle (maize mixed)	
Sudan	low	medium	roots (tree/root crop)		
	medium	low		livestock + coarse grain (irrigated)	
	medium	low		cattle + pulses + coarse grain (cereal/root crop)	
	medium	low		cattle dominated (pastoral/agropastoral)	
	medium	high	cattle + cassava (cereal/root crop)		
	high	low			coarse grain + groundnuts + livestock (irrigated)
Togo	high	low			cattle + cassava (cereal/root crop)
	high	medium			roots (coastal)

Table 5.2 Continued

Country	Population density	NDVI	Market access		
Zambia	low	medium	roots (tree/root crop)		
	low	medium	cattle + cassava (cereal/root crop)		
	low	medium		cattle + cassava + maize (pastoral/agropastoral)	
Zimbabwe	medium	low		roots + maize + tobacco (maize mixed)	
	medium	medium		cattle + maize (highlands)	
	medium	medium		cattle + cassava + maize (pastoral/agropastoral)	

Source: Authors' calculations.

Note: NDVI = Normalized Difference Vegetation Index.

The tables provide a useful framework to identify a country's comparative advantages and constraints in the agricultural sector, allowing a more tailored diagnosis of binding constraints on economic and human development within a country context. In Ethiopia, for example, the national government recognized the existence of many agroecological zones in the country with different climatic and soil conditions (Ethiopia, Ministry of Finance and Economic Development 2003). However, the government divided the whole country into only three broad clusters: eastern arid land with cattle herding, western lowlands, and highlands suitable for farming but challenged by high population density. This analysis provides a much finer distinction across Ethiopia by identifying a very complex agricultural sector with five farming systems and nine subsystems (Table 5.3). Population distribution is uneven, with density spanning a wide range from low to high, and agricultural production is concentrated in areas of medium to high density. Agricultural potential and soil fertility are generally medium, but development is hindered by an underdeveloped road network. Almost the entire country falls into the category of low market access, suggesting long travel times to actively participate in commercial transactions for agricultural inputs and outputs.

Livestock is key to agricultural development and rural livelihoods in Ethiopia, as various subsystems all rely heavily on livestock and the livestock sector generally contributes more than half of agricultural production. Maize and coarse grains, including sorghum, millet, and barley, are major grain crops in the country (teff is not discussed, as it is largely a local crop grown primarily in Ethiopia). This production pattern suggests that the country can be vulnerable to recurrent droughts, as reflected by the scarce irrigation facilities and dependence on rainfall for grazing pasture. Hence, we can safely conclude that Ethiopia has a comparative advantage in livestock production and is vulnerable to climate shocks, especially droughts, with a medium NDVI. Limited investment and insufficient rural infrastructure could dampen development efforts due to inadequate linkages to markets for knowledge transfer and access to inputs and outputs.

Based on the stylized facts summarized above, improving market connectivity and increasing resilience in responding to adverse weather events should be development priorities. A robust livestock sector calls for more policy support for the sector in terms of breeding, veterinary care, vaccines, and marketing services to improve both quality and quantity of livestock. Furthermore, population density varies within the country even under similar levels of agricultural potential (NDVI), which implies differentiated policies by population distribution, even within the same agroecological zone, to achieve development goals. In regions with high population density, development of the crop sector, especially staples such as maize and teff, could have a larger impact on poverty reduction than in sparsely populated areas. The results in terms of income generation could be larger if crop policy were complemented by

construction of rural infrastructure such as roads and irrigation. In areas of medium population density, the same policy package might not achieve the same cost efficiency due to demographic constraints, and a different policy with an adjusted focus could be more effective.

Ghana is another example of how policy can be tailored based on local conditions to achieve development goals. Auspicious climate and fertile land are reflected in a high NDVI value, suggesting great potential for agricultural development if policies support sustainable use of the country's comparative advantage in natural endowments. There is generally a sufficient labor supply, given medium to high population density. Market access is at or above SSA's average in most agricultural producing zones of the country (Table 5.4). Agriculture in Ghana is dominated by a single major subsystem, cocoa + cassava + banana (within the tree/root crop system), supplemented by a minor subsystem. Both tree and root crops play important roles in agriculture in the major system, which accounts for 78 percent of agricultural output. More attention should be given to groundnuts in the minor subsystem for its strategic role in income generation. Clearly, policies targeting improving agricultural productivity should accommodate local economic conditions and agricultural patterns as reflected in various subsystems, as technology requirement for producing and marketing tree crops is quite different from that of groundnuts or coarse grain. In the major subsystem, promotion of value chain of cocoa and root crops not only contributes to income generation but also helps in rural employment and development. In areas under the minor subsystem, research and development on groundnuts to improve product quality and establish groundnut processing facilities are more likely to generate extra income for many smallholders in the country.

Table 5.3 Agriculture by subsystem in Ethiopia

Farming system	Subsystem	Population density	NDVI	Market access	Share in agriculture value (%)					Share in national agricultural production (%)
					Maize	Coarse grain	Coffee	Cattle	Sheep	
Major										
Highlands	cattle + maize	high	medium	low	9.7	8.9	1.5	52.3	8.6	55.6
Minor										
Maize mixed	cattle + maize	medium	medium	low	11.5	12.7	7.5	45.4	7.6	17.2
Pastoral/ agropastoral	cattle + cassava + maize	high	medium	low	10.5	5.8	7.6	46.6	7.8	12.3
Marginal										
Highlands	cattle + maize	high	high	low	10.6	5.1	5.0	60.9	6.6	8.3
Pastoral/ agropastoral	cattle dominated	medium	low	low	4.1	2.9	4.9	52.5	17.7	2.7
Cereal/root crop	cattle + cassava	medium	medium	low	6.9	6.2	0.1	64.0	7.6	2.2
Pastoral/ agropastoral	coarse grain + cattle + groundnuts	medium	medium	low	6.3	33.5	2.0	46.0	7.9	1.5
Irrigated	coarse grain + groundnuts + livestock	low	low	medium	9.7	22.6	1.4	49.3	7.4	0.2
Irrigated	cattle	low	medium	low	2.2	6.3	0.8	86.2	3.0	0.0

Source: Authors' calculations.

Note: NDVI = Normalized Difference Vegetation Index.

Table 5.4 Agriculture by subsystem in Ghana

Farming system	Subsystem	Population density	NDVI	Market access	Share in agriculture value (%)							Share in national agricultural production (%)
					Maize	Coarse grain	Sweet potato	Cassava	Banana	Cocoa	Ground nut	
Major												
Tree/root crop	cocoa + cassava + banana	high	high	medium	3.1	0.2	12.7	26.6	15.1	30.2	0.3	73.2
Minor												
Cereal/root crop	cassava + coarse grain + groundnuts	medium	medium	high	10.6	13.2	15.2	3.8	0.0	0.0	21.0	16.2
Marginal												
Tree/root crop	roots	medium	medium	medium	7.2	4.2	26.5	18.8	6.5	0.0	6.6	5.9
Coastal	roots	high	medium	high	6.7	0.1	9.0	42.3	17.5	0.0	0.0	4.7
Tree/root crop	livestock	low	low	high	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coastal	groundnuts + sheep + coarse grain + rice	high	low	high	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: Authors' calculations.

Note: NDVI = Normalized Difference Vegetation Index.

6. CONCLUSIONS AND DISCUSSION

To effectively fight poverty and malnutrition, investment and policy interventions must take into account the considerable spatial diversity of farms' potential and constraints. We recognize that focusing on different research issues can lead to different classifications and hence different typologies. This cluster typology analysis spatially groups APZs into categories sharing similar biophysical, demographic, and socioeconomic environmental conditions. The APZs are defined in terms of interactions between farming systems, administrative borders, and agricultural potential, which are grouped into subsystems according crop patterns and social development indicators as the typologies summarized in Table 4.3. This approach provides a natural linkage between national-level analysis and localized production information, hence allowing researchers to identify detailed agricultural production and socioeconomic characteristics (attributes) at the subnational level without compromising the overall regional structure or distracting from the interpretation of results.

This analysis can be useful in several ways. First, the subsystems within a country provide a more localized measure of the prevailing output mix and input constraints, as aggregated measurements of productivity mask significant regional differences (Corradie, Piesse, and Thirtle 2009a, 2009b). The classificatory analysis clearly illustrates that different agricultural activities are carried out in different subsystems, as illustrated in the country-level examples of targeted policy interventions based on local productivity typologies. Traditional productivity analysis, usually carried out at various levels of administrative units, cannot be easily adjusted to incorporate rich spatial information because natural spatial variation rarely follows administrative boundaries. This typology analysis provides an intermediate solution to linking aggregate national agricultural statistics with pixel-level GIS data on agricultural production.

Second, the classification is useful in identifying commonalities and promoting mutual learning by revealing similar constraints beyond country borders, and it thus encourages regional organizations to search for common solutions to similar agricultural development challenges that impede agricultural productivity improvement. Countries can be vulnerable to some common external shocks due to their proximity to each other, or due to similar soil, climate, and infrastructure constraints. Hence, production areas sharing similar agroclimatic and socioeconomic characteristics across countries can benefit from each other's knowledge and experience in agricultural development even though they are not geographically located next to each other.

This exercise has important implications for policy scaling up or replication. The cross-learning process helps governments more effectively and efficiently design and implement policies to achieve development and food security goals, in line with the continent's recent increased interest in identifying the common policy and institutional constraints to promoting growth and development (Badiane, Makombe, and Collins 2014). For example, investment in roads can be one development priority for countries with low market access but high agricultural potential and favorable soil and climate conditions, and coordinated actions and technical innovations can promote the optimal use of resources. The typology analysis can also be used in addressing emerging development issues. Climate change, represented by shifting precipitation patterns and the increasing frequency of severe weather disasters, will have an effect on the distribution of cropping systems. Concerted efforts by national governments and regional and international coalitions can help farmers cope with the increasingly hostile environment and mitigate the impact on the continent.

The results also have implications for the usefulness of the categories currently used by the international development community to discuss agricultural productivity concerns. The widely used farming system classification defined by FAO can be too broad and inevitably results in a considerable degree of heterogeneity within any given farming system. This study highlights the wide variations of farm practices categorized by subsystem, while a broad farming system appears features multiple types of agricultural profile. Grouping APZs according to similarities in their agricultural productivity profiles allows for a more refined analysis of possible pathways to improve productivity. Governments should be

judicious in transplanting policies, as simply imitating without taking into account local conditions might lead to detrimental instead of beneficial results in improving agricultural productivity.

For instance, countries with fertile arable land and a favorable climate are in an excellent position to improve national and regional food security by taking advantage of their agricultural potential with low investment requirements for productivity increases. The countries in this category include Guinea, Madagascar, Swaziland, and Togo. In contrast, many countries in SSA are plagued by major soil constraints such as aluminum toxicity, lowering the supply response to modern technology. This could be corrected by choosing proper soil management practices (such as liming), and many areas in countries in SSA could benefit from this technology. For a subsystem that faces erratic and volatile rainfall but has soil and climate conditions that are otherwise suitable for crop production, investment in irrigation and water-reservation-related technologies has been shown to be effective in improving crop outputs and yields. Many countries exploit their potential by targeting stable water sources for agricultural productivity growth: Benin, Ethiopia, the Gambia, Lesotho, Malawi, Mozambique, Senegal, and Zimbabwe.

In summary, an effective agricultural sector development strategy needs to precisely define opportunities and challenges within each subsystem before specifying and implementing development strategies. More important, the production patterns in subsystems can help policymakers detect the impact of policy interventions such as irrigation or fertilizer subsidies at a less aggregated level. Localized knowledge provides a basis for relevant and effective policy design and implementation tailored to local conditions in representative APZs. It also helps policymakers set the right priorities for agricultural investment at the country or regional level or deliver location-specific technologies based on local agroecological characteristics and production systems, aiming at both productivity and sustainability. The policy prescriptions to improve agricultural productivity are not discussed, as they are beyond the scope of this paper. Empirical evidence suggests that improvements in agricultural research and development, infrastructure, markets, extension, and agricultural policy can all contribute to enhanced agricultural productivity in SSA (Fuglie and Rada 2012; Nin-Pratt and Yu 2012).

This typology analysis does have some limitations. First, it does not cover all the dimensions of development, in the sense that it uses a set of selected indicators to represent the socioeconomic status in the area under observation. High-resolution data on poverty and access to services will expand the coverage and possible issues in development for this type of analysis. Second, the analysis presents long-term patterns of agricultural production but fails to incorporate short-term changes in weather and the latest developments in the socioeconomic domain, such as a recent flood in a river basin or a serious drought. A time-series analysis of APZs could capture shifts in agricultural production over a relatively short period of time. In addition, household surveys with detailed production questions and updated GIS spatial information could be applied to the typology analysis to identify the determinants of agricultural productivity at the local or farmer level with richer detail. Furthermore, this analysis could be improved if additional or alternative measures of agricultural potential were incorporated in the analysis of farming systems, such as land variables (elevation, slope, and soil fertility, for example), which would feed into a mechanical model to estimate potential productivity.

APPENDIX: SUPPLEMENTARY TABLES

Table A.1 Average annual NDVI by farming system

Farming system	Central	East	South	West	SSA
Tree/root crop	3.8	3.3	NA	3.6	3.6
Forest based	4.0	3.4	NA	4.0	4.0
Highlands	3.7	3.2	2.7	3.4	3.2
Cereal/root crop	3.0	2.8	NA	2.5	2.8
Maize mixed	3.9	3.1	3.3	NA	3.1
Pastoral/agropastoral	1.4	1.4	1.7	1.2	1.3
Irrigated	3.0	1.9	NA	1.3	1.7
Rice/tree crop	NA	3.3	NA	NA	3.3
Coastal	3.9	3.6	NA	3.9	3.7
Large commercial and smallholder	NA	3.4	1.7	NA	1.8
Average	3.3	2.4	1.8	1.9	2.5

Source: Authors' calculations based on NDVI indexes from NASA (2011).

Notes: NA = not applicable; NDVI = Normalized Difference Vegetation Index.

Table A.2 Cropland area by farming system, in 1,000 hectares in 2005

Farming system	Central	East	South	West	SSA
Tree/root crop	3,539	4,138	NA	24,110	31,788
Forest based	4,521	529	NA	34	5084
Highlands	713	9,884	261	357	11,215
Cereal/root crop	2,863	4,997	NA	22,524	30,384
Maize mixed	249	16,829	404	NA	17,483
Pastoral/agropastoral	2,666	10,773	505	27532	41,476
Irrigated	NA	2,176	NA	2,218	4,394
Rice/tree crop	NA	1,336	NA	NA	1,336
Coastal	137	1,546	NA	1856	3,539
Large commercial and smallholder	NA	83	5653	NA	5,736
Average	14,688	52,292	6,824	78,632	152,436

Source: Authors' calculations based on Ramankutty (2008).

Notes: NA = not applicable.

Table A.3 Travel time by farming system, in hours to cities with population greater than 50,000 inhabitants

Farming system	Central	East	South	West	SSA
Tree/root crop	12.2	11.2	NA	4.3	9.4
Forest based	12.4	9.7	NA	5.6	12.2
Highlands	5.1	7.6	9.6	11.3	7.5
Cereal/root crop	10.1	9.4	NA	4.2	7.9
Maize mixed	7.2	9.0	5.2	NA	8.7
Pastoral/agropastoral	25.5	9.6	13.7	26.5	18.8
Irrigated	10.7	5.8	NA	4.4	5.4
Rice/tree crop	NA	7.3	NA	NA	7.3
Coastal	9.6	6.9	NA	4.1	6.4
Large commercial & smallholder	NA	4.5	5.7	NA	5.7
Average	14.2	9.2	9.6	17.7	12.8

Source: Authors' calculations based on You and Guo (2011).

Notes: NA = not applicable.

Table A.4 Rural population density by farming system, in persons per square kilometer in 2005

Farming system	Central	East	South	West	SSA
Tree/root crop	9.9	21.8	NA	73.8	33.5
Forest based	16.2	19.9	NA	15.0	16.3
Highlands	85.3	136.9	48.5	31.4	122.3
Cereal/root crop	16.5	17.5	NA	47.7	26.9
Maize mixed	28.9	38.0	75.7	NA	39.5
Pastoral/agropastoral	4.6	13.9	2.2	12.5	10.6
Irrigated	2.9	25.2	NA	52.1	34.7
Rice/tree crop	NA	35.9	NA	NA	35.9
Coastal	72.3	44.1	NA	210.4	91.8
Large commercial & smallholder	NA	73.6	26.1	NA	27.0
Average	14.1	30.9	17.4	33.9	25.5

Source: Authors' calculations based on GRUMP (2005).

Notes: "Not labeled" are made of grid cells that do not have a farming system because of differences in the delineation of water and land interfaces (e.g., coastlines, lake areas) between data layers. N.A. = not applicable.

Table A.5 Typology of marginal subsystems by country in Africa south of the Sahara

Country	Population density	NDVI	Market Access		
			Low	Medium	High
Angola	low	low	cattle dominated (pastoral/agropastoral)		
	low	medium	cattle (irrigated)		
	low	high	cassava + banana (forest based)		
	medium	low			cattle + maize (highlands)
	high	low		cassava + coarse grain + groundnuts (cereal/root crop)	
	high	high			coarse grain + cattle + groundnuts (pastoral/agropastoral)
	high	high			banana + roots (highlands)
Benin	high	low			groundnuts + sheep + coarse grain + rice (coastal)
Botswana	low	medium	cattle + maize (maize mixed)		
Burkina Faso	medium	medium		roots (tree/root crop)	
	high	medium			cattle + cassava + maize (pastoral/agropastoral)
Burundi	low	low			livestock + cassava (highlands)
	high	low			cattle + maize (highlands)
Cameroon	low	medium			cattle + cassava + maize (pastoral/agropastoral)
	low	high	cassava + coarse grain + groundnuts (cereal/root crop)		
	medium	low			cattle dominated (pastoral/agropastoral)
	medium	medium		cattle + maize (highlands)	
	medium	high	banana + roots (highlands)		
	high	medium			coarse grain + cattle + groundnuts (pastoral/agropastoral)
	high	high			roots (coastal)

Table A.5 Continued

Country	Population density	NDVI	Market Access		
			Low	Medium	High
Central African Republic	low	high	cattle + maize (maize mixed)		
Chad	low	high		cattle + cassava + maize (pastoral/agropastoral)	
	medium	high		cassava + coarse grain + groundnuts (cereal/root crop)	
	medium	high		roots (tree/root crop)	
Côte d'Ivoire	medium	medium			cattle + cassava (cereal/root crop)
	high	medium			groundnuts + sheep + coarse grain + rice (coastal)
	high	high			roots (coastal)
Democratic Republic of Congo	low	low			roots + maize + tobacco (maize mixed)
	low	low			livestock + cassava (highlands)
	low	low			livestock (tree/root crop)
	medium	low	cattle + rice + cassava (forest based)		
	medium	low			cattle + maize (highlands)
	high	medium			cattle + cassava (cereal/root crop)
	high	medium			cattle + maize (maize mixed)
Equatorial Guinea	low	medium			groundnuts + sheep + coarse grain + rice (coastal)
Eritrea	medium	low			livestock + coarse grain (irrigated)

Table A.5 Continued

Country	Population density	NDVI	Market Access		
			Low	Medium	High
Ethiopia	low	low		coarse grain + groundnuts + livestock (irrigated)	
	low	medium	cattle (irrigated)		
	medium	low	cattle dominated (pastoral/agropastoral)		
	medium	medium	coarse grain + cattle + groundnuts (pastoral/agropastoral)		
	medium	medium	cattle + cassava (cereal/root crop)		
Gabon	low	low	groundnuts + sheep + coarse grain + rice (coastal)		
Gambia	high	medium			groundnuts + sheep + coarse grain + rice (coastal)
Ghana	low	low			livestock (tree/root crop)
	high	low			groundnuts + sheep + coarse grain + rice (coastal)
	high	medium			roots (coastal)
Guinea	medium	low			cattle + pulses + coarse grain (cereal/root crop)
	medium	high			cocoa + cassava + banana (tree/root crop)
	high	medium			rice + cattle (coastal)
Guinea-Bissau	medium	low		cattle + pulses + coarse grain (cereal/root crop)	
Kenya	medium	low			livestock + cassava (highlands)
	medium	medium	roots (tree/root crop)		
	high	low			cattle + maize (highlands)
	high	high			roots (coastal)
Liberia	low	low			groundnuts + sheep + coarse grain + rice (coastal)

Table A.5 Continued

Country	Population density	NDVI	Market Access		
			Low	Medium	High
Malawi	low	low			cattle + maize (maize mixed)
	medium	low			cattle + pulses + coarse grain (cereal/root crop)
Mali	low	low	livestock (pastoral/agropastoral)		
	low	low		rice + livestock (irrigated)	
	low	high		roots (tree/root crop)	
	medium	low			coarse grain + groundnuts + livestock (irrigated)
	medium	high		cattle + cassava (cereal/root crop)	
	high	medium			cattle + cassava + maize (pastoral/agropastoral)
Mauritania	medium	low		livestock + coarse grain (irrigated)	
Mozambique	low	low			livestock (tree/root crop)
	low	low			roots + maize + tobacco (maize mixed)
	low	low		cattle + maize (maize mixed)	
	high	low			groundnuts + sheep + coarse grain + rice (coastal)
	high	low			cattle + pulses + coarse grain (cereal/root crop)
	high	high		banana + roots (highlands)	
	high	high			maize + cattle + sugarcane + wheat (large commercial & smallholder)
Namibia	low	low	sheep (pastoral/agropastoral)		
	low	medium	tobacco + maize (maize mixed)		
	low	high	cattle + cassava + maize (pastoral/agropastoral)		

Table A.5 Continued

Country	Population density	NDVI	Market Access		
			Low	Medium	High
Niger	low	low	livestock (pastoral/agropastoral)		
	low	high		cattle + cassava + maize (pastoral/agropastoral)	
	medium	low			coarse grain + groundnuts + livestock (irrigated)
	medium	low		cattle + pulses + coarse grain (cereal/root crop)	
Nigeria	low	high			cattle + cassava + maize (pastoral/agropastoral)
	medium	medium	banana + roots (highlands)		
	high	low			coarse grain + groundnuts + livestock (irrigated)
	high	low			cattle + pulses + coarse grain (cereal/root crop)
	high	low			livestock (tree/root crop)
	high	low			groundnuts + coarse grain + cattle (irrigated)
	high	high		roots (coastal)	
Republic of Congo	low	low		cattle + rice + cassava (forest based)	
	low	medium		cocoa + cassava + banana (tree/root crop)	
	medium	high		cattle + cassava (cereal/root crop)	
	high	high	roots (coastal)		
Rwanda	high	low			livestock + cassava (highlands)
	high	high	roots (tree/root crop)		

Table A.5 Continued

Country	Population density	NDVI	Market Access		
			Low	Medium	High
Senegal	medium	low			rice + livestock (irrigated)
	high	medium			groundnuts + sheep + coarse grain + rice (coastal)
	high	medium			cattle + cassava + maize (pastoral/agropastoral)
	high	high			cassava + coarse grain + groundnuts (cereal/root crop)
Somalia	low	medium	cattle + cassava + maize (pastoral/agropastoral)		
South Africa	low	low		sheep (pastoral/agropastoral)	
	medium	low			tobacco + maize (maize mixed)
	medium	low		cattle + cassava + maize (pastoral/agropastoral)	
	high	medium		cattle + maize (highlands)	
	high	high		cattle + maize (maize mixed)	
Sudan	low	low	sugarcane + cattle (maize mixed)		
	low	medium		livestock (tree/root crop)	
	low	medium	cattle + maize (maize mixed)		
	low	high	livestock (pastoral/agropastoral)		
	medium	medium		cattle + cassava + maize (pastoral/agropastoral)	
Swaziland	medium	high		maize + cattle + sugarcane + wheat (large commercial & smallholder)	

Table A.5 Continued

Country	Population density	NDVI	Market Access		
			Low	Medium	High
Tanzania	low	low			livestock (tree/root crop)
	low	low			livestock + cassava (highlands)
	low	low	cattle dominated (pastoral/agropastoral)		
	low	medium	livestock (pastoral/agropastoral)		
	medium	medium		cattle + cassava + maize (pastoral/agropastoral)	
	high	medium		cattle + maize (highlands)	
	high	high		banana + roots (highlands)	
	high	high		roots (coastal)	
Togo	high	high			cassava + coarse grain + groundnuts (cereal/root crop)
	high	high			groundnuts + sheep + coarse grain + rice (coastal)
Uganda	low	medium	coarse grain + cattle + groundnuts (pastoral/agropastoral)		
	medium	low			livestock + cassava (highlands)
	medium	low			roots + maize + tobacco (maize mixed)
Zambia	low	low			livestock (tree/root crop)
	low	high	cattle (irrigated)		
	medium	medium		livestock + coarse grain (irrigated)	
	high	low		sugarcane + cattle (maize mixed)	

Table A.5 Continued

Country	Population density	NDVI	Market Access		
			Low	Medium	High
Zimbabwe	low	low	livestock (large commercial & smallholder)		
	low	low		cattle dominated (pastoral/agropastoral)	
	medium	low		tobacco + maize (maize mixed)	
	high	low			livestock + coarse grain (irrigated)
	high	high	cassava + coarse grain + groundnuts (cereal/root crop)		
	high	high		sugarcane + cattle (maize mixed)	

Source: Authors' calculations.

Note: NDVI = Normalized Difference Vegetation Index.

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