YIELD GAPS

AND POTENTIAL AGRICULTURAL GROWTH IN WEST AND CENTRAL AFRICA

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Foreword

Investments in agricultural research and extension increased in Sub-Saharan Africa in the late 1970s, as the success of Asia's Green Revolution became apparent. However, at the time, donors promoted importing into Africa successful technologies developed elsewhere in previous decades, while supporting extension programs that had no appropriate innovations to extend. In addition, the economic crisis that Africa suffered in the 1980s and 1990s affected investments in agricultural research, because public services in many African countries faced bankruptcy or privatization.

Today most African economies have recovered from the crisis after a costly process of structural reforms and policy changes, which was helped by the end, in recent years, of many civil conflicts that had devastated regional economies. Sub-Saharan African governments and the donor community now recognize the importance of investment in agricultural research and development in sustaining economic growth, alleviating poverty, and preventing future food crises. The importance of investing in agriculture in West and Central Africa is especially pronounced, given the region's generally poor economic performance, compounded by periods of political instability and erosion of both physical and human capital. Given these difficulties, promoting future investment and attracting the funds needed to accelerate economic growth in the region require policymakers to identify clear priorities based on the potential economywide impact of investments in different agricultural subsectors and regions.

This monograph's primary purpose is to contribute to the identification of these priorities by using a methodology derived from both an aggregate, economywide perspective and a spatially disaggregated perspective, taking into account the diverse economies, underlying constraints, and opportunities in West and Central Africa. The study develops an innovative approach that distinguishes between the impacts of agroclimatic factors and economic factors by using databases assembled in recent years, in part to study the effects of climate change. Spatial data are combined with a multimarket model that links the detailed information on specific agroecological conditions to markets while determining household income endogenously. This allows the authors to capture the impact of differential agroecological conditions and technological possibilities on economic growth, demand for agricultural products, and income in the region.

This integrated spatial and economywide investigation points to staple crop (cereals and roots and tubers) and livestock production as the subsectors with the greatest potential to stimulate productivity and achieve overall growth and poverty reduction goals in West Africa. Traditional export crops, such as cotton and cocoa, could make a significant contribution to growth in their major exporting countries, while nontraditional exports and other high-value crops could be important sources of growth in some countries along the West African coast.

This timely analysis will be a valuable resource for both policymakers and donors interested in identifying priorities for research and development investments in Africa. Equally important, this study also contributes an innovative methodology that can be further developed and applied elsewhere, providing a more complete picture of the potential spatial and economywide impacts of investment in agricultural research and development.

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Director General, International Food Policy Research Institute

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Acronyms and Abbreviations

AEZ	agroecological zone
AgGDP	agricultural gross domestic product
CAADP	Comprehensive Africa Agriculture Development Programme
CAR	Central African Republic
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultural Tropical
CIESIN	Center for International Earth Science Information Network
CORAF/ WECARD	West and Central African Council for Agricultural Research and Development
DRC	Democratic Republic of Congo
ECOWAS	Economic Community of West African States
EMM	economywide multimarket
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GE	generalized entropy
GIS	geographic information system
GNI	gross national income
HYV	high-yield variety
IAC	InterAcademy Council
IFAD	International Fund for Agricultural Development
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis

IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Centre for Africa
LGP	length of the growing period
MBS	marginal budget share
MDGs	millennium development goals
MPC	marginal propensities to consume
NBER	National Bureau of Economic Research
OPV	open pollinization variety
PFP	partial factor productivity
RSLI	ratio semilog inverse function
SAA	Sasakawa Africa Association
SAGE	Center for Sustainability and the Global Environment
SPAM	spatial production allocation model
SSA	Sub-Saharan Africa
TAC	Technical Advisory Committee
TFP	total factor productivity
UN	United Nations
UNIDO	United Nations International Development Organization
WARDA	Africa Rice Center

Summary

We identify a set of development priorities for agriculture that cut across West Africa at both the country and regional levels to achieve economywide growth goals in the region. To do this we adopt a modeling and analytical framework that involves the integration of spatial analysis to identify yield gaps determining the growth potential of different agricultural activities for areas with similar conditions and an economywide multimarket model to simulate ex ante the economic effects of closing these yield gaps. Results indicate that the greatest agriculture-led growth opportunities in West Africa reside in staple crops (cereals and roots and tubers) and livestock production. Contributing the most to agricultural growth in the Sahel are livestock, rice, coarse grains, and oilseeds (groundnuts); in Coastal countries, staple crops such as cassava, yams, and cereal seems to be relatively more important than other subsectors; and in Central Africa livestock and root crops are the sources of growth with highest potential. Our results also point toward an essential range of policies and investments that are needed to stimulate the productivity growth of prioritized activities. These include developing opportunities for regional cooperation on technology adaptation and diffusion, strengthening regional agricultural markets, exploiting opportunities for greater regional cooperation and harmonization, diversifying traditional markets, and enhancing linkages between agricultural and nonagricultural sectors.

CHAPTER 1

Introduction

Many African countries have undergone a number of development initiatives over the past four decades to find ways to spur growth and development that will enhance welfare and provide a more humane lifestyle for its citizens. Among them, the experience of countries in West and Central Africa provides a useful backdrop of the kinds of hurdles and challenges that have faced the region on the road toward achieving these goals. Out of 16 countries in this region, only one (Ghana) is on track to halving poverty and hunger by 2015 (Breisinger et al. 2008), a shared commitment among many countries in the region to the United Nations millennium development goals (MDGs). Achieving this goal requires consistent and broad-based growth accompanied by dramatic improvements in infrastructure, governance, and a host of social indicators. This is a significant challenge for most poor African countries faced with limited resource endowments, a harsh physical and socioeconomic environment, and a predominantly rural and agrarian population. In West Africa these challenges are especially pronounced given the region's poor overall economic performance, compounded by periods of political instability and erosion in both physical and human capital. Moreover, the small size and isolation of many of the economies in the region, their fragile agroecologies and high dependency on rainfed agriculture, and their frequent susceptibility to droughts and tropical diseases, make generating any growth especially challenging (Abdulai, Diao, and Johnson 2005).

A key sector in the overall performance and rural welfare of the region's national economies is the agricultural sector. Although most of the economies in West and Central Africa depend on agriculture for export revenues, employment, national income, and rural livelihoods, agriculture remains characterized by small family farms that still rely heavily on rainfed production systems, natural methods for soil fertility maintenance, and infrequent year-long access to large market centers. Consequently, a majority of rural West African farmers continue to face low productivity and high production and marketing risks, which in turn increase the variability in production and income growth of the sector. The use of modern inputs—such as irrigation, fertilizer, and improved seeds and machinery—remains very limited. Although this is hardly an encouraging picture, it offers West African countries the opportunity for rapid growth by closing the gap between current and potential production and productivity in the region. It also fuels the need for a sustained agriculture-led growth strategy that would allow the region to meet or at least approach the MDGs.

The primary purpose of this monograph is to identify a set of alternative development priorities that tap into the potential for agricultural productivity growth in the crops and livestock sectors and cut across West and Central Africa to achieve economywide growth goals in the region.[1] In other words, the focus of this study is on defining development priorities by looking at the potential impact of different activities on economic growth. It is important to note, however, that this study does not discuss how this growth can be brought into effect. This question, involving the analysis of policies, investments, and their overall economic and social impacts, is beyond the scope of this study. Another limitation of the study is that no consideration is given to how future climate change can affect our estimated growth potential and thus the conclusions of our study.

To identify priorities to accelerate growth in the region, our methodology needs to be derived from both an aggregate economywide perspective and a spatially disaggregated one, given the diverse economies, underlying constraints, and opportunities facing the region. In what follows we introduce the approach used to define priorities for agriculture in West Africa and outline the contents of the study.

The presence of different agroecological conditions within West Africa suggests that even as the entire region relies heavily on agriculture as a way of life or a driver of growth, agricultural and growth performances will vary considerably depending on the location. For instance, many of the countries in the coastal areas, which have witnessed considerably better agricultural and overall economic performance, have also seen greater reductions in poverty. In contrast, countries in the Sahel have witnessed lower agricultural growth rates and little change in poverty rates. Therefore, any study that attempts to examine regionwide policy options for agriculture cannot do so without accounting for such diversity. In recognition of this, the economic analysis in this monograph was conceived, from the very beginning, as a series of integrated analytical steps that can explicitly capture the diversities within and

[1] The focus region of this study includes countries that are members of CORAF/WECARD, the West and Central African Council for Agricultural Research and Development. These countries are Benin, Côte d'Ivoire, Ghana, Guinea, Liberia, Nigeria, Sierra Leone, Togo, Cameroon, the Central African Republic, Democratic Republic of Congo, Republic of Congo, Gabon, Burkina Faso, Cape Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, and Senegal.

across countries while analyzing national and regionwide options for attaining higher agricultural and economic growth rates. We highlight what we consider innovative elements in the literature on the identification of policy priorities.

First, we distinguish the impacts of agroclimatic and economic factors by taking advantage of databases assembled in recent years in part to study the effects of climate change. These data provide a consistent and more detailed description of the weather, soils, and hydrology of West Africa than has been previously available. Second, we use these spatial databases to estimate the yield gaps for 40 agricultural products, taking into consideration specific agroecological conditions at the pixel level to determine potential yields and yields obtained at present under farming conditions. Third, we complement estimates of yield gaps by a review of the literature on agricultural innovation and adoption of new technology to check yield gap estimates and better justify our results. Fourth, we develop a multimarket model that links the detailed information on specific agroecological conditions to markets by calibrating supply functions to the available spatial information on agroecological zones. Fifth, we develop an economywide model that determines household income endogenously, allowing us to capture the impact of differential agroecological conditions and technological possibilities on growth, demand, and welfare.

This integration of location (with all its dimensions of market access, demographics, and agroclimate variation) with an economywide model is key to better understanding the potential for technology use and is a major contribution of this study. (For the importance of integrating spatial information in economic analysis see, for example, Staal et al. 2000, 2002; Bullock, Lowenberg-DeBoer, and Swinton 2002; Mertens et al. 2002; Kristjanson et al. 2005; Lesschen, Verburg, and Staal 2005; Baltenweck and Staal 2007; Bell and Dalton 2007; Gibson and McKenzie 2007.) Our approach also contributes to the economic modeling literature by the innovative approach of calibrating an economywide model to detailed spatial information (see Croppenstedt et al. 2007 for a recent survey of multimarket models).

A first step in our analysis is to use a geographic information system (GIS) model (see methodology in Chapter 3) to pinpoint those geographic areas across the region in which development problems and opportunities are likely to be similar. Teasing out the effects of increased productivity for a given location requires knowledge of the location's ability to produce and generate increases in productivity. We have used a combination of three factors to determine the site-specific growth potential: agricultural potential (biophysical elements), market access, and population density, all of which are part and parcel of the determinants of productivity. The combination of these three factors gives rise to so-called development domains (Wood et al. 1999), which are a tool for researchers to use to assess areas within regions or countries with similar growth potential. Introducing these elements into the model allows for a greater understanding of the region's response to policy interventions, as well as the degree to which responses vary within the region.

A methodological contribution to the spatial analysis in this study is the application of generalized entropy (GE) methods to allocate the production and area of different crops (originally collected at the district or province level) at a more disaggregated, that is, pixel level, which can then be aggregated to the desired development domain level (see You and Wood 2006; You et al. 2007; and this volume, Chapter 3, for details). Combining the development domain information with the aggregated crop production/yield information allows us to calculate crop- and domain-specific yield gaps, defined as the difference between potential and actual yield. Properly and correctly identifying these gaps for the various development domains provides an increased level of confidence in the elaboration of strategies or policies that may be developed to close or reduce these gaps. This happens as the targeting and intensity with which interventions need to occur become much more precise from a geographic and biophysical perspective, because individual locations have varying gaps.

The core analysis of future options for growth relies on a regional and economywide multimarket (EMM) model developed for West and Central Africa. The model uses the information on yield in the different development domains defined by the spatial analysis to simulate ex ante the effects of closing the yield gaps to maximize production possibilities. The model estimates the contributions to overall economic growth among different crops and agricultural activities obtained from bridging the yield gaps. By using valuable information on actual yield gaps within each development domain, the analysis ensures sufficient robustness and accuracy in estimating the likely effects of policy interventions on economic welfare and growth given local agroclimatic conditions, farming systems, market access, and population density. Ultimately, this is intended to provide a set of strategic policy recommendations that are fully cognizant of the region's underlying factor endowments and potential for generating sustained growth in agriculture and the overall economy.

Altogether, the modeling and analytical framework adopted in this monograph involves the application and integration of various economic and statistical tools, which results in a number of unique advantages. First, detailed spatial information, GIS analysis, and the use of a spatial production allocation model (SPAM) are needed to estimate meaningful yield gaps at a disaggregated level, where conditions for agricultural production are homogenous. Second, the framework maintains an *economywide* perspective through the use of the multimarket model, which incorporates the detailed spatial information, including that on the production of different crops, with information on agriculture and nonagriculture production, consumption, prices, and trade.

Aside from the methodological contributions, this monograph has resulted from extensive research in the literature on the role of agriculture in West and Central Africa. It reviews the theoretical arguments and evidence as well as the unique challenges and opportunities affecting the performance of the sector and its potential to affect growth and poverty reduction in Africa in general. This review, together with the integrated pieces of analysis included, enriches the literature and evidence on the future alternatives for achieving such goals in West and Central Africa.

The monograph is organized as follows. Chapter 2 presents a general characterization of agriculture in West Africa,[2] showing how supply- and demand-side factors affect agricultural potential in different West African regions. On the supply side, we look at the importance of the sector in the region's economy, the quality and spatial distribution of natural resources determining the potential for agricultural production, major commodities produced in different regions, and the performance of agriculture in recent years. On the demand side, our focus is on staple crops and livestock, mainly because of the potential constraint that demand for these products could impose on the expansion of output in the region through a drop in prices of agricultural goods. This discussion is followed in Chapter 3 by the methodological approach developed to assess the future regionwide strategic options for stimulating agricultural growth. The spatial analysis helps to initially define the development domains that are used as the basic units of analysis in the economic simulation models. Meanwhile, the basic structure and components of the economic simulation model used in this study (the multimarket model) are developed to reflect the typical supply and demand characteristics reviewed earlier in Chapters 2. The estimation of yield gaps associated with each development domain and generated from the spatial analysis is introduced in Chapter 3. These yield gaps are a key input of our analysis and are used in the EMM model to define productivity growth scenarios for closing the yield gaps.

Chapter 4 presents a brief discussion of yield gaps as measures of potential output growth, comparing them with the concepts of technical and allocative efficiency and total factor productivity and pointing at some of the limitations of this approach. We then proceed to define yield gaps and to describe

[2] Hereafter we will refer to our focus region as West Africa, which includes, unless otherwise stated, Central African countries as well.

the methodology followed to estimate them, presenting summary results of yield gaps for different crops. This is followed by a discussion of the evidence found in the literature on the availability of production technologies in the region. We contrast this information with our yield gap estimates as a way to check whether the estimated gaps are supported by evidence of existing technology in West Africa. The chapter ends with a broader discussion that goes beyond technical aspects of production, reviewing some of the recent ideas and hypotheses about the problem of agriculture intensification in West Africa.

Definition of the main scenarios and the results of the simulations using the EMM model are presented in Chapter 6, focusing attention on measuring the impact of each growth scenario on agricultural and overall economic growth. Based on these results, we discuss how the different crop and livestock products and growth scenarios compare across countries—in terms of their impact on growth and relative to the 6 percent agricultural growth target of the Comprehensive Africa Agriculture Development Programme (CAADP)[3]—to define priority subsectors and corresponding policy and investment options. This final chapter offers conclusions and policy implications.

[3] CAADP is one of the programs of the New Partnership for Africa's Development, an economic development program of the African Union adopted at the 37th session of the Assembly of Heads of State and Government in July 2001 in Lusaka, Zambia. CAADP is aimed at assisting the launching of a "green revolution" in Africa, based on a belief in the key role of agriculture in development.

CHAPTER 2

The Importance of Agriculture: The Economy and Regionwide Context

Agriculture Potential: Supply-Side Considerations

The theoretical and empirical literature suggests that the role of agriculture in the economy is highly related to a country's stage of development (Johnston and Mellor 1961; Block and Timmer 1995; Kydd et al. 2004; Hazell and Diao 2005). With most West African countries classified as low-income countries, agriculture comprises a large share of their national economies (see Figure 2.1 for an overview of the countries in West and Central Africa and Table 2.1 for the importance of agriculture in those countries).[1]

Although there is a rapidly increasing industrial sector in some West African countries rich in minerals or oil, agriculture comprises an average of close to 30 percent of the region's gross domestic product (GDP) and contributes a considerable share to agricultural processing industries and the service sector. In 2003–06, agriculture accounted for 31 percent of the region's total GDP, averaging shares from 27 to 33 percent in the three major subregions identified by CORAF/WECARD: the Coastal, Central, and Sahel regions.[2] However, these subregional averages mask large differences across countries. For example, Table 2.1 shows that agriculture accounts for 61 percent of national GDP in Guinea-Bissau and 56 in the Central African Republic, but only 5 and 8 percent, respectively, in the oil-rich, middle-income Republic of Congo and Gabon. These countries are among the four countries (the others being Guinea and Senegal) in West Africa for which agriculture accounts for less than 20

[1] The World Bank uses gross national income (GNI) per capita to classify countries as low income, middle income (lower and upper), and high income. Almost all West and Central African countries are classified as low-income countries (less than 2008 US$905 of GNI in 2006). Exceptions are Cameroon and Republic of Congo (lower middle income) and Gabon (upper middle income). Small and oil-rich Equatorial Guinea is actually the country with the highest income per capita but is not included in this discussion because it is not part of the group of countries in CORAF/WECARD (see note 1 on page 2).

[2] Find information from CORAF/WECARD at <http://www.coraf.org/English/en.php> and in CORAF/WECARD (2009).

Figure 2.1 Countries in West and Central Africa

Source: CORAF/WECARD (2009).

percent of total GDP. For the rest of West Africa, agriculture shows a strong potential to serve as a driver of growth and poverty reduction.

As shown in the third column of Table 2.1, most West African countries also have large rural populations, accounting, on average, for 68 percent of the total population in the Sahel, 58 percent in Coastal countries, and 47 in Central countries. Moreover, poverty rates are above the Sub-Saharan Africa (SSA) averages of 50 percent in 9 of 19 countries for which information is available. Of these, 5 countries (Guinea, Nigeria, the Central African Republic, Chad, and Niger) show poverty rates above 60 percent, with a large share of the poor in these countries living in rural areas.

In this context, agriculture still provides, on average, the dominant livelihood for 60 percent of the population, with most of regional poverty still concentrated in rural areas among smallholder farmers. Generating higher agricultural growth, particularly in the smallholder sector, would increase

Table 2.1 Income, agriculture, and poverty in West and Central Africa, 2003–06

Region/country	GDP per capita (2000 US$)	Rural population (%)	Share of AgGDP in GDP (%)	Poverty headcount, 2003[a] (%)
Coastal				
Benin	323	60	32	47
Ghana	278	53	37	30
Guinea	400	67	18	70
Côte d'Ivoire	560	55	24	23
Nigeria	418	52	22	64
Sierra Leone	212	60	46	53
Togo	240	60	42	39
Sahel				
Burkina Faso	250	82	32	57
Chad	251	75	25	62
Gambia	311	47	32	34
Guinea-Bissau	134	70	61	49
Mali	282	70	37	51
Mauritania	446	60	22	21
Niger	166	83	40	66
Senegal	489	58	17	34
Central				
Cameroon	678	46	21	33
Central African Republic	219	62	56	62
Congo, Democratic Republic of	88	68	47	59
Congo, Republic of	1,082	40	5	54
Gabon	4,249	17	8	n.a.
Coastal	347	58	32	47
Sahel	291	68	33	47
Central	1,263	47	27	43
West Africa	630	59	31	46

Source: World Bank (various years).
Note: AgGDP means agricultural gross domestic product; n.a. means not available.
[a]The percentage of the population earning US$1.25 a day. The year of the measure for different countries varies between 2000 and 2003.

rural incomes and food supplies. It would also stimulate broad-based economic growth through linkages with the nonagricultural sector. By contrast, growth in the nonagricultural sector alone, especially in the mineral-based industrial sector, would not have a broad impact on poverty reduction (Fan, Chan-Khang, and Mukherjee 2005).

Natural Resources and Absolute Advantage in Agriculture

Agriculture's overall contribution to economic growth depends in part on the quality of natural resources used in production, which is a strong indicator of the absolute advantage of agricultural production for any particular location. Within West Africa, where agriculture is dominated by subsistence-oriented smallholders, two of the most binding constraints on agricultural production potential are water availability and soil quality.

On a very broad scale, there are at least four distinctive agroecological zones in West and Central Africa: the humid, semihumid, semiarid, and the arid zone (see Dixon, Gulliver, and Gibbon 2001). While the first three are suitable for agriculture growth, the arid zone of the Sahel has very limited rainfall and little vegetation coverage and is hence used primarily for livestock herding. Given that much of smallholder agriculture is rainfed, a key measure of the agricultural potential is the amount of rainfall, which is one of the determining factors of the length of the growing period (LGP) and whether crops can complete their natural growth cycle (Voortman, Sonneveld, and Keyzer 2000).[3]

Table 2.2 breaks down the LGP by crop, pasture, and rural population shares. Across West and Central Africa, 47 percent of cropland and 53 percent of the population fall within areas where the LGP exceeds 6 months per year. There is considerable variation across countries, and much of it is captured by the major ecozone groupings. These, in turn, influence the types of cropping systems found in each major agroecological zone.

In the semiarid zone, for example, the dominant products are traditional coarse grains, such as sorghum and millet, and livestock. This zone is also particularly vulnerable to climatic variability, including frequent droughts as well as flooding. The droughts in the region produce serious crop failures, resulting in declining terms of trade for both livestock and cereals (cereal prices rise, while livestock prices decline) and in widespread hunger and famine at the extreme. The duration of periods of low rainfall (dry spells) versus high (wet spells) can last for decades. In fact, the Sahel has been in a relatively drier spell beginning with the drought of the 1970s after experiencing a wetter period in the 1950s and 1960s (Figure 2.2). Despite the dry climate, the irrigation levels in the Sahel are extremely low, even where irrigation is the only viable option for crop production. Less than 2 percent of cropland in the Sahel is irrigated, even in those countries where irrigation is more common.

In West and Central Africa's sizable humid zone, which is found mainly within the Coastal and Central regions, common threats to agricultural production are related more to forest degradation, labor constraints, pests, and diseases. Cropping systems are typically mixed and characterized as forest-

[3] The LGP measures the total number of months that rainfall exceeds evapotranspiration, leaving sufficient excess water to support the growth of crops and pasture.

Table 2.2 Crop, pasture, and rural population shares in West and Central Africa by length of growing period

Length of growing period (months)	Crop area (thousands of ha)	Pasture (thousands of ha)	Rural population (thousands)	Crop area (%)	Pasture (%)	Rural population (%)
0	466	42,540	2,732	1	17	1
1	40	9,057	1,681	0	4	1
2	1,543	23,697	10,432	4	10	5
3	9,211	26,100	22,961	22	11	11
4	5,408	27,519	21,301	13	11	11
5	1,427	17,873	17,297	3	7	9
6	4,296	28,896	17,692	10	12	9
7	5,407	26,733	21,754	13	11	11
8	3,965	15,745	25,085	9	6	13
9	5,705	18,168	33,164	14	7	17
10	2,454	8,390	18,536	6	3	9
11	1,071	2,047	4,585	3	1	2
12	968	1,249	2,839	2	1	1
West and Central Africa total	41,961	248,014	200,059	100	100	100

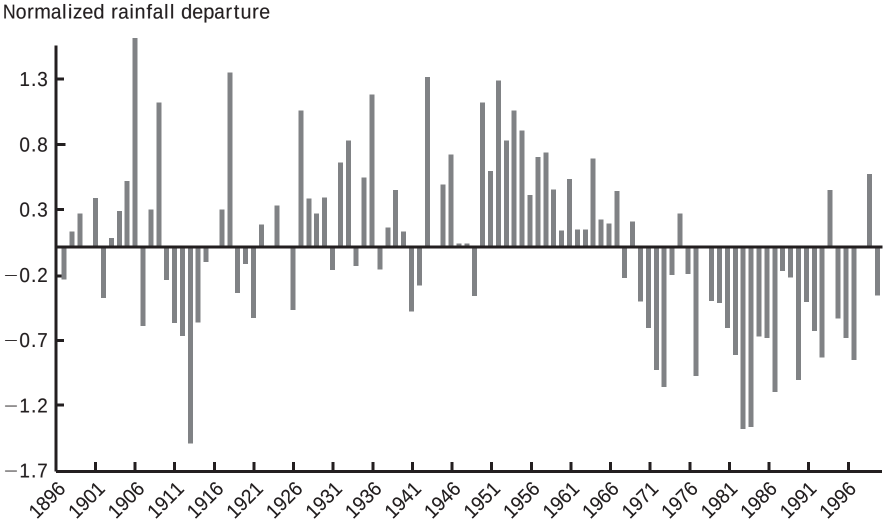
Source: Authors' calculations based on Fischer, Velthuizen, and Nachtergaele (2002) and FAO (various years).

based or tree-crop-based systems. The most common tree crops grown include cocoa, palm oil, coffee, and rubber, which serve as the region's primary agricultural exports. Thus, typically tree crops are integrated with food crops, including roots and tubers such as yams and cassava.

In the semihumid zone, located between the humid and semiarid zones, land is more abundant and the major cropping systems are either root-crop-based or maize-based systems. Typical crops include cassava, maize, pulses (or legumes), coarse grains, and cash crops such as cotton. Due to its relatively lower population densities and land availability, this zone has always been regarded as having greater agricultural potential (Dixon, Gulliver, and Gibbon 2001), especially with agricultural intensification, as has occurred in the cotton and maize zones of West Africa (for example, Benin, Burkina Faso, and Mali).

With respect to livestock, we can observe a clear spatial stratification of production systems because of the constraints imposed in the region by trypanosomiasis. Pastoral grazing systems are found mostly in the northern part of the region, mixed crop-livestock systems in the subhumid unimodal rainfall zone. Specialized intensive livestock periurban systems (for example, poultry

Figure 2.2 Time series of departures from average normalized April–October rainfall for 20 stations in the West African Sahel, 1896–1996



Source: Elaborated by authors from data in L'Hote et al. (2002), Table 2.

production) can be found around major cities, most of which are in the southern region along the coast. Historically, livestock raised in grazing systems in the north have subsequently been transported to the south, often over a distance of 1,000 kilometers or more, for sale in urban areas (Tarawali et al. 2004).

A growing population has begun to put some pressure on land resources in both the humid and the subhumid zones. Already at least half of West Africa's farmland shows some degree of soil erosion due to intensive "mining" practices in which nutrients are removed from the soil but not replaced (see IFAD 2001; Koning, Heerink, and Kauffman 2001). This region is also vulnerable to the likelihood of increased conflicts between farmers and nomadic herders as land becomes more of a constraint.

Much of the region suffers from highly variable rainfall (including frequent droughts and flooding) and vulnerability to pestilence and disease. In this challenging and unstable environment, in which the majority of farmers rely on rainfed irrigation, the availability of water is generally the binding constraint.

Spatial Distribution of Population

As mentioned earlier, agroecological conditions determine the agricultural potential and the absolute advantage for agricultural production of a particular location. However, a region's comparative advantage, or the extent to which this potential might actually be realized, is conditioned by other factors, of which population density and market access have been shown to be reliable predictors (Pender, Place, and Ehui 1999).

Agricultural production and people are concentrated in the Coastal region (41 percent of total production compared to only 9 and 8 percent in the Sahel and Central regions) and along the Niger River and in the Great Lakes region on the eastern Democratic Republic of Congo (DRC) border. The Coastal region is also the one with the highest population density: 0.73 people per hectare of total area compared to 0.36 for the Sahel and 0.15 for the Central region. On the other hand, pastoral lands (two-thirds of the area) tend to have low population densities and are mainly concentrated in broad West-East swathes that correspond to Sahelian grasslands with low rainfall and to the savannah and mixed root-crop areas found in the northern portions of coastal West Africa. Sahelian cropland is strongly associated with the river systems in the area, although irrigation levels are extremely low: only 1 percent of croplands are irrigated regionwide and less than 2 percent in the Sahelian countries.

The spatial information on agroecological zones and population density presented here is used later together with information on market access to define geographic areas endowed with similar realizations of these three attributes, for which a given agricultural development strategy is likely to have similar relevance (these are the so-called development domains; see Wood et al. 1999). The definition of areas with similar agricultural potential is presented in the methodology chapter.

Structure of Agricultural Production

The contrasting conditions in terms of agroecological endowments and population density determine considerable variation in the structure of agricultural production across countries (Table 2.3). Much of this variation is captured by the major ecozone groupings shown in Table 2.2. With restrictive conditions for agriculture, livestock production in the Sahel shows a share of 35 percent in total agricultural output, compared with only 19 percent in Coastal countries. The main livestock products are beef and milk, along with sheep and goat meat in the most arid environments. Agriculture in the Sahel is limited to cereals such as sorghum and millet, while maize is grown in areas where water is less restrictive; rice is mostly under irrigation where the total irrigable lands are estimated to cover about 2 million hectares, in Burkina Faso, Mali, Niger, and Senegal. This is more than 10 times the current irrigated surface area in the four countries. Looking at average output shares in the Sahel, we verify that livestock, cereals, and export crops explain more than

70 percent of the total output in the region. Cotton produced for export also contributes significantly to the total agricultural output in the Sahel. Oil crops and pulses are also important in the region, in particular groundnuts, a crop adapted to low humidity. The major producing areas for this crop are in northern Guinea in ecological zones north of 10° N latitude, where the soils and agroclimatology conditions are favorable.

West Africa's sizable semihumid and humid regions are found mainly within the Coastal and Central regions. Production in these regions is more diversified, including West Africa's most common tree crops, cocoa and coffee, and fruits and vegetables. These are the region's primary global exports and are produced in the humid zones. Root-crop farming systems including yams and cassava, and mixed farming systems including crop-livestock and cereal–root crop systems are also prevalent in the semihumid and humid zones of Coastal countries. As shown in Table 2.3, cereals, export crops, roots and tubers, oil crops and pulses, and fruits and vegetables all contribute similar shares to total agricultural output in the region. In Central Africa, roots and tubers and fruits and vegetables are the dominant products, explaining, on average, more than 50 percent of total output. Although water availability is not a concern, farming systems in these areas face considerable challenges, including soil erosion, weeds, pestilence, and disease. In addition to these biotic constraints, heat and humidity require special transport and storage mechanisms.

Table 2.4 summarizes the main characteristics of agricultural production in West Africa, showing input relationships and land and labor productivity reflecting the relative use and abundance of land, labor, and capital in the region. The poor environment for agricultural production in the Sahel is reflected in the higher number of workers and animals per hectare of arable land and the lower output per hectare and worker obtained compared to the Coastal region. There are no major differences in the use of fertilizers and tractors between regions, with both factors used at very low levels compared to those observed in other regions of the world. The Central region, with abundant natural resources relative to labor, uses land intensively, saving in the use of labor and obtaining, on average, the lowest output per hectare among the three subregions.

Agricultural Performance and Prospects for Future Growth

Production and Productivity

A common characteristic of most West African countries is that their agricultural sectors have not performed at the levels required to make meaningful contributions to growth, poverty reduction, and food security. Between 1967

Table 2.3 Average agricultural subsector output, as a percentage of total national agricultural output, in West and Central Africa, 2000–03

Country	Rice	Other cereals	Export crops	Roots and tubers	Oilseeds and pulses	Fruits and vegetables	Beef and milk	Shoat meat	Chicken and pig meat	Crops	Livestock	Total output
Benin	1.3	11.9	25.1	21.3	16.1	14.5	4.8	1.1	3.8	90.2	9.8	100.0
Ghana	2.3	8.1	13.9	27.6	8.6	30.4	1.7	1.3	6.1	90.9	9.1	100.0
Guinea	19.4	1.6	6.6	9.9	16.6	30.6	10.2	1.7	3.3	84.8	15.2	100.0
Côte d'Ivoire	7.9	3.3	48.8	4.0	6.2	22.3	2.5	0.4	4.6	92.4	7.6	100.0
Nigeria	4.9	18.4	3.8	19.7	17.7	21.2	4.3	2.9	7.2	85.7	14.3	100.0
Sierra Leone	21.3	2.0	9.9	10.6	14.1	25.6	4.2	1.2	11.0	83.6	16.4	100.0
Togo	3.5	21.1	27.8	12.6	12.8	9.3	2.5	3.1	7.3	87.1	12.9	100.0
Burkina Faso	1.5	28.1	15	0.3	19.4	3.5	19.0	5.2	8.0	67.8	32.2	100.0
Chad	2.6	17.2	10.6	3.4	28.3	3.8	23.8	6.1	4.2	66	34	100.0
Gambia	5.6	22.7	0.1	0.5	54.8	2.6	8.5	1.6	3.6	86.3	13.7	100.0
Guinea-Bissau	11.6	5.6	1.4	6.5	7.4	48.1	8.4	1.8	9.4	80.5	19.5	100.0
Mali	11.3	15.7	19	0.5	9.6	4.6	18.2	8.1	13.1	60.7	39.3	100.0
Mauritania	5.1	2.8	0	0.2	4.5	0.4	25.4	25.4	36.3	13.0	87.0	100.0
Niger	1.3	39.1	1.5	1.1	16.7	8.6	13.7	7.4	10.7	68.2	31.8	100.0
Senegal	5.1	15.5	4.7	1.8	39.5	8.4	12.4	4.1	8.7	75.0	25.0	100.0
Cameroon	0.6	8.2	16.6	9.0	13.2	30.7	10.7	2.8	8.2	78.3	21.7	100.0
Central African Republic	1.2	4.1	4.6	8.5	15.5	11.8	36.9	4.0	13.5	45.6	54.4	100.0
Congo, Democratic Republic of	2.7	5.9	3.4	44.7	11.8	21.9	1.1	1.3	7.4	90.3	9.7	100.0
Congo, Republic of	0.2	0.4	6.5	35.8	10.1	24.7	2.1	0.9	19.4	77.7	22.3	100.0
Gabon	0.1	1.9	3.3	10.3	7.1	46.9	1.0	1.1	28.4	69.6	30.4	100.0
Coastal	5.7	14	12.8	17.8	14.8	22.3	4.0	2.2	6.4	87.4	12.6	100.0
Sahel	4.9	22.1	10.3	1.3	20.0	6.3	17.6	7.1	10.5	64.9	35.1	100.0
Central	1.6	6.3	8.5	26.9	12.4	25.1	7.8	2.1	9.2	80.9	19.1	100.0
West Africa	4.9	14.3	11.6	16.1	15.4	19.7	7.3	3.1	7.7	81.9	18.1	100.0

Source: FAO (various years).

Table 2.4 Technical indicators of agricultural production in West African countries, 2000 -03 (average)

Region/country (%)	Output share [a]	Workers per 1,000 ha[b]	Tractors per 1,000 ha[b]	Animals per 1,000 ha[b]	Fertilizer (kg/ha)	Output (international dollars) per hectare[b]	Output (international dollars) per worker[c]
Coastal							
Benin	1.8	557	0.1	323	14.8	495	889
Ghana	4.5	907	0.6	157	2.6	562	620
Guinea	1.3	2,043	0.3	911	2.0	592	290
Côte d'Ivoire	4.8	458	0.6	137	13.0	547	1,193
Nigeria	27.5	472	0.9	321	5.8	664	1,405
Sierra Leone	0.4	1,811	0.1	410	0.4	471	260
Togo	0.7	449	0.0	126	7.0	202	449
Sahel							
Burkina Faso	1.9	1,183	0.4	906	6.4	324	273
Chad	1.3	767	0.0	865	5.1	288	375
Gambia	0.1	1,738	0.1	553	2.5	336	193
Guinea-Bissau	0.2	928	0.0	594	1.7	292	314
Mali	2.1	1,708	0.9	1,451	15.0	586	343
Mauritania	0.4	1,300	0.8	2,576	5.6	623	479
Niger	1.6	315	0.3	109	2.7	86	275
Senegal	1.2	1,286	0.3	751	13.9	368	286
Central							
Cameroon	3.0	519	0.1	462	5.9	325	627
Central African Republic	0.8	628	0.2	865	4.7	298	475
Congo, Democratic Republic of	3.6	1,698	1.8	102	2.1	355	209
Congo, Republic of	0.3	106	1.3	134	7.2	367	348
Gabon	0.3	418	3.0	151	0.6	404	968
Coastal	41.0	957	0.4	341	6.5	505	729
Sahel	8.9	1,153	0.3	976	6.6	363	317
Central	7.9	674	1.3	343	4.1	350	525
All countries	57.8	1,037	1.0	754	9.0	481	463

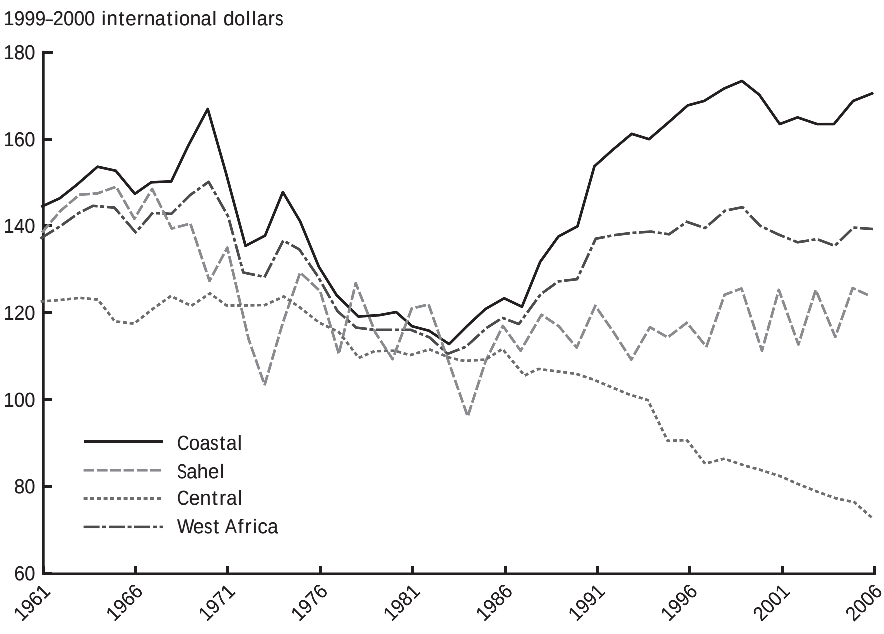
Source: FAO (various years).
[a]Output share in total Sub-Saharan agricultural output.
[b]Land is arable land, that used under annual and permanent crops.
[c]Workers are the economically active population in agriculture.

and 2006, West African countries saw deteriorating levels of per capita production (see Figure 2.3). Production performance was poor during the first half of the period, due in part to policies that were implemented in an attempt to promote industrial growth but actually embodied a bias against agriculture. Policy changes in the mid-1980s resulted in better performance of the agricultural sector, at least compared with previous years. This improved performance is explained by a significant increase in the rate of output growth in Coastal countries. Sahel countries showed only modest recoveries in the 1990s, while the performance of countries in central West Africa was still poor by the end of the period, showing a declining trend in output per capita.

Figure 2.4 shows that agricultural growth in West Africa has historically relied on increased levels of inputs, with output increasing mainly as a result of new land and more labor added to the production process rather than improved productivity.

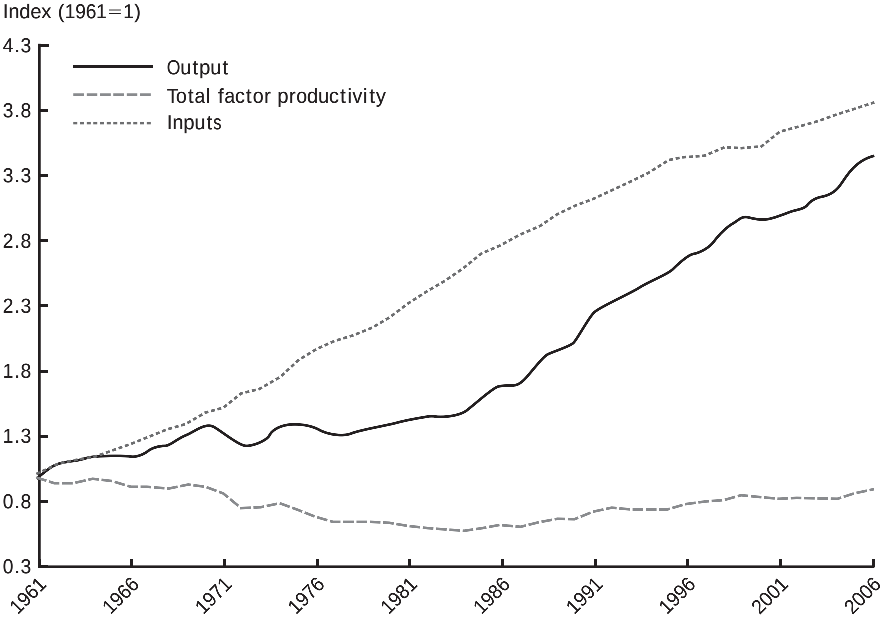
Estimates from Nin-Pratt and Yu (2008) of the evolution of total factor productivity (TFP) at the aggregate level for agriculture and the region in the past 45 years (1961–2006) show that the weighted average annual growth for

Figure 2.3 Evolution of agricultural output per capita in West Africa and subregions, 1961–2006



Source: Authors' calculations using data from FAO (various years).

Figure 2.4 Evolution of agricultural output, inputs, and productivity in West Africa, measured as indexes, 1961–2006



Source: Adapted by authors from Nin-Pratt and Yu (2008).

a group of 19 West African countries was almost zero (–0.05 percent). During 1987–96 there was a clear improvement in the performance of West Africa's agriculture, with average TFP growth rates of about 2.90 percent per year for the region. However, TFP growth slowed down between 1997 and 2006, decreasing to an annual rate of 1.37 percent. Results from this study also suggest a link between policy changes in SSA countries between the mid-1980s and the second half of the 1990s and the improved performance of the agricultural sector. In particular, the recovery that started in the mid-1980s was led by Ghana and Nigeria. Other countries followed after the devaluation of the CFA franc in francophone West Africa in 1994.

Similar results were found for SSA in an earlier study by Block (1995). This study shows that in the early 1980s, SSA reversed its poor performance of the 1970s and started a period of productivity growth. That performance was sustained until the last year for which information was available, in the late 1980s. Block conducted an econometric analysis to measure the contribution of different factors to increased agricultural TFP and found that technical change, measured by expenditures for agricultural research, and macroeconomic reform, which leads to improved economic incentives for agriculture, might account for up to two-thirds of this recovery.

A recent study by Fuglie (2009) also finds that agricultural output growth for the region accelerated in the 1990s. Fuglie's results indicate that most of the recent rise in output growth is due to resource expansion that can be explained in part by improved macroeconomic and political environments. The author also finds evidence that TFP growth improved in some countries (the Coastal countries of Benin, Côte d'Ivoire, Ghana, and Nigeria, as well as Burkina Faso in the Sahel). However, productivity remains low and is falling further behind the global mean.

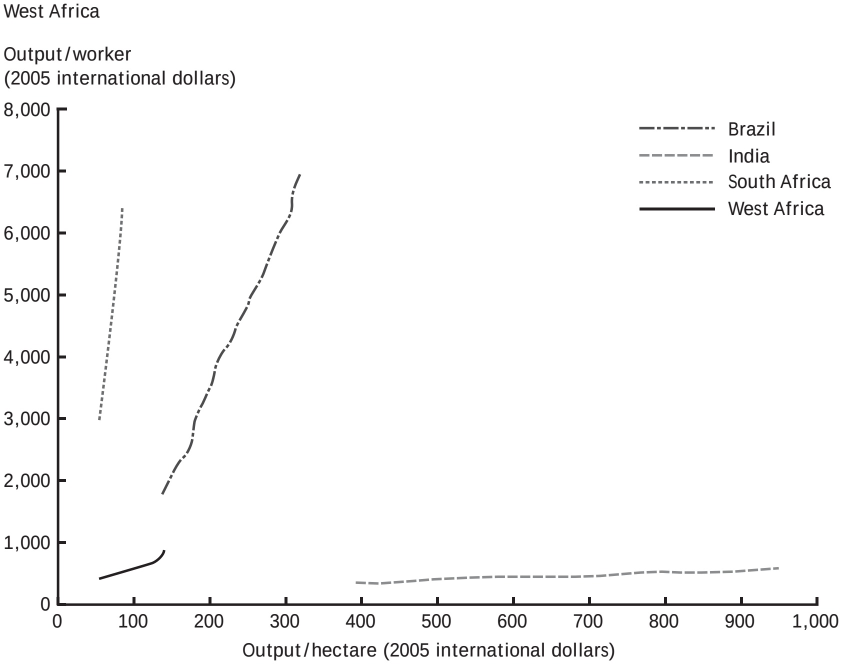
Evidence of the improved growth performance of West Africa's agricultural sector is good news, but it is far from showing that the region is in a sustainable growth path. In many cases, this growth appears to be a rebound after years of stagnant or shrinking TFP, and there are already signs of a slowdown in some countries. For a better perspective on the performance of the region, we compare West African agricultural growth since 1980 with that of other countries using partial factor productivity (PFP) measures.

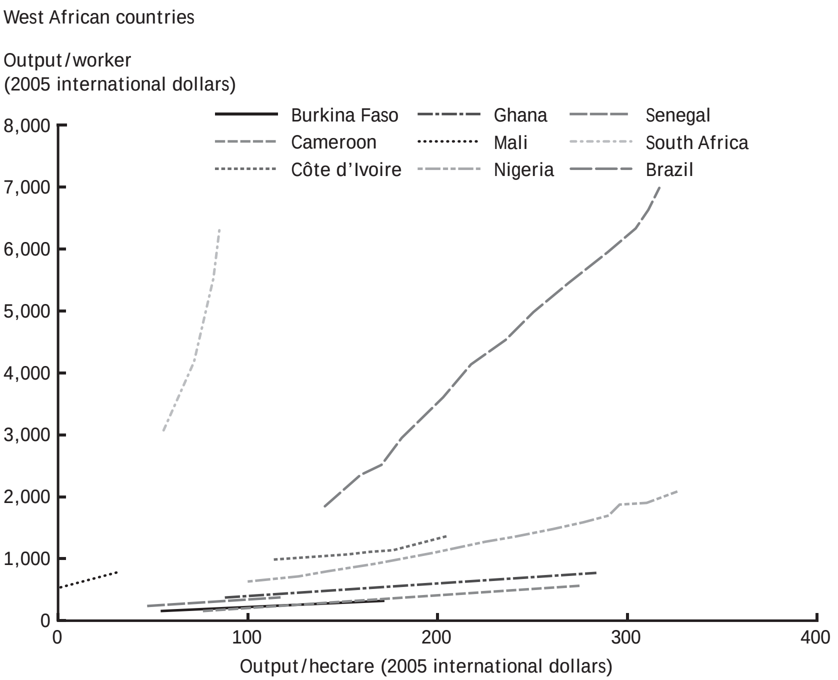
Land and labor PFP measures allow us to check for output growth and the growth path of the region in terms of the intensity of the use of inputs. The top panel of Figure 2.5 plots land and labor productivity in agriculture between 1980 and 2007, comparing West and Central Africa with Brazil, India, and South Africa. Land productivity is measured as the ratio of gross output to the total number of hectares used in agriculture, whether irrigated or non-irrigated cropland, pastureland, or rangeland. Labor productivity is the ratio of gross agricultural output and the size of the economically active population in agriculture. The slope of each region's productivity locus reflects its growth path, where growth paths can be classified into three groups: (1) a land constraint path in which output per hectare rises faster than output per worker, (2) a land abundance path in which output per worker rises more rapidly than output per hectare, and (3) an intermediate growth path in which output per worker and per hectare grow at similar rates.

The top panel of Figure 2.5 reveals several interesting characteristics of the agricultural sector in West Africa. The first thing to notice is the very low level of both land and labor productivity in the region. As expected, India follows a clear land-constrained path and has the highest land productivity. India's land productivity even in 1980 was almost four times that of West Africa in 2007.

More interesting is the comparison between West Africa and labor-constrained Brazil and South Africa. First, the productivity locus for West and Central Africa is much shorter than those for Brazil and South Africa, indicating very poor growth performance. Second, although West Africa appears to

Figure 2.5 Evolution of labor and land productivity, comparing West Africa and selected West African countries with Brazil, India, and South Africa, 1980–2007





Source: Authors using FAO data.

be relatively land abundant, its growth path is relatively flat, indicating modest increases in land productivity and very little growth in labor productivity, putting the region on a similar path to that of South Asia but with much lower growth rates. Finally, it is worth noticing the very low labor productivity shown by West Africa (in 2007 it was one-third of the labor productivity in 1980s South Africa).

The bottom panel of Figure 2.5 plots land and labor productivity in agriculture between 1980 and 2002 as in the top panel, but for selected West African countries. For comparison purposes, values for Brazil and South Africa are also included. All West African countries appear to be following a land-constrained path of productivity growth compared to Brazil and South Africa, increasing land productivity faster than labor productivity. The best growth performers in West Africa appear to be Ghana, Nigeria, and Cameroon. This generalized growth pattern in the region reflects the problems of fast population growth and slow technical change and capitalization experienced by the region in the past 20 years.

Agriculture's Contribution to Overall Economic Growth

What are the implications for economic growth and poverty alleviation of the past performance of the agricultural sector in West Africa? To determine the degree to which agriculture contributes to economic growth within each country, we broke down total GDP growth into the share and growth rates of the sectors. If agriculture has a dominant share in the economy and demonstrates high growth performance, the sector can become a key engine of growth. Conversely, a less dominant, poorly performing sector will contribute little to overall growth.

Between 1986 and 2005, agriculture contributed to about 32.0 percent of West Africa's overall GDP growth, about the same as its share in the economy in 1986 (Table 2.5). In other words, of the region's 2.5 percent annual GDP growth between 1986 and 2005, 0.8 percent can be attributed to growth in the agriculture sector alone. Industry and services combined accounted for the remaining 1.7 percent. The highest rate of agricultural growth occurred in the Coastal region, averaging 3.59 percent per year, almost 1 percentage point above the rate of growth in the Sahel and practically doubling the Central region's 1.92 percent growth rate.

In the Coastal and Sahel subregions, agriculture contributed to 32.3 and 28.9 percent of overall economic growth, which was smaller than the sector's share in these regions' overall economy, indicating a poorly performing sector on the whole, with slower growth in agriculture than in the overall economy due to rapid growth in other sectors. In the Central region, slow growth in nonagricultural sectors resulted in a major contribution of agriculture to

Table 2.5 Contribution of agriculture to overall economic growth in West and Central Africa, 1986–2004 (percent)

Region/country	GDP growth rate	AgGDP growth rate	Share of agriculture (1986)	Contribution to GDP growth: Agriculture	Crops	Livestock
Coastal						
Benin	3.51	4.71	33.7	39.8	100	0
Ghana	4.35	3.13	47.8	31.8	97	3
Guinea	3.64	3.98	23.9	24.2	83	17
Côte d'Ivoire	1.30	2.82	28.5	40.5	92	8
Nigeria	3.99	3.88	38.7	25.6	93	7
Togo	2.25	3.04	34.8	40.4	90	10
Sahel						
Burkina Faso	3.51	3.69	28.4	34.3	70	30
Chad	5.05	3.77	32.6	23.9	80	20
Gambia	3.42	2.35	34.5	24.2	78	22
Guinea-Bissau	1.66	3.28	45.3	91.6	83	17
Mali	4.11	3.35	42.4	34.8	82	18
Mauritania	2.76	-0.46	26.6	-6.1	23	77
Niger	2.20	3.13	34.7	50.9	81	19
Senegal	3.22	2.26	22.3	14.4	35	65
Central						
Cameroon	0.66	2.97	22.4	109.1	74	26
Central African Republic	0.45	2.46	50.3	218.1	4	96
Congo, Democratic Republic of	-2.13	0.85	33.6	-9.0	134	-34
Congo, Republic of	2.13	2.59	12.1	6.3	69	31
Gabon	1.94	0.73	9.2	3.6	77	23
Coastal	3.17	3.59	37.8	32.3	93	7
Sahel	3.23	2.66	31.6	28.9	70	30
Central	0.60	1.92	28.6	65.0	94	6
West Africa	2.51	2.76	34.6	32.0	90	10

Source: World Bank (various years).
Note: AgGDP means agricultural gross domestic product; GDP means gross domestic product.

growth (65 percent of total GDP growth, whereas agriculture contributes only 20 percent to total GDP).

Regional averages mask large variances across countries. Benin, Ghana, Guinea, Nigeria, Burkina Faso, and Chad experienced relatively high agricultural GDP growth rates (3.5 percent and over), while the growth rates in DRC, Gabon, and Mauritania were close to zero. In many of the countries in the Coastal region experiencing high agricultural growth rates (for example, Benin, Guinea, and Nigeria), most of this growth came from crop production, whereas in the Sahelian region we see a larger contribution to growth from the livestock sector. (Thirty percent of output growth in the Sahel is explained by livestock, with an equivalent figure of 7 percent of total growth in the Coastal region and 6 percent growth in the Central region; see Table 2.5.)

With these growth rates in agriculture, only 1 percentage point higher than the region's average population growth rate, West Africa will reach the target of MDG 1 after 2020, many years later than the targeted 2015.[4] Because of the great variation in growth performance, the growth rates required to attain MDG 1 will vary across countries in the region (Table 2.6). For example, due to steady growth over the past 20 years and significant poverty reduction between 1990 and 2004, Ghana does not need a 6 percent agricultural growth rate to achieve MDG 1. This country should be able to meet this poverty reduction target before 2015 even following its current growth path. Unfortunately, many other West African countries would not meet the goal at the national level at their recent rates of growth. Côte d'Ivoire, Guinea, Nigeria, Chad, Guinea-Bissau, and Niger, for example, could need 5–20 years to reach the MDG 1 target. Because of a lack of progressive growth in the 1990s, Guinea-Bissau and Niger will likely need rapid economic growth in the coming years to support a 7–10 percent annual poverty reduction and meet MDG 1; they would need decades to meet the goal doing business as usual.

In this section, we have shown that West Africa has the potential to accelerate growth and contribute significantly to overall economic growth and poverty alleviation in the region. To improve the performance of the agricultural sector, the region will need to increase productivity growth, which in the long run could be achieved by increased investment in agricultural R&D and human capital and infrastructure. However, and given the long-term nature of these investments, we cannot use these instruments to target productivity increases in the medium run to achieve the MDG goals. Instead, and given the time constraint, we need to look at available technologies that resulted from R&D investment in the past and evaluate the potential impact of the application of these technologies on productivity.

Agricultural Markets: Demand-Side Considerations

The previous section focused on the issue of production potential and its determinants on the supply side. Understanding the role of demand and markets is essential, because demand plays a key role in determining whether the gains in outputs will in fact result in welfare improvements in the long run. Without a concomitant increase in demand and functioning markets to distribute and allocate increased production, the drop in prices of agricul-

[4] MDG 1 is to "halve, between 1990 and 2015, the proportion of people whose income is less than $1 a day." United Nations MDG website, <http://www.un.org/millenniumgoals/poverty.shtml>, accessed June 21, 2010.

Table 2.6 National poverty rates and projections for reaching MDG 1 in West and Central Africa

AgGDP share / country	1990 poverty rate[a] rate	2004 poverty [a]	MDG 1 poverty rate	Years to meet MDG 1: Business as usual[b]	Years to meet MDG 1: 6% agricultural growth
AgGDP share below 35%					
Burkina Faso	44.5	40.5	33.7	2018	2015
Côte d'Ivoire	33.6	32.3	17.8	n.a.	2043
Gambia	81.6	60.8	40.8	2021	2012
Guinea	45.7	38.8	22.8	2031	2022
Mali	76.0	60.8	38.0	2024	2014
Nigeria	72.8	68.4	36.4	2032	2021
Senegal	57.9	53.9	29.0	2030	2015
AgGDP share above 35%					
Benin	34.9	30.7	17.5	2015	2015
Cameroon	53	34.9	26.5	2017	2009
Chad	80.8	82.4	40.4	2025	2017
Ghana	52	34	26	2010	2009
Guinea-Bissau	53.4	84.2	26.7	n.a.	2027
Niger	70.8	76.6	35.4	2039	2019
West Africa	60	54.2	30	2022	2015
Africa	44.6	47.5	22.3	2027	2018

Sources: Poverty rates are from available national household surveys. If no national poverty rate is available, data from the United Nations Industrial Development Organization are used.

Note: AgGDP means agricultural gross domestic product; MDG 1 means Millennium Development Goal 1; n.a. means not available.

[a]The countries might not have conducted the surveys in 1990 and 2004, in which case the surveys closest to those two years are used.

[b]With business as usual in nonagricultural growth.

tural goods will certainly affect producers, which in turn will have reduced incentives to invest in ways to further increase production (Poulton, Kydd, and Dorward 2006).

For the purposes of this study, we are particularly concerned with the effects of growth on the demand for food, especially given the importance of food security in a region such as West Africa. Our discussion focuses on the demand for staple crops and livestock for three reasons. First, because these commodities contribute to a large share of total agricultural output in the three subregions considered, faster and sustained growth of staple crops and livestock products is needed to accelerate agricultural gross domestic product (AgGDP) growth. Second, although these commodities play a major role in providing food security, the region has no comparative advantage to become an international exporter of these commodities. As a result, increased production of staple crops and livestock will need to rely on domestic or regional markets, which could impose constraints on agricultural growth, as indeed has been shown to be the case for Africa as a whole and for East Africa (Diao, Dorosh, and Rahman 2003; Diao and Dorosh 2007). In addition, the market for cash and traditional export crops is often subjected to changes in international prices and consumer preferences (related to the types or varieties of crops), as well as the emergence of new competitors. Finally, staple crops and livestock provide an interesting contrast in the changes in consumption patterns as incomes grow, with staple crops normally experiencing a reduction in their share of total consumer expenditure while consumption of livestock products (highly income elastic) increases with income.

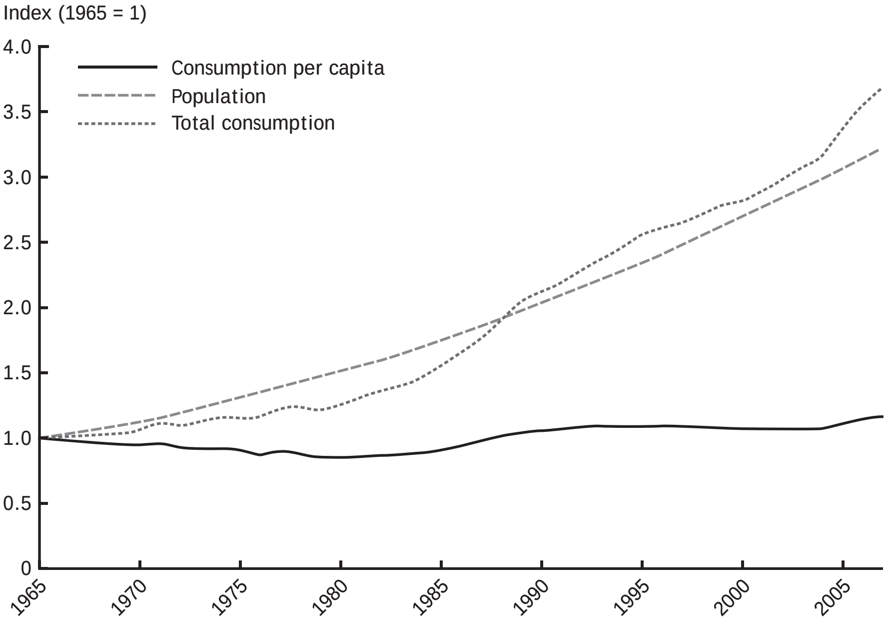
The remainder of this chapter presents an overview of the general trade patterns of agricultural commodities in West Africa, briefly laying out the context in which growth affects demand for food in low-income countries and placing West Africa in that context. It also highlights the importance of staple crops and livestock for the region and the key role that they can play in increasing trade possibilities and providing food security.

One of the most directly observable phenomena that result from growth in poor countries is the increase in the demand for food. This growth can be explained by higher incomes derived from economic growth and by higher population growth rates already observed in poor countries. The importance of income and population growth in determining demand growth depends on the level of pregrowth development. In the very early stages of growth, demand for food can increase up to 30 percent above its previous levels (Mellor 1983). Typically, countries have difficulties in generating enough production to meet the growth in demand, and very often they have to resort to food imports.

In West Africa we observe some of the stylized facts just outlined. Population growth in the region has led to a boost in demand for agricultural foods. That the majority of countries in the region are net importers of most agricultural products suggests that the region was not able to accommodate growth in demand and therefore still resorts to food imports. This is what happened in the case of cereals.

Figure 2.6 shows the cumulative growth of cereal consumption broken down into growth in population and growth in consumption per capita. The population in West Africa more than tripled between 1965 and 2007, and cereal consumption followed population growth, growing faster than the population in recent years due to an increase in consumption per capita. Cereal production could not follow the pace of demand. This resulted in an increase of net imports of cereals as a percentage of the quantity of output produced (Figure 2.7). In 1965 the region imported a volume representing only 5 percent

Figure 2.6 Cumulative growth of cereal consumption in West and Central Africa, 1965–2005, broken down into growth in population and growth in consumption per capita



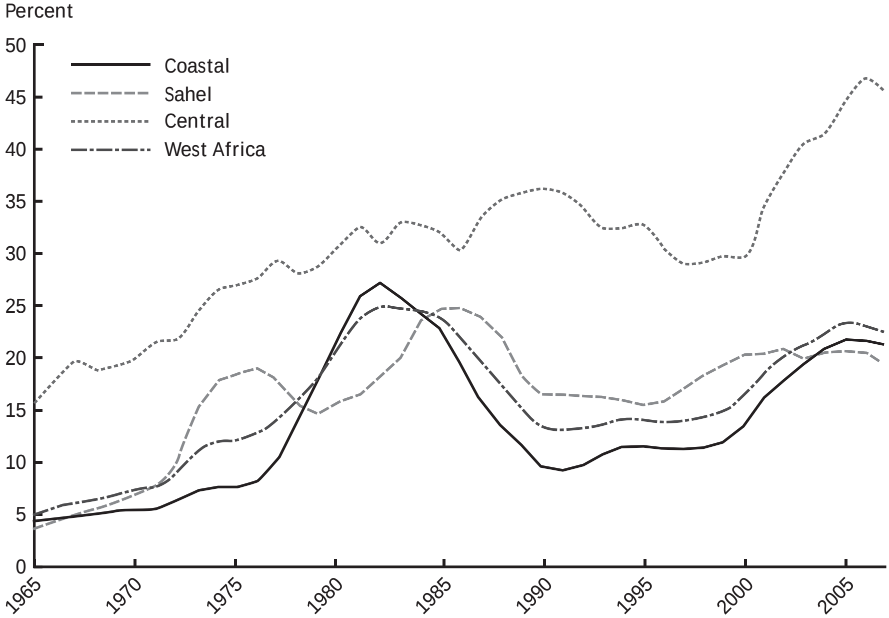
Source: Authors' calculations using data from FAO (various years).

of output. Imports increased to 25 percent of production in the early 1980s, went down to 13 percent in the early 1990s, and increased in the past 10 years to more than 23 percent of production.

Trade profiles across countries vary by crop, food group, and trade destination. We have compiled estimates of trade flows (imports and exports) for four broad groups of commodities (staples and livestock, nontraditional products, traditional products, and other products), each group containing a number of commodities (Table 2.7). For each of these groups, data on exports and imports were also tabulated according to the source/destination of trade. For our purposes, three particular sources/destinations were used: the world (the entire world minus SSA and West Africa), SSA, and West Africa (regional trade). The following discussion refers to these groups as the world, SSA, and the region. We begin our discussion with imports to and from these groups.

Other cereals (those other than maize), fish, and sugar were some of the food items most imported from the rest of the world, accounting for over half of the region's imports (relative to total world imports). Across food

Figure 2.7 Net imports of cereals to West and Central Africa as a percentage of the quantity of output produced, 1965–2005



Source: Authors' calculations using data from FAO (various years).

groups, staples and livestock products were the commodities most imported, accounting for 43 percent of the region's imports. Nontraditional, traditional, and other products accounted for 36, 15, and 7 percent, respectively. These figures change considerably when we look at import patterns from SSA and within the West African region. When the source of imports was SSA, the share of staples in total imports (from SSA) fell to 13 percent, while the share of nontraditional commodities increased to 62 percent. Import shares of traditional and other commodities remained almost unchanged. Fairly similar figures were observed for imports from the region.

On the export side, the most exported crops were cocoa and cotton. These two crops combined accounted for nearly half of the region's total exports to the world. Across different destinations of exports, a very different pattern emerged. Staple crops were a very minimal part (less than 1 percent) of the share of exports to the world, while traditional commodities represented 57 percent of total exports. Patterns of exports to SSA and within West Africa also showed considerable changes.

Nontraditional commodities constituted most of the exports to SSA and to the region (59 and 65 percent, respectively). Staples and livestock, tradi-

Table 2.7 Composition of imports and exports for different sources and destinations, 2007 (percent)

	Import Export							
Import/export category/item	World	Sub-Saharan Africa	West Africa	Share of intraregional trade[a]	World	Sub-Saharan Africa	West Africa	Share of intraregional trade[a]
Staples and livestock								
Cereals excluding maize	29.4	5.8	5.1	2.0	0.3	4.5	5.1	82.3
Meat	12.2	3.5	2.5	2.8	0.2	2.2	2.5	64.9
Livestock	0.5	1.1	0.5	23.0	0.1	2.2	2.6	98.3
Maize	0.3	2.2	2.6	64.4	0.0	0.5	0.5	88.7
Cassava	0.3	0.3	0.2	10.2	0.0	0.0	0.0	0.4
Beans	0.0	0.0	0.0	90.0	0.0	0.2	0.2	67.2
Subtotal	42.8	12.8	11.0	3.0	0.7	9.6	11.0	79.8
Nontraditional products								
Fish	12.3	35.3	37.1	28.8	15.8	31.5	37.1	12.1
Vegetables and fruits	7.8	10.3	12.2	13.2	7.8	2.6	3.0	2.0
Oils and fats	6.5	7.7	8.6	11.9	2.8	10.4	12.2	23.0
Miscellaneous	3.9	3.9	3.0	10.1	2.4	3.5	0.4	8.9
Oilseeds	3.4	2.3	1.9	6.7	1.2	1.5	1.4	7.7
Processed food	1.6	0.7	0.4	4.4	0.9	7.4	8.6	51.5
Beverages	0.3	1.2	1.4	44.4	0.2	1.7	1.9	59.6
Subtotal	35.8	61.5	64.5	17.2	31.0	58.6	64.5	11.5

Traditional products								
Cocoa beans	10.9	4.4	3.0	4.0	32.8	2.0	0.4	0.4
Cotton	1.3	0.8	0.3	6.2	14.5	13.2	8.1	5.5
Coffee, green	1.1	0.9	0.4	8.3	7.5	0.6	0.4	0.5
Cashew nuts	0.9	6.8	8.1	76.2	1.4	0.1	0.1	0.6
Sugar	0.2	1.5	0.4	65.7	0.8	2.7	3.0	21.5
Other nuts	0.2	0.1	0.1	4.3	0.3	1.3	1.4	25.2
Tobacco	0.1	1.1	1.4	89.0	0.1	0.3	0.4	17.4
Tea	0.1	0.3	0.4	31.1	0.0	0.3	0.3	49.1
Other fibers	0.0	0.1	0.1	80.5	0.0	0.0	0.1	14.2
Subtotal	14.9	16.1	14.1	10.8	57.5	20.6	14.1	2.2
Other products								
Processed cocoa	4.1	3.4	3.3	8.3	6.3	2.4	0.5	2.3
Animal skins	1.1	3.9	4.6	35.9	2.0	0.4	0.5	1.2
Coffee, roasted	0.6	1.3	1.3	20.2	1.1	4.0	4.6	22.1
Feed stuffs	0.3	0.5	0.5	19.4	1.0	1.5	1.3	9.2
Cigarettes	0.2	0.1	0.1	4.8	0.3	2.9	3.3	68.1
Spices	0.2	0.4	0.5	20.1	0.1	0.1	0.1	7.6
Subtotal	6.5	9.6	10.4	14.8	10.8	11.2	10.4	6.3
Total (US$ million)	4,437.0	444.0	363.0	10.0	7,084.0	430.0	363.0	6.1

Source: Authors' calculations from United Nations (2007).
Note: "Other cereals" are those other than maize.
[a]Calculated as the share of the value of West African imports/exports from/to Sub-Saharan Africa in the value of West African imports/exports from/to the world.

tional commodities, and other commodities represented, respectively, 10, 21, and 11 percent of exports to SSA and 11, 14, and 10 percent of exports within West Africa. It is worth highlighting that staple crops are to a large extent imported and play almost no role in the region's exports. This disparity between imports and exports once again shows the wide gap between domestic production and consumption and that the region has not been able to meet its internal demand for staples.

The dominance of imports in the region, however, does not translate into a lack of export potential, especially within Africa. Between 1996 and 2000, the annual value of West Africa's agricultural exports amounted to more than US$7.084 billion per year (last row in Table 2.7). Total exports to the region (intraregional trade) yielded US$363 million per year. Within the Economic Community of West African States, intraregional exports equaled about 11.1 percent of total exports. Within the West African Economic and Monetary Union, trade equaled 12.6 percent of total exports (United Nations 2007). Trade in nontraditional goods has also grown, increasing from US$26 million in 1993 to about US$75 million by 2001 (United Nations 2007). These statistics capture only formal trade within the region.

These figures suggest that there is significant potential for agricultural growth in West Africa if countries can successfully tap domestic and regional market opportunities for staples and livestock products, especially given the rapid urbanization trends in the region and the growing imports of these commodities, with domestic demand for food staples (including farmers' own consumption levels) valued at US$20 billion or more (see Hazell and Diao 2005). This is more than three times the level of West Africa's international exports and 50 times the level of intraregional trade captured by official statistics.

CHAPTER 3

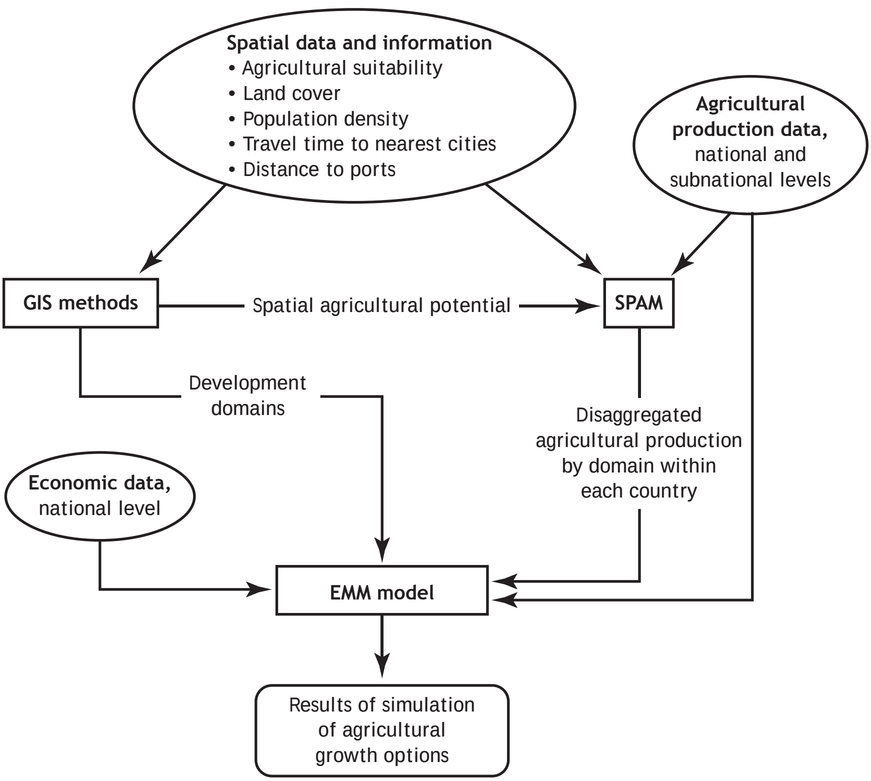
Analytical Approach

In this chapter we present the methodology used to analyze opportunities to accelerate agricultural growth in West African countries. Our approach links different datasets and models and uses detailed spatial information of crop production and production systems, spatial distribution and quality of natural resources, population, and infrastructure within the framework of an ex ante economic model simulation. Three key components characterize our approach. First, our approach uses GIS methods to capture the diverse agroecological, social, and economic conditions of the region to classify West Africa into different homogenous areas or domains according to agricultural development potential as defined in Wood et al. (1999).

The second component in our approach is a SPAM that uses information on agroecological conditions from the development domains and complementary information from different sources to spatially allocate aggregated agricultural production data at a very spatially disaggregated pixel level. Production data allocated at the pixel level are then aggregated again, but now at the development domain level. In this way we obtain the area and production of different crops in different domains that are homogenous in terms of agroecological conditions, population density, and market access. This component is needed because information on the agricultural production of the different countries in the region is available only at the national or subnational administrative level. Production information at this level of aggregation is not useful for our purposes because, to be able to estimate meaningful yield gaps, we need to identify production, areas, and yields at the development domain level in homogenous agroecological and economic conditions.

The third component of our approach is an EMM model developed for West Africa that we use to simulate different growth scenarios by introducing exogenous shocks on productivity. The EMM model uses the outcomes of the other two components of our method as inputs in two ways. First, the specific agroecological and economic characteristics of the development domains are used to calibrate the supply functions in the model so that they reflect the diverse environments and growth potentials in different areas within the region. Information on access to markets and population density in each domain, combined, defines the spatial distribution of demand and costs that producers in different development domains face in gaining access to markets. Second, the yield gaps estimated at the development domain level using SPAM are used to define the productivity shocks for the different scenarios. Figure 3.1 presents a diagram of the three components of our approach as an interlinked framework. Details of these different components are discussed in the following sections.

Figure 3.1 Analytical framework of the authors' approach



Source: Authors.
Notes: EMM means economywide multimarket; GIS means geographic information system; SPAM means spatial production allocation model.

Spatial Analysis Using Geographic Information System Methods

Geographic factors such as agroecological conditions, population distribution, and production and market locations and infrastructure are much more important in agricultural development strategy than in the development of other sectors of the economy. Thus, the first component of our analytic approach involves gaining a better appreciation of regional patterns of agriculture potential and economic factors determining challenges and opportunities for agricultural development. We do this using GIS tools and databases. Visualizing similarities and differences in the context of agriculture across the region is a powerful means to focus attention on areas and issues that span national borders.

We conduct our spatial analysis in two stages. First, we illustrate the spatial extent, distribution, and intensity of cropland and rangelands across the region and juxtapose that information with some of the region's key resources and infrastructure features. Second, we use the information from the first state to disaggregate the region into geographic units (termed "development domains") in which similar agricultural development problems or opportunities are likely to occur. The goal is to use spatial information regarding attributes that constrain or enable different agricultural development options and develop a single set of domain criteria that would allow us to consistently compare strategic options across the region.

There are three key attributes, according to empirical research findings, that need to be considered to define these domains: agricultural potential, population density, and market access. Although the agricultural potential of any location is a strong indicator of its absolute advantage in agricultural production, market access and population density determine its comparative advantage (Pender, Place, and Ehui 1999).

Data used in the spatial analysis are drawn from a wide variety of secondary sources. Satellite-based interpretations of topography and land cover are from the Global Land Cover 2000 Project, the U.S. National Geospatial-Intelligence Agency, and the U.S. National Aeronautics and Space Administration. Population density and human settlement data come from the Center for International Earth Science Information Network and the International Food Policy Research Institute (IFPRI). Road infrastructure data are from the U.S. National Imagery and Mapping Agency and IFPRI. Spatially interpolated rainfall and climate station data are obtained from the U.K University of East Anglia. Regional soil and protected area maps are compiled and harmonized from national sources via the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programmes's World Conservation Monitoring Centre. Biophysical crop suitability information is from the International Institute for Applied Systems and FAO and published in Fischer, van Velthuizen, and Nachtergaele (2002).

Using the spatial information and GIS models mentioned earlier, we first divide the region according to agricultural potential using LGP as the determinant criterion. The implications for agricultural production of different agroecological zones as defined by LGP were shown in Chapter 2.

The second step is to add information on population density to information on the defined agroecological zones. Population density reflects the land-labor ratio, which has been used to explain the allocation of land and labor to production and the use of labor- or land-saving technologies in agriculture (Boserup 1981). Holding other factors constant, farmers in areas of high population density are more likely to undertake labor-intensive production strategies than are those in areas of low population density. The most densely populated areas in West Africa are the Coastal areas along the Niger River and in the Great Lakes region on the eastern DRC border. Population densities tend to be quite low in much of the Sahel region, as well as in the forested areas of Central Africa.

To fully understand how a location's agricultural potential translates into a comparative advantage for different products requires information on access to markets (Omamo 1998a, 1998b). We characterize access based on travel time to a variety of locations with different economic implications. Markets within 4 hours' travel of large cities of 500,000 or more inhabitants, within 2 hours of towns of 100,000 or more, or within 1 hour of towns of 10,000 or more are considered "high-access" areas. Areas of "medium access" are those within 6 hours of large cities, within 4 hours of large towns, or within 2 hours of smaller towns. Other locations are considered "low access." Travel times to target market locations are estimated using a GIS model that jointly assesses information on road location and quality, slope, and off-road land cover.

There are significant areas in both Central African and Sahelian countries that are very far from these regional trading centers. For the region as a whole, over two-thirds of all cropland and almost 60 percent of the rural population are more than 8 hours' travel away from such markets. Only 5 percent of cropland and 7 percent of rural populations are within 2 hours' travel. Using a similar method, we also assess the accessibility of the nearest seaports (for international trade routes), which is an important condition for developing export-oriented agriculture in the region.

The intersection of the three geographic aspects of West Africa just discussed indicates the feasibility and attractiveness of specific agricultural development strategies and livelihood choices in different locations within the region. The distinct areas described by the intersection of these three factors are defined as agricultural development domains—areas for which a given agricultural development strategy is likely to have similar relevance (Wood et al. 1999). Within each domain, the land and output of different crops are defined under assumed levels of inputs and management conditions as belonging to three production system types that obtain attainable crop yields for all major food and fiber crops factors of production. These three production system types are defined in Table 3.1. A map to describe these development domains can be found in Appendix 3A (together with tables showing the distribution of different land types by development domain), where the definition and estimation of yield gaps are presented in detail.

The Spatial Production Allocation Model

Although spatially disaggregated agricultural production statistics are required to understand the distinguishing patterns of agricultural production that are heterogeneous within countries, collecting such detailed subnational data is difficult for most developing countries. In most cases, information is available only at national or highly aggregated subnational levels (such as for regions or districts). Such geographically coarse data are unable to reflect important variations within countries and are insufficient for the estimation of yield gaps for different agroecological conditions as intended in this study.

Table 3.1 Production system types used by FAO/IIASA suitability datasets and the SPAM

Production	**systems**		
System features	**High-input irrigated**	**High-input rainfed**	**Low-input rainfed**
Market orientation	++	+	-
Irrigation	Yes	No	No
Varieties of crops planted	HYV	Improved	Traditional
Mechanization	++	-	-
Labor intensity	-	+	++
Fertilizer	++	+	-
Chemical pest and disease control	++	+	-
Weed control	++	+	-

Source: Elaborated by the authors based on Fischer et al. (2001).
Note: FAO means Food and Agriculture Organization of the United Nations; HYV means high-yield varieties; IIASA means International Institute for Applied Systems Analysis; SPAM means spatial production allocation model; ++ refers to a high level or intensive use of the option; + refers to a medium level of use or partial use of the option; – refers to no use or very low levels of use of the particular option.

Thus, to obtain spatially disaggregated information on production and actual yields we use an innovative approach that takes advantage of several sources of information to fill such data gaps. This approach uses a SPAM developed by researchers at IFPRI to disaggregate production data from large reporting units, such as a country or state, into smaller spatial units organized as cells of a regularly spaced grid: pixels (You and Wood 2006; You et al. 2007).

The SPAM uses output of GIS analysis, together with other spatial information such as satellite land cover images, maps of irrigated areas, and crop suitability assessments as inputs to help disaggregate the actual aggregated production data and spatially allocate land and production by crop at the pixel level. Production at the pixel level is then aggregated at the desired level of aggregation. As discussed later, our aggregation level of interest is the development domain, our basic spatial unit of analysis.

The analysis that allows us to allocate aggregated production data starts with the spatial aggregated administrative units for which we have been able to obtain agricultural production statistics. The second step is to reinterpret the already classified satellite land cover imagery into cropland and noncropland. This cropland surface provides valuable information for the allocation at the pixel level. The third step defines crop-specific (for example, maize) suitability using information on local climate and soil conditions and uses this information to allocate land by crop at the pixel level. This is what is called "prior" estimates of the spatial distribution of individual crops. Using these preliminary allocation results, the SPAM then applies a cross-entropy approach to obtain the final estimation of crop distribution. The objective function of the model is to minimize the differences between the prior allocation and a final allocation, subject to constraints,[1] to obtain an area allocation consistent with the available information on actual crop production areas while ensuring that the results will be the closest estimate to the initial suitability-based allocation given the available information.

It should be pointed out that the allocation method described here faces some challenges. The most serious is the inconsistency among the various constraints due to imperfect data. For example, the total crop area obtained at the national level could be larger than the cropland area obtained from

[1] Four constraints are included in the optimization problem: (1) the sum of the pixel-level crop areas has to be equal to the corresponding subnational statistic data; (2) within a pixel, the total areas allocated to different crops have to be less than the crop cover areas shown by the satellite image; (3) at the pixel level, the allocated crop areas cannot exceed what are suitable for a particular crop defined by the suitability data in the literature; and (4) the sum of allocated irrigated areas at the pixel level cannot exceed the area equipped for irrigation indicated in the African map of irrigation in the literature.

satellite images. These inconsistencies occur for many countries in West Africa, as well as in other regions of SSA. We overcome this inconsistency problem by assuming the reported production/area statistics as the reference value, then modifying areas from other sources. We also used expert opinions from the region to validate some of the model results.[2] To minimize the possible effect of downscaling errors on the economywide modeling analysis, we use only aggregated results of the SPAM defined at the development domain level for EMM modeling analysis.

An Economywide Multimarket Model for West Africa

An EMM model based on neoclassical microeconomic theory has been developed for this study with the fundamental aim of quantifying the economic implications of alternative policy decisions or scenarios. The fundamental aim of the EMM model is to quantify the economic implications of alternative policy decisions or scenarios measuring the direct effects on supply, demand, and trade of different commodities in several interlinked markets.

Although similar EMM models have been developed and used for other studies focusing either at the country level (for example, Diao and Nin-Pratt 2007 for Ethiopia) or the regional level (for example, Omamo et al. 2007 for East Africa), the model developed for this study has been tailored to the situation of West Africa in terms of both agricultural production patterns and regional specification.

There are at least two special features of this model that differentiate it from other multimarket models found in the literature (see Croppenstedt et al. 2007 for a recent survey on the use of multimarket models for the analysis of agricultural policy impact). One of these features is the economywide nature of the model. The model focuses on agriculture but puts the agricultural sector in an economywide context by including two nonagricultural sectors, allowing for the endogenous determination of regional- and national-level GDP and AgGDP.

A second characteristic that differentiates the EMM developed for this study is the spatially explicit approach used to calibrate the production side of the model, allowing for analysis at multiple levels: regional, national, and subnational. Specifically, subnational information on the spatial distribution of production of 40 commodities is used to define supply for each commodity at the development domain (zone) level, integrating biophysical and socioeconomic information. Table 3.2 presents these commodities grouped in 10

[2] This was particularly important in forested areas of some Central and Coastal African countries, where crops may grow under trees and satellite images identified them as forested instead of cropped areas.

Table 3.2 Commodities included in the economywide multimarket model

Subsector	Commodities
Cereals	Maize, rice, sorghum, millet, barley, wheat, other cereals
Root crops	Cassava, potatoes, sweetpotatoes, yams, other roots
Pulses	Beans, other pulses
Oil crops	Groundnuts, soybeans, other oil crops
Traditional export crops	Cocoa, coffee, cotton, tea, tree nuts
Nontraditional export crops	Exportable vegetables, exportable fruits
Other high-value crops	Vegetables mainly for domestic markets, fruits mainly for domestic markets, plantains/bananas, palm oil, sugar, rubber
Livestock and fish	Cattle, goats and sheep, beef, sheep/goat meat, poultry and eggs, other meats, milk, fish
Other	Vegetable oil, other processed foods
Nonagriculture	Other manufactured items, services

Source: Authors.

subsectors. The model also includes two aggregated nonagricultural sectors, thereby permitting us to capture linkages between agriculture and the rest of the economy at the national and regional levels.[3]

Supply

Supply functions calibrated at the zonal level for three different technologies (production systems presented in Table 3.1) are used to capture each representative producer's response to the market. As in other multimarket models, crop supply functions have two components. The first component is a yield function that is used to capture supply response to own prices given the area allocated to the given crop:

$$Y_{R,Z,i,t} = \bullet_{R,Z,i,t} P_{R,Z,i,t}^{\bullet_{R,Z,i}}, \tag{3.1}$$

where $Y_{R,Z,i,t}$ is the yield of crop i in country R and domain Z, $P_{R,Z,i}$ is the producer price for i in country R, and $\bullet_{R,Z,i,t}$ is a shift parameter to capture growth in yield, which is country and domain specific.

[3] Because the nonagricultural sectors, and hence demand for agricultural, products are country specific, we have to fit the spatial analysis results (as development domains and spatial production allocation) into country boundaries.

The second component of crop supply is a land allocation function that is a function of all prices and hence is responsive to changing profitability across different crops given the total available land:[4]

$$A_{R,Z,i,t} = \bullet_{R,Z,i,t} \bullet_{j} P^{\bullet_{R,Z,j}}_{R,j,t} \quad \text{and} \quad \bullet_{j}^{J} \bullet_{R,Z,j} = 0, \tag{3.2}$$

where $A_{R,Z,i,t}$ is the harvest area for crop *i* in country *R* and domain *Z, P* is the vector of producer prices, and $\bullet_{R,Z,i,t}$ is the shift parameter to capture land expansion. The total supply for each commodity in different countries and domains results from combining equations (3.1) and (3.2):

$$S_{R,Z,i,t} = Y_{R,Z,i,t} A_{R,Z,i,t}. \tag{3.3}$$

The EMM model is dynamic, and thus both yields and land change over time. To capture such changes, the growth rate in yields, $g_{Y_{R,Z,i,t}}$ acts on the productivity shift parameter $\bullet_{R,Z,i,t+1} = \bullet_{R,Z,i,t} (1 + g_{Y_{R,Z,i}})$, while crop area expands because $\bullet_{R,Z,i,t}$ is a function of an annual area expansion rate. Shocks to the model to simulate improved production performance are introduced through changes in the productivity growth rate at the domain level within a country.

Demand

The demand side of the model is defined at the national level. Representative rural and urban consumers are defined for each country. The demand for each representative consumer and consumption good is derived as follows:

$$Dpc_{H,R,i,t} = \bullet_{j} PC^{\bullet_{H,R,i,j}}_{R,j,t} GDPpc^{\bullet^{I}_{H,R,i}}_{H,R,t}, \tag{3.4}$$

where $Dpc_{H,R,i}$ is per capita demand for commodity *i* in country *R*'s rural or urban areas and $PC_{R,j}$ is the consumer price for good *j* in country *R*. Commodity *j* = 1, 2, . . . , 42 (including two aggregate nonagricultural goods). $GDPpc_{H,R}$ is per capita income for country *R*'s rural or urban consumers. $\bullet_{H,R,i,j}$ is price elasticity between demand for commodity *i* and price for commodity *j,* and $\bullet^{I}_{H,R,i}$ is income elasticity.

[4] The supply of livestock products has only one component, which is similar to the land allocation function for the case of crop supply.

Markets and Trade

The multiple market structure of the model assumes perfect substitution between domestically and internationally produced commodities. However, transportation and other market costs distinguish trade in the domestic market from imports and exports. For example, although imported and domestically produced maize are assumed to be perfect substitutes, maize may still not be profitable to import if its domestic price is lower than the import parity price less any transactions costs. Maize can be imported only when domestic demand for maize grows faster than domestic supply and the local market price rises significantly.

A similar situation applies to exported commodities. Even though certain horticultural products are exportable, if domestic production is not competitive in international markets, due to either low productivity or high transaction costs, exports will not be profitable. Only when domestic producer prices plus market costs are lower than the export parity price of the same product does it become profitable to export.

The model does not capture bilateral trade flows across countries, given that there is no further information to distinguish regional trade from international trade. However, the model does identify which countries have a surplus or deficit in which products, and thus it provides information that can be used to justify possible intraregional trade in the analysis.

Prices

For most agricultural commodities (except traditional and nontraditional export crops and rice and wheat, which are highly dependent on imports in the region) and manufactured goods, prices are endogenously determined by the equilibrium between demand (including consumption, feed, and other demand) and supply in each country's domestic markets, at least in the early periods in the model. The price linkages between domestic and international markets occur only if domestic prices for a commodity shift to import parity prices when rapidly growing demand exceeds supply growth. In such situations, the commodity is imported, even if there is initially no trade in it.

Specifically, the following relationship describes the possible linkages between import parity prices and consumer prices in each country's domestic markets:

$$PC_{R,i,t} \bullet (1 + WM_{R,i})PWM_i,\ M_{R,i} > 0 \text{ if } PC_{R,i,t} = (1 + WM_{R,i})PWM, \quad (3.5)$$

where $Wm_{R,i}$ is the trade margin for country R and commodity i between border prices, PWM_i, and consumer prices, $PC_{R,i}$, in domestic markets. When $PC_{R,i}$ is less than $(1+Wm_{R,i})PWM_i$, $PC_{R,i}$ is an endogenous price determined by domestic supply and demand. The equality in equation (3.5) holds only when the imports are positive. In this situation, domestic prices become exogenous in country *R*.

Similarly, the following relationship holds between domestic producer prices and export parity prices:

$$P_{R,i,t} \bullet (1 - We_{R,i})PWE_{i,}\ E_{R,i} > 0 \text{ if } P_{R,i,t} = (1 - We_{R,i})PWE_i, \tag{3.6}$$

where $P_{R,i}$ is producer prices and PWE_i is export border prices. If $P_{R,i}$ is greater than $(1 - We_{R,i})PWE_i$, $P_{R,i}$ is an endogenous price determined by domestic supply and demand. The equality in equation (3.6) holds for country *R* only when the exports are positive. Consumer and producer prices are not necessarily the same:

$$PC_{r,i,t} = (1 + Dm_{R,j})P_{R,i,t}, \tag{3.7}$$

where *Dm* is the margin between consumer and producer prices in a country's domestic market. It should be pointed out that West African countries have diverse production and consumption patterns; hence, the same agricultural product could be an export crop for a country (for example, Burkina Faso), an import crop for other countries (for example, Chad), or a self-sufficient product for a third country (for example, Ghana) (see Appendix 3B for the initial export, import, and self-sufficient situation of each West African country by individual crop or livestock product). Although domestic prices for maize will be different for these three types of countries, the following relationship holds for each commodity within each country:

$$(1 - Wm_{R,i})PWE_i < P_{R,i,t} \bullet PC_{R,i,t} < (1 + WM_{R,i})PWM_i, \tag{3.8}$$

and

$$\bullet_Z S_{R,Z,i,t} + M_{R,i,t} - E_{R,i,t} = \bullet_H Dpc_{H,R,i,t} PoP_{H,R,t}. \tag{3.9}$$

Equation (3.9) solves for the price of commodity *i* in country *R* if both *M* and *E* are zero in that country. Otherwise, it solves for the value of *M* or *E* for country *R*.

Household Income

The most important feature of the EMM model is its economywide scope, which makes household income endogenous to the model. Given that the model does not explicitly include labor and capital inputs (it includes only land), income is endogenously determined by production revenues, and producer prices are adjusted to represent the value-added part of revenue. Thus, national GDP comprises AgGDP and nonagricultural GDP, both endogenous in the model:

$$AgGDP_{R,t} = \bullet_{Z,j} P_{R,j,t} S_{R,Z,j,t},\ \mathrm{j} = 1, 2, \ldots 40;\ NonAgGDP_{R,t} = \bullet_{i} P_{R,i,t} S_{R,i,t},\ i = 1, 2. \tag{3.10}$$

We assume that within each country agricultural income goes to rural households, while urban households earn income from the nonagricultural sectors only. However, part of nonagricultural income is also shared by the rural households, and initial income levels for an average rural and urban household, together with rural and urban population distribution, determine the share. Given this share, per capita income is endogenously determined by changes in agricultural and nonagricultural GDP:

$$GDPpc_{H,R,t} = \frac{s_{H,A} AgGDP_{R,t} + s_{H,N} NonAgGDP_{R,t}}{PoP_{H,R,t}},\ s_{\mathrm{rural},A=1}, \tag{3.11}$$

where $PoP_{H,R}$ represents country *R*'s rural or urban total population and grows exogenously according to the country's recent population growth rate.

Elasticities

Similar to other simulation models, the EMM model critically depends on the elasticities applied in both supply and demand functions. Ideally, the elasticities should be estimated using sources of data similar to those on which the model is built. However, given the size of the EMM model and the details in its sector and country coverage, this is not possible.

Alternatively, elasticities drawn from the literature can be used in the model. However, there is no evidence in the literature that the supply elasticity for all 40 agricultural products analyzed in the model has been consistently estimated for any West African country. Given these constraints, we assign a value of 0.2 to the price elasticity in the yield function uniformly across all activities and countries, and calibrate cross-price elasticities in the area functions (equation 3.2) according to production value shares and land allocation by sector, together with this own price elasticity. While the own price elasticity is the same, due to different production patterns calibrated cross-price elasticities vary across the countries.

The choice of a value of 0.2 for the own price elasticity in the supply function is supported by the literature, although there are variations depending on the product (see, for example, Thiele 2000, 2003; Alemu, Oosthuizen, and van

Schalkwyk 2003; Abrar, Morrissey, and Payner 2004; Leaver 2004; Olubode-Awosola, Oyewumi, and Jooste 2006). Given the economywide feature of the EMM model, we decided to apply this rather low end of elasticity in the supply function. Moreover, a sensitivity test shows that, because of the size of the model (in terms of the number of agricultural subsectors and the number of supply functions for each subsector), the results are not sensible to the choice of this elasticity in a range of values between 0.1 and 0.3.

On the demand side, we estimated income elasticities econometrically for Ghana, Mali, and Senegal using recent living standard survey data from these countries. No such data were available for other countries, so we used Ghana's income elasticity in the demand functions of the other six Coastal countries and Mali's elasticity in the demand function of the other six Sahel countries and the five Central countries. The estimation method is drawn from King and Byerlee (1978) (see Appendix 3C). The price elasticities are then derived from the linear expenditure demand system using the current expenditure shares and income elasticities such that the budget constraint is satisfied for each demand function. That is:

$$\sum_{j}^{J} \varepsilon_{H,R,i,j} + \varepsilon^{I}_{H,R,i} = 0, \quad \text{and} \quad \sum_{j}^{J} sh_{H,R,j}\,\varepsilon^{I}_{H,R,j} = 1, \qquad (3.12)$$

where $sh_{H,R,j}$ is the expenditure share of commodity i for household H in country R.

Although we use the same income elasticity for a particular good within the different subregion, there are different market opportunities for a similar food product across countries due to different consumption patterns and hence different average budget shares of each commodity in households' total expenditure. For example, currently sorghum and millet account for 21.4 percent of rural consumption in Mali (in terms of average budget share), but they account for only 0.9 and 7.8 percent, respectively, of total consumption expenditure in Ghana and Senegal for rural households as whole. With a marginal budget share of sorghum and millet of 7.8 percent in Mali, the value of the income elasticity for sorghum and millet for this country is 0.4. On the other hand, the marginal budget share for sorghum and millet is negative for Ghanaian rural households as a whole, indicating an absolute decline in consumption with income growth.

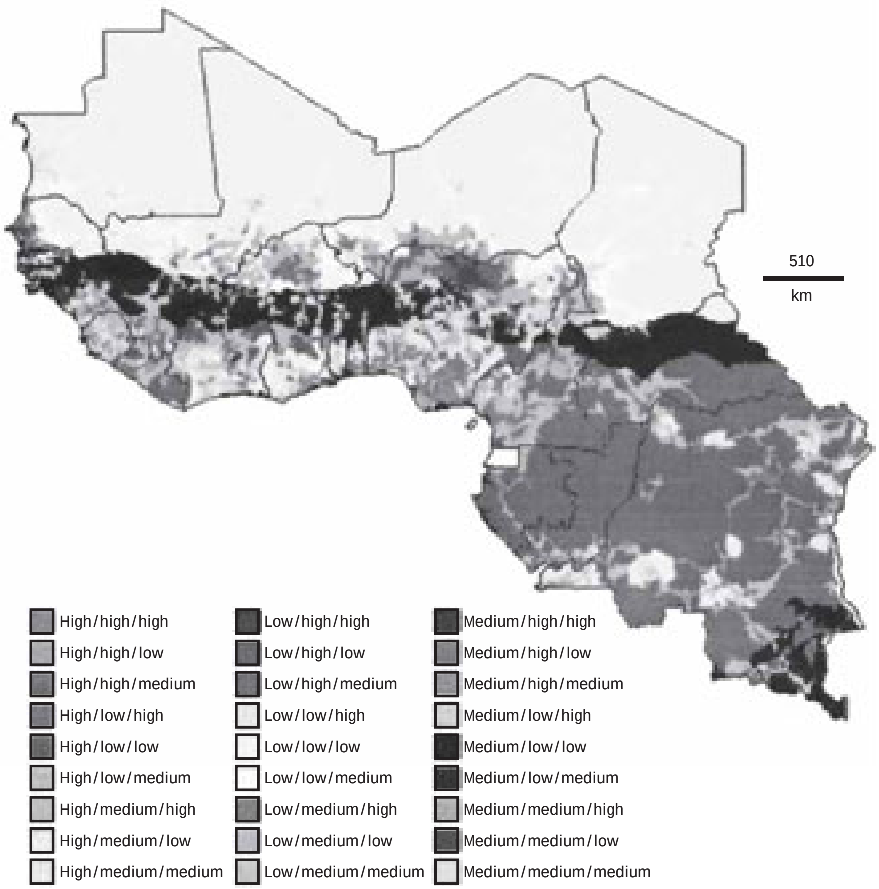
Such differences in food consumption patterns and income elasticities imply that domestic market opportunities for growth in sorghum and millet are very limited in Ghana, while there is potential in Mali to increase sorghum and millet supply. Such differential demand responses will affect the model results presented in the following chapter of this report. We include in Appendix 3C both average and marginal shares of food consumption in the three countries so that differences and changes in consumption patterns among these three countries can be further explored there.

The analytic framework presented in this chapter, with its three methodological components, allows us to examine a range of issues central to agricultural development. These issues are addressed in Chapter 4, where the analysis of yield gaps provides the input for model simulations in Chapter 5.

Appendix 3A: Development Domains

Using available information on agroecological conditions, population, and distance to markets, we define unique "development domains" as geographic areas that are similarly endowed in these three attributes. Figure 3A.1 illustrates the resulting development domains for West Africa based on the intersection of agricultural potential, population density, and market access. Three different levels of each of these three factors (high, medium, and low) are combined and result, in the case of West Africa, in 27 domains. Domains straddle national and subnational boundaries, delimiting areas where development conditions and potential for a particular crop are similar.

Figure 3A.1 Development domains for West and Central Africa



Source: Authors' calculations.

LGP is used as a basis for classifying areas as having high, medium, or low agricultural potential. The availability of water—be it from rainfall, local groundwater, or surface water or from formal irrigation schemes—is generally the most binding of constraints and determines the most prominent agroecological zones in West Africa: humid, semihumid, semiarid, and arid zones. Humid and semihumid zones are defined as the regions with high agricultural potential, while medium- and low-potential regions correspond to semiarid and arid zones, respectively. In general, humidity in the region increases from north to south. This can be seen in the map in Figure 3A.1 as three broad west–east swathes corresponding to arid, semiarid, and semihumid/humid zones, captured respectively as groups of domains with low, medium, and high agricultural potential. Although zones of medium and high agricultural potential are suitable for agriculture growth, zones of low agricultural potential (mostly the arid zone of the Sahel) have very limited rainfall and little vegetation coverage and are hence used primarily for livestock herding.

Africa's sizable humid and subhumid agroclimatic zones are found mainly within the Coastal and Central regions, where forest-based farming systems and tree-crop farming systems are prevalent. The Coastal region concentrates 41 percent of total West African production compared to only 9 and 8 percent in the Sahelian and Central regions, respectively. West Africa's most common tree crops (cocoa and coffee) are predominant here. Fruits and vegetables, root crops including yams and cassava, and mixed farming systems, including crop-livestock and cereal–root crop systems, are also very common. The semiarid agroclimatic zone is predominantly found in the Sahelian and Central subregions of West Africa. This zone has a limited growing season, but its environment is more conducive to agriculture. Here traditional coarse grains and cereals, crop-livestock systems, and cereal–root crop systems dominate.

High population density in West Africa follows strict patterns, represented as -/high/- domains in Figure 3A.1.[5] The most densely populated areas are found primarily in the Coastal areas (0.73 people per hectare of total area), along the Niger River, and in the Great Lakes region on eastern DRC border. Population densities tend to be quite low in much of the Sahelian region, as well as in the forested areas of Central Africa (0.36 and 0.15 people per hectare of total area in the Sahel and Central regions, respectively).

To define access to markets in different regions, this study focuses on a simplified set of criteria that reflect the physical accessibility (expressed in terms of expected travel times) to a range of markets (identified as towns

[5] Population densities are assumed to be "high" at densities of 100 persons per square kilometer or greater; "medium" at 20–100; and "low" at fewer than 20.

or cities of different sizes for domestic markets and major ports for export markets).[6] Although several distinct types of markets may be identified, here we characterize access based on travel time to a variety of locations with different economic implications. In general, the Sahelian and Central African countries have the largest areas of low access, while the West African Coastal countries have the broadest high-access conditions. Still, no area is predominantly or uniformly characterized by high access.

The importance of the different domains by country is shown in Tables 3A.1–3A.4. The largest individual domain is the one with low agricultural potential, low population density, and low markets access, which includes 37 percent of West Africa land area. Areas with high agricultural potential and high market access account for only 2 percent of the land area but include more than 8 percent of cropland and almost 20 percent of the rural population. Enormous portions of the region are economically underused. The low-access, low-density areas of the Sahelian and Central African forest together account for almost 60 percent of the total area. Even if these areas are fundamentally more limited, exploring sustainable or nonextractive uses of the resources of these areas should be part of a regional development strategy.

[6] Markets within four hours travel of major seaports or large cities of 500,000 or more inhabitants (for international trade routes), within two hours of towns of 100,000 or more, or within one hour of towns of 10,000 or more are considered to be “high access” areas. Areas of “medium access” are those within six hours of large cities, within four hours of large towns or within two hours of smaller towns. Other locations are considered to be “low access.”

Table 3A.1 Land area shares by country and development domain, 2000 -03 (average)

Domain	Benin	Burkina Faso	Cameroon	Central African Republic	Chad	Congo, Democratic Republic of	Congo, Republic of	Côte d'Ivoire	Gabon	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mali	Mauritania	Niger	Nigeria	Senegal	Sierra Leone	Togo	West and Central Africa total
High/high/high	3		1								5							7		3	1	1
High/high/medium	3		1			1					4			2				6		1	1	1
High/high/low						1								3				2				
High/medium/high	2		3			1	1	10			5	5						5		20	9	1
High/medium/medium	4		2			5		21			17	6		2				9		26	18	3
High/medium/low	3		1			4	1	5			13	1		2				3			5	2
High/low/high	1		8	2		3	4	5	3			10		18				1		8		2
High/low/medium	2		33	14		13	8	22	10		9	20		35				2		42	4	7
High/low/low	1		32	46		63	86	15	87		11	1		37				3			4	22

Medium/high/high	1	1									2							2			3	
Medium/high/medium											1							2			3	
Medium/high/low																						
Medium/medium/high			1					1			2		18					2	1		3	
Medium/medium/medium	5	3	3		1			1			8	1	9		1			11	2		14	2
Medium/medium/low	2										1	5						5			3	1
Medium/low/high	5	1				1		1			2	13	16		1			1			1	1
Medium/low/medium	40	11	3	3	3	2		11			14	31	50		3			4	7		20	4
Medium/low/low	17	2	5	30	2	6		8			5	7	5		2			3	5		11	5
Low/high/high		2								4								3	4			
Low/high/medium		1																7	1			1
Low/high/low																						
Low/medium/high		9	3							20					1		2	2	7			1
Low/medium/medium		24	4		1					44					3		6	10	8			3
Low/medium/low		4													1		1	1				
Low/low/high		3			1					6					2	1	1	2	4			1
Low/low/medium	3	24			7					26			1		10	5	7	5	31			5
Low/low/low	7	15		5	83										76	94	82	2	29			37
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: Authors' calculations based on a broad set of databases covering various years. See You and Wood (2006) and You et al. (2007) for information on data sources.

Note: An empty cell means that the country does not have the particular development domain.

Table 3A.2 Rural population shares by country and development domain, 2000 –03 (average)

Domain	Benin	Burkina Faso	Cameroon	Central African Republic	Chad	Congo, Democratic Republic of	Congo, Republic of	Côte d'Ivoire	Gabon	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mali	Mauritania	Niger	Nigeria	Senegal	Sierra Leone	Togo	West and Central Africa total
High/high/high	18		10			3					17	2						17		12	1	9
High/high/medium	17		8			7		1			9			16				13		3	2	8
High/high/low			1			6					1			26				3				2
High/medium/high	4		7			5	9	17			9	9		1				3		26	12	4
High/medium/medium	6		6			15	6	37			20	15		4				8		35	22	10
High/medium/low	4		2			12	7	8			12	1		3				2			4	3
High/low/high			5	6		3	18	4	1			9		14						4		2
High/low/medium	1		16	28		10	13	15	17		3	16		20				1		20	2	5
High/low/low			9	49		35	47	7	82		5	1		16				1			2	9

Medium/high/high	8	3									5	2						3	1		8	2
Medium/high/medium	3	1									3							4			8	2
Medium/high/low																						
Medium/medium/high		1	7		1			1			2	1	35		3			1	3		3	1
Medium/medium/medium	7	4	8		11			1			7	1	16		3			8	5		17	5
Medium/medium/low	2				3						1	6						3			4	2
Medium/low/high	3	1			1			1			1	14	16		2							1
Medium/low/medium	17	5	1	6	10	1		5			4	18	26		9			1	4		9	3
Medium/low/low	6	1	1	11	6	3		3			1	4	4		3			1	1		6	2
Low/high/high		7								8							1	8	23			4
Low/high/medium		3															8	13	4			5
Low/high/low																			17			
Low/Medium/high		15	8		2					24			1		6		13	1	15			3
Low/medium/medium		34	11		14					51					18		46	7				9
Low/medium/low		4													8	3	4	1	3			1
Low/low/high		1			2					2					5	8	3		16			1
Low/low/medium	1	13			15					15			2		19	19	12	1	8			3
Low/low/low	2	6			35										24	70	13					4
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: Authors' calculations based on population distribution data from CIESIN/CIAT (2005).

Note: An empty cell means that the country does not have the particular development domain.

Table 3A.3 Cropland areas by country and development domain, 2000–03 (average)

Domain	Benin	Burkina Faso	Cameroon	Central African Republic	Chad	Congo, Democratic Republic of	Congo, Republic of	Côte d'Ivoire	Gabon	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mali	Mauritania	Niger	Nigeria	Senegal	Sierra Leone	Togo	West and Central Africa total
High/high/high	1					1	66	10			3	5						4		1	12	7
High/high/medium	1		1			12														15	11	1
High/high/low											3											
High/medium/high	7		69			17	17	1			2			4						2		14
High/medium/medium	2		1			16		6			42	3						2		32	1	4
High/medium/low						6		7				10		24							15	2
High/low/high	1		9			23		36	7			4		12				2		2		6
High/low/medium			6	7		11	14	11	62		14	12		12				2				5
High/low/low	22			3			3	23	27		12	1		9						1	18	4

Medium/high/high											2	18									6	1
Medium/high/medium	1										4										3	
Medium/high/low																		2				
Medium/medium/high	5				1						1	3	12						2		1	1
Medium/medium/medium	1				12			1			3	5	1					2	2		2	1
Medium/medium/low	6		11		2						3	1									14	2
Medium/low/high					6							9	6								2	1
Medium/low/medium	12	1		4	5	11						23	9	37	2				1		5	4
Medium/low/low	37	8		78		1		5				4	36		2						10	4
Low/high/high		6								11	5							16	18			4
Low/high/medium		2				2											3	27	3			5
Low/high/low																		1				
Low/medium/high		23	2							45	6		22		4		12	4	21			5
Low/medium/medium		33	1		1					19					14		41	21	15			9
Low/medium/low		3			15							2			4			2				2
Low/low/high		2			3					7			13		5	2	9	5	5	47		3
Low/low/medium	2	18			12					18			1	2	36	77	25	9	20			8
Low/low/low	2	4		8	43				4						33	21	10	1	13			7
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: Authors' calculations based on crop and pasture distribution data from SAGE (2002).
Note: An empty cell means that the country does not have the particular development domain.

Table 3A.4 Pasture area shares by country and development domain, 2000 –03 (average)

Domain	Benin	Burkina Faso	Cameroon	Central African Republic	Chad	Congo, Democratic Republic of	Congo, Republic of	Côte d'Ivoire	Gabon	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mali	Mauritania	Niger	Nigeria	Senegal	Sierra Leone	Togo	West and Central Africa total
High/high/high			1				64	4			14	6						2			4	3
High/high/medium			1			26												5		13	1	2
High/high/low			1								1							1				
High/medium/high	10		57			5	14	1			3			29				2		4		6
High/medium/medium	1		1			32		6			15	3						6		57	3	4
High/medium/low	2					5	2	14				11		13				2			4	2
High/low/high	1		6			12	1	13	5			16		28				5		3		4
High/low/medium			5	6		8	9	12	79		18	2		3				4		3	1	3
High/low/low	4			3			10	26	14		7			3				1			11	2

Medium/high/high		1				1					1	19									3	1
Medium/high/medium		1									16										14	1
Medium/high/low																		1				
Medium/medium/high	35	1						1			4		3					1			2	2
Medium/medium/medium	2		5		7	2		3			6	9	2		1			3	2		6	3
Medium/medium/low	13	1	11		1						5	7									26	3
Medium/low/high	1		1		1			1				8	3								2	1
Medium/low/medium	3	6	1	1	4	5		2				16	7	22	4			1	3		10	4
Medium/low/low	22	5	1	81				17				3	9		2				2		13	4
Low/high/high		2								4	8							8	5			1
Low/high/medium		1				4											1	15	1			2
Low/high/low																						
Low/medium/high		10	3							20	2		60		1		4	4	9			3
Low/medium/medium		26	4							43					5		14	23	9			6
Low/medium/low		4			2										3		1	2				1
Low/low/high		3			2					8			16		3	1	3	4	4	20		2
Low/low/medium	2	25			15					25				2	15	15	16	7	32			10
Low/low/low	4	14	2	9	68				2						66	84	61	3	33			30
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: Authors calculations based on crop and pasture distribution data from SAGE (2002).
Note: An empty cell means that the country does not have the particular development domain.

Appendix 3B: Supplementary Tables

Table 3B.1 Agricultural importing and exporting countries in West Africa, 2000–04 (average): Cereals

Country	Maize	Rice	Wheat	Sorghum	Barley	Millet	Other cereals
Burkina Faso	E	M	M		M		
Chad	M		M		M		
Gambia	M	M	M		M		
Guinea Bissau	M	M	M		M		
Mali	M	M	M		M	M	
Mauritania	M	M	M	M	M		
Niger	M	M	M		M		
Senegal	M	M	M		M		
Guinea	M	M	M		M		
Sierra Leone	M	M	M		M		
Côte d'Ivoire		M	M	M	M		
Ghana		M	M		M		M
Togo		M	M		M		
Benin		M	M		M		
Nigeria		M	M		M		
Cameroon	M	M	M		M		
Central African Republic		M	M		M		
Gabon	M	M	M		M		
Congo, Republic of	M	M	M		M		
Congo, Democratic Republic of	M	M	M		M		

Source: Authors' calculations using FAO data.
Note: M indicates that the ratio of imports to domestic consumption is greater than 1.5%; E indicates that the ratio of exports to total production is greater than 1.5%; an empty cell indicates that there is nearly a balance in production and consumption.

Table 3B.2 Agricultural importing and exporting countries in West Africa, 2000–04 (average): Roots, tubers, and bananas

Country Cassava	Potatoes	Sweet potatoes	Yams	Other roots	Bananas
Burkina Faso				M	M
Chad					
Gambia				M	
Guinea-Bissau					
Mali			M	M	M
Mauritania				M	M
Niger			M	M	M
Senegal					M
Guinea	M				
Sierra Leone	M			M	
Côte d'Ivoire	M				E
Ghana	M				
Togo	M				
Benin	M				
Nigeria					
Cameroon					E
Central African Republic					
Gabon	M	M		M	
Congo, Republic of	M			M	
Congo, Democratic Republic of	M				

Source: Authors' calculations using FAO data.

Note: M indicates that the ratio of imports to domestic consumption is greater than 1.5%; E indicates that the ratio of exports to total production is greater than 1.5%; an empty cell indicates that there is nearly a balance in production and consumption.

Table 3B.3 Agricultural importing and exporting countries in West Africa, 2000–04 (average): Beans, oilseeds, and vegetable oil

Country	Beans	Groundnuts	Soybeans	Other oil crops	Palm oil	Vegetable oil
Burkina Faso	M			E		M
Chad						M
Gambia		E		M		M
Guinea-Bissau					E	M
Mali	M	E		M	M	M
Mauritania		M	M	M		M
Niger	E			E		M
Senegal	M	E		M		M
Guinea	M		M			M
Sierra Leone	M	M				M
Côte d'Ivoire	M			E	E	
Ghana	M		M	E	M	M
Togo		E		E	E	M
Benin			M	E	E	M
Nigeria	M		E	E	E	M
Cameroon	E		M	M		M
Central African Republic	M					M
Gabon	M	M	M			M
Congo, Republic of	M	M	M	M	E	M
Congo, Democratic Republic of	M			M		M

Source: Authors' calculations using FAO data.
Note: M indicates that the ratio of imports to domestic consumption is greater than 1.5%; E indicates that the ratio of exports to total production is greater than 1.5%; an empty cell indicates that there is nearly a balance in production and consumption.

Table 3B.4 Agricultural importing and exporting countries in West Africa, 2000–04 (average): Export crops

Country	Raw sugar	Cocoa	Coffee	Cotton	Tree nuts	Rubber	Tea	Vegetables	Fruits
Burkina Faso	M	M	M	E	M		M	E	E
Chad	M		M	E	M		M	E	
Gambia	M	M	M	E			M	E	E
Guinea-Bissau	M	M	M	E	E		M	E	E
Mali	M	M	M	E	M		M	E	E
Mauritania	M	M	M	M			M	E	E
Niger	M	M	M	E	M		M	E	E
Senegal	M	M	M	E	E		M	E	E
Guinea	M	E	E	E	E	E	M	E	E
Sierra Leone	M	E	E				M	E	E
Côte d'Ivoire	E	E	E	E	E	E	E	E	E
Ghana	M	E	E	E	E	E	M	E	E
Togo	M	E	E	E	E	M	M	E	E
Benin	M	M	M	E	E	M	M	E	E
Nigeria	M	E	M		E	E	M	E	E
Cameroon	M	E	E	E		E	M	E	E
Central African Republic	M	M	E	E		E	M	E	
Gabon	E	E	M	M	M	E	M		
Congo, Republic of	E	E	E	M	M	E	M	E	
Congo, Democratic Republic of	M	E	E	M	M	E	E	E	

Source: Authors' calculations using FAO data.

Note: M indicates that the ratio of imports to domestic consumption is greater than 1.5%; E indicates that the ratio of exports to total production is greater than 1.5%; an empty cell indicates that there is nearly a balance in production and consumption.

Table 3B.5 Agricultural importing and exporting countries in West Africa, 2000–04 (average): Livestock products and fish

Country	Cattle	Sheep and goats	Beef	Sheep and goat meat	Poultry and eggs	Other meat	Fish	Milk
Burkina Faso	E	E					M	M
Chad	E	E						M
Gambia					M	M		M
Guinea-Bissau			M		M		E	M
Mali	E	E					M	M
Mauritania		E			M		E	M
Niger	E	E					E	M
Senegal	M	M	M		M		E	M
Guinea	E	E	M		M	M	M	M
Sierra Leone	M	M	M	M	M	M	E	M
Côte d'Ivoire	M	M	M		M	M	M	M
Ghana	M	M	M	M	M	M	M	M
Togo	M		M		M	M	M	M
Benin	M	M			M	M	M	M
Nigeria	M	M					M	M
Cameroon	M				M	M	M	M
Central African Republic	E	M					M	M
Gabon	M		M	M	M	M	M	M
Congo, Republic of		M	M	M	M	M	M	M
Congo, Democratic Republic of	M		M		M		M	M

Source: Authors' calculations using FAO data.
Note: M indicates that the ratio of imports to domestic consumption is greater than 1.5%; E indicates that the ratio of exports to total production is greater than 1.5%; an empty cell indicates that there is nearly a balance in production and consumption.

Appendix 3C: Estimating Consumer Demand Dynamics

The estimation model follows the ratio semilog inverse function (RSLI) suggested by King and Byerlee (1978). This model estimates the relationship between household expenditure of a diverse set of commodities and income, controlling household size. Marginal budget shares (MBSs) are then calculated from the coefficients obtained from the consumption regression equation. This approach satisfies several unique requirements for the study of income effects.

First, the model is flexible enough to present the income–consumption relationship of various commodities over the whole range of income in the sample, especially at extreme levels of income. Second, the RSLI function satisfies the economic restrictions of additivity. In other words, marginal propensities to consume (MPCs) for all commodities will sum to unity because commodity groupings are exhaustive and mutually exclusive. In addition, perfect additivity is confirmed at all income levels, enabling interclass comparisons of consumption patterns. Third, the significance of parameter estimates and goodness of fit are considered in model specification, because the dependent variable is not specified in logarithmic form, which is less adversely affected by zero observations.

The functional form is as follows:

$$C_{ij} = a_i Y_j + b_{1j} Y_j \ln \bar{y}_j + b_{2i} N_j + \bullet_{ij},$$

where C_{ij} is total expenditure on good i by household j, Y_j is total expenditure by household j, $\bar{y}_j$ is per capita total consumption expenditure by household j, N_j is the number of people in household j, and a_i, b_{1i}, b_{2i} are parameters to be estimated.

Because the specified function passes through the origin, any zero expenditure level could be included in the estimation. Expression of the MPC derived from this model is expressed by

$$\frac{\bullet C_i}{\bullet Y} = a_1 + b_{1i} + b_{1i} \ln \bar{y}.$$

MBS is allowed to be increasing, decreasing, or constant for a given commodity. The coefficients were defined for different income groups within a country for rural and urban households.

Table 3C.1 Mali: Average budget share by income quintile

Area	Quintile	Rice	Wheat	Maize	Millet	Sorghum	Other cereals	Roots	Beef	Mutton	Milk
Urban	Lowest	15.0	1.1	1.2	10.9	1.5	0.5	0.6	7.7	1.9	0.9
	Second	15.0	2.3	1.4	7.8	0.9	0.1	1.1	6.7	2.4	1.2
	Third	13.9	2.4	1.1	6.6	0.7	0.3	1.5	7.2	2.4	1.7
	Fourth	11.6	3.0	0.6	5.4	1.0	0.1	2.0	6.8	2.5	1.9
	Highest	8.1	3.3	0.5	3.7	0.7	0.2	2.0	5.8	1.8	2.7
	Urban total	11.2	2.8	0.8	5.6	0.9	0.2	1.7	6.5	2.1	2.0
Rural	Lowest	4.0	0.3	5.5	33.6	4.9	0.3	0.9	1.9	2.0	0.8
	Second	8.1	0.4	4.9	27.2	4.4	0.5	0.7	2.6	2.0	1.4
	Third	10.3	0.5	4.0	23.9	3.5	0.4	0.5	3.5	1.9	1.5
	Fourth	11.7	0.7	2.3	17.5	4.5	0.5	0.7	5.4	2.2	2.0
	Highest	12.5	1.5	1.3	10.7	2.7	0.2	1.1	5.9	2.2	2.1
	Rural total	10.9	0.9	2.7	17.8	3.6	0.4	0.9	4.8	2.1	1.8
National	Lowest	5.2	0.4	5.1	30.4	5.0	0.4	1.1	2.3	2.1	1.0
	Second	9.5	0.5	4.6	25.1	3.6	0.6	0.4	3.2	1.8	1.3
	Third	12.4	0.7	2.2	17.7	3.9	0.3	0.7	5.7	2.1	1.7
	Fourth	13.1	1.6	1.7	12.1	2.2	0.4	0.9	6.1	2.7	1.8
	Highest	10.7	2.6	0.7	6.0	1.4	0.2	1.7	6.2	1.9	2.2
	National total	11.0	1.7	1.8	12.5	2.4	0.3	1.2	5.5	2.1	1.9

Source: Mali, DNSI (2003).

Table 3C.2 Mali: Marginal budget share by income quintile

Area	Quintile	Rice	Wheat	Maize	Millet	Sorghum	Other cereals	Roots	Beef	Mutton	Milk
Urban	Lowest	12.9	4.1	0.4	4.1	0.9	-0.2	2.6	7.5	2.1	2.4
	Second	10.2	4.0	0.3	3.2	0.8	-0.1	2.6	6.6	2.0	2.5
	Third	8.5	3.9	0.3	2.6	0.7	0.0	2.6	6.0	1.9	2.6
	Fourth	7.0	3.9	0.2	2.1	0.6	0.1	2.6	5.4	1.8	2.6
	Highest	3.8	3.7	0.1	1.1	0.4	0.2	2.7	4.3	1.7	2.7
	Urban total	7.7	3.9	0.2	2.4	0.6	0.0	2.6	5.7	1.9	2.6
Rural	Lowest	21.5	1.8	0.9	11.1	2.9	0.2	1.2	10.5	3.9	2.5
	Second	18.8	1.6	0.8	9.2	2.4	0.2	1.0	9.0	3.3	2.1
	Third	16.8	1.4	0.7	7.8	2.1	0.1	0.9	7.9	2.9	1.9
	Fourth	14.9	1.2	0.6	6.4	1.8	0.1	0.8	6.9	2.5	1.6
	Highest	10.9	0.8	0.4	3.6	1.1	0.1	0.6	4.7	1.7	1.1
	Rural total	15.5	1.3	0.6	6.8	1.9	0.1	0.9	7.2	2.6	1.7
National	Lowest	20.4	3.1	0.2	4.1	1.2	0.1	2.0	10.8	3.1	2.3
	Second	17.1	3.0	0.2	3.2	1.0	0.1	2.0	9.3	2.7	2.2
	Third	14.6	3.0	0.1	2.6	0.8	0.1	2.0	8.2	2.4	2.1
	Fourth	12.0	2.9	0.1	1.9	0.7	0.1	2.0	7.0	2.1	2.1
	Highest	7.4	2.8	0.1	0.7	0.4	0.1	1.9	4.9	1.6	2.0
	National total	13.1	2.9	0.1	2.2	0.7	0.1	2.0	7.5	2.2	2.1

Source: Mali, DNSI (2003).

Table 3C.3 Ghana: Average budget share by income quintile

Area	Quintile	Maize	Rice and wheat	Coarse grains	Roots	Chicken	Other livestock	Fish
Urban	Lowest	3.7	4.7	0.4	7.5	1.0	11.3	2.3
	Second	2.1	4.9	0.2	7.0	1.5	11.9	2.3
	Third	1.5	4.4	0.2	6.2	1.5	12.3	2.1
	Fourth	1.3	4.2	0.1	5.2	1.7	12.6	2.1
	Highest	0.7	2.7	0.1	2.9	1.7	8.7	1.7
	Urban total	1.2	3.6	0.2	4.6	1.6	10.5	1.9
Rural	Lowest	8.0	3.2	6.4	8.5	0.7	10.7	1.2
	Second	5.6	3.6	1.9	12.7	0.9	12.9	2.4
	Third	5.0	4.2	0.9	11.8	1.1	13.2	2.5
	Fourth	4.3	3.8	0.9	11.5	1.4	13.4	2.5
	Highest	2.9	3.5	0.6	9.3	1.5	12.5	2.3
	Rural total	4.1	3.6	1.2	10.5	1.3	12.8	2.3
National	Lowest	6.9	3.5	4.3	9.0	0.7	11.3	1.7
	Second	4.7	4.1	1.1	11.4	1.1	12.8	2.5
	Third	3.9	4.3	0.6	9.8	1.3	12.6	2.5
	Fourth	2.6	4.2	0.5	8.7	1.4	13.0	2.1
	Highest	1.4	3.1	0.3	5.1	1.7	10.4	2.0
	National total	2.6	3.6	0.6	7.4	1.5	11.6	2.1

Source: Authors' calculations based on available Ghana household surveys.

Table 3C.4 Ghana: Marginal budget share by income quintile

Area	Quintile	Maize	Rice and wheat	Coarse grains	Roots	Chicken	Other livestock	Fish
Urban	Lowest	1.0	3.9	0.2	3.7	2.8	12.7	2.6
	Second	0.8	3.2	0.2	3.0	2.4	10.5	2.3
	Third	0.7	2.8	0.2	2.7	2.1	9.4	2.2
	Fourth	0.6	2.4	0.1	2.3	1.9	8.1	2.0
	Highest	0.3	1.7	0.1	1.5	1.4	5.8	1.7
	Urban total	0.6	2.5	0.1	2.4	2.0	8.5	2.1
Rural	Lowest	6.4	5.8	1.1	17.3	1.9	15.3	1.9
	Second	4.7	4.4	0.8	13.3	1.7	12.7	3.0
	Third	3.9	3.8	0.6	11.4	1.7	11.4	3.5
	Fourth	3.1	3.1	0.5	9.4	1.6	10.1	4.1
	Highest	1.4	1.8	0.2	5.5	1.4	7.5	5.2
	Rural total	3.3	3.3	0.5	10.0	1.6	10.5	3.9
National	Lowest	2.1	4.8	0.1	7.4	2.6	14.5	3.8
	Second	1.6	3.9	0.1	5.9	2.2	12.0	3.4
	Third	1.4	3.5	0.1	5.1	2.0	10.7	3.1
	Fourth	1.2	3.0	0.1	4.4	1.8	9.5	2.9
	Highest	0.7	2.1	0.1	2.8	1.4	6.8	2.4
	National total	1.2	3.1	0.1	4.5	1.9	9.8	3.0

Source: Authors' calculations based on available Ghana household surveys.

Table 3C.5 Burkina Faso: Average budget share by income quintile

Area	Quintile	Maize	Rice and wheat	Coarse grains	Roots	Chicken	Other livestock	Fish
Urban	Lowest	3.7	4.7	0.4	7.5	1.0	11.3	2.3
	Second	2.1	4.9	0.2	7.0	1.5	11.9	2.3
	Third	1.5	4.4	0.2	6.2	1.5	12.3	2.1
	Fourth	1.3	4.2	0.1	5.2	1.7	12.6	2.1
	Highest	0.7	2.7	0.1	2.9	1.7	8.7	1.7
	Urban total	1.2	3.6	0.2	4.6	1.6	10.5	1.9
Rural	Lowest	8.0	3.2	6.4	8.5	0.7	10.7	1.2
	Second	5.6	3.6	1.9	12.7	0.9	12.9	2.4
	Third	5.0	4.2	0.9	11.8	1.1	13.2	2.5
	Fourth	4.3	3.8	0.9	11.5	1.4	13.4	2.5
	Highest	2.9	3.5	0.6	9.3	1.5	12.5	2.3
	Rural total	4.1	3.6	1.2	10.5	1.3	12.8	2.3
National	Lowest	6.9	3.5	4.3	9.0	0.7	11.3	1.7
	Second	4.7	4.1	1.1	11.4	1.1	12.8	2.5
	Third	3.9	4.3	0.6	9.8	1.3	12.6	2.5
	Fourth	2.6	4.2	0.5	8.7	1.4	13.0	2.1
	Highest	1.4	3.1	0.3	5.1	1.7	10.4	2.0
	National total	2.6	3.6	0.6	7.4	1.5	11.6	2.1

Source: Authors' calculations based on available Burkina Faso household surveys.

Table 3C.6 Burkina Faso: Marginal budget share by income quintile

Area	Quintile	Maize	Rice and wheat	Coarse grains	Roots	Chicken	Other livestock	Fish
Urban	Lowest	1.0	3.9	0.2	3.7	2.8	12.7	2.6
	Second	0.8	3.2	0.2	3.0	2.4	10.5	2.3
	Third	0.7	2.8	0.2	2.7	2.1	9.4	2.2
	Fourth	0.6	2.4	0.1	2.3	1.9	8.1	2.0
	Highest	0.3	1.7	0.1	1.5	1.4	5.8	1.7
	Urban total	0.6	2.5	0.1	2.4	2.0	8.5	2.1
Rural	Lowest	6.4	5.8	1.1	17.3	1.9	15.3	1.9
	Second	4.7	4.4	0.8	13.3	1.7	12.7	3.0
	Third	3.9	3.8	0.6	11.4	1.7	11.4	3.5
	Fourth	3.1	3.1	0.5	9.4	1.6	10.1	4.1
	Highest	1.4	1.8	0.2	5.5	1.4	7.5	5.2
	Rural total	3.3	3.3	0.5	10.0	1.6	10.5	3.9
National	Lowest	2.1	4.8	0.1	7.4	2.6	14.5	3.8
	Second	1.6	3.9	0.1	5.9	2.2	12.0	3.4
	Third	1.4	3.5	0.1	5.1	2.0	10.7	3.1
	Fourth	1.2	3.0	0.1	4.4	1.8	9.5	2.9
	Highest	0.7	2.1	0.1	2.8	1.4	6.8	2.4
	National total	1.2	3.1	0.1	4.5	1.9	9.8	3.0

Source: Authors' calculations based on available Burkina Faso household surveys.

CHAPTER 4

Yield Gaps

This chapter presents the methodology used to measure potential for agricultural growth in West Africa. Our approach is based on the estimation of yield gaps for more than 40 crop and livestock products and determines potential growth for these different products as the incremental output that could be obtained if the region closes this yield gap through changes in management practices and the use of inputs in the context of present knowledge and available technologies.

The concept of a yield gap is frequently used in technical agronomic analysis of production as a measure of performance because it implies a comparison between yields actually obtained under particular agroecological conditions on commercial farms and the maximum or potential yield in that region. The potential yield is determined by producing the crop without constraints that are normally found at the farm level, such as nutrient and water stress, inadequate cultivation practices, and so on.[1]

There are at least two reasons for the extensive use of yields and yield gaps as a measure of production performance in agriculture. The first and less controversial reason is that the information needed to estimate yields, such as data on production and cultivated area in the case of crops or production and number of heads of animal stock in the case of livestock, can be directly observed and are easy to obtain.

The second and more questionable reason is that yields are used as a measure of productivity and technical efficiency of the production process, and the narrowing of the yield gap is frequently targeted as a mean to reach other goals.[2] The use of yields as a measure of productivity is convenient because

[1] The difference between potential and observed yields could also be explained by economic constraints, because the optimal technical yield does not correspond with the yield that maximizes profits or minimizes costs.

[2] Together with increased production, closing the yield gap is frequently aimed also to improve the efficiency of land and labor use, to reduce the cost of production, and to increase sustainability (for example, see Chaudhary 2000).

in agronomic analyses of production, total output growth is frequently broken down into yield increase and area increase. High yields are then associated with output expansion through "intensification" and the use of new technologies, while output growth, merely by incorporating new land to production, is seen as an "extensive" source of growth. Although the use of yields and yield gaps could provide indicators of these processes, their use does not come without problems.

Given these considerations, in this chapter we present, first, a brief discussion on yield gaps as measures of potential output growth, comparing them with measures of technical and allocative efficiency and TFP, pointing at some of the limitations of this approach. We then proceed to define yield gaps and to describe the methodology followed here to estimate these gaps, presenting summary results of yield gaps for different crops. This is followed by a discussion of the availability of production technologies in the region in which we look at the evidence found in the literature. We contrast this information with our yield gap estimates as a way to check whether the estimated gaps are supported by evidence of existing technology in the West Africa region. The chapter ends with a broader view that goes beyond technical aspects of production as we discuss problems and prospects for agriculture intensification.

Yields, Productivity, and Efficiency

The best expression of production performance and the prospects for longer-term increases in output is the growth of TFP, the ratio of output to inputs in the production process, with productivity increased when growth in output outpaces growth in input (see the discussion of the concept of TFP in Lipsey and Carlaw 2004). Productivity growth is the best kind of growth to aim for rather than attaining a certain level of output by increasing inputs, because when some of the inputs (for example, land) are constrained, output growth is subject to diminishing marginal returns. There could also be negative effects on the quality of natural resources and on the sustainability of the production process.

Productivity varies due to differences in the environment in which production occurs, differences in production technology, and differences in the efficiency of the production process (Lovell 1993). Here we are interested in productivity changes related to technology and efficiency in different environments, so we focus on these two concepts.

Lovell (1993) refers to the efficiency of a production unit as the comparison between observed and optimal values of its outputs and inputs. This comparison takes the form of the ratio of observed to maximum potential output obtainable from given inputs or, alternatively, the ratio of minimum potential inputs to observed inputs required to produce a given amount of output. The optimum or maximum efficiency is defined in terms of production possibilities and results from output obtained by fully efficient firms using available production technologies. These technologies represent the current state of our knowledge of what can be produced and how to combine resources to produce desired products. Thus, technological change occurs when technical knowledge increases (Lovell 1993).

It is important to distinguish two components of production efficiency: technical efficiency and allocative efficiency. Koopman (1951 cited by Lovell 1993) provided a formal definition of technical efficiency: a production unit is technically efficient if an increase in any output requires a reduction in at least one other output or an increase in at least one input and if a reduction in any input requires an increase in at least one other input or a reduction in at least one output. This definition implies that an inefficient producer could produce the same output with less of at least one input or could use the same inputs to produce more of at least one output. On the other hand, allocative or price efficiency refers to the ability to combine inputs and outputs in optimal proportions in light of prevailing prices (Lovell 1993). Farrell (1957) introduced the methodology to measure technical efficiency, originating a vast literature on the subject.

These ideas can be expressed formally following Färe et al. (1994). The production technology describes the possibilities for the transformation of input vector x_t into output vector y_t in a particular year t. Without loss of generality we define the technology to produce a single output ($\boldsymbol{y}$) using two inputs:

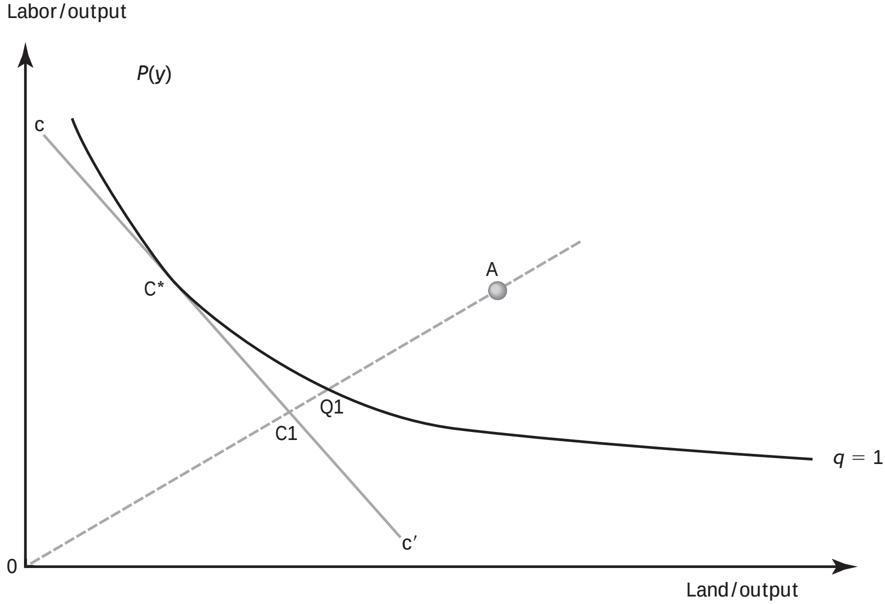
$$(\boldsymbol{x_1},\boldsymbol{x_2}) \text{ in year } t \text{ as: } P(y) = \{x_i \bullet \ R^2_+ \mid (y, x_i) \bullet \ t\} \quad \text{and} \quad i = \{1, 2\}. \quad (4.1)$$

This technology is illustrated in Figure 4.1 as an input possibility set showing the amounts of two inputs needed to obtain one unit of output where the unit isoquant shown represents the technological frontier.

The frontier of the input possibilities for a given output vector is defined as the input vector that cannot be reduced by a uniform factor without leaving the set. In Figure 4.1, the frontier is the isoquant of fully efficient units represented by $q = 1$. Using this frontier as the reference, we can measure the technical efficiency of production unit A as the ratio TE = 0Q1/0A. Similarly, knowing land and labor prices (represented in the slope of the isocost line c–c•), the allocative efficiency of the production unit operating at A is defined as the ratio AE = 0C1/0A, where the distance C1–A represents the reduction in production costs that would occur if A were to produce at the allocatively (and technically) efficient point C* instead of at the technically efficient but allocatively inefficient point Q1.

The possibility of expanding production results precisely from the distance between production unit A and the frontier along a ray through the origin.

Figure 4.1 Technology and technical and allocative efficiency



Source: Authors.

If the knowledge needed to produce at the frontier is available, access to this knowledge by A will allow it to close the gap. The potential to increase output is then given by the size of the observed inefficiencies.

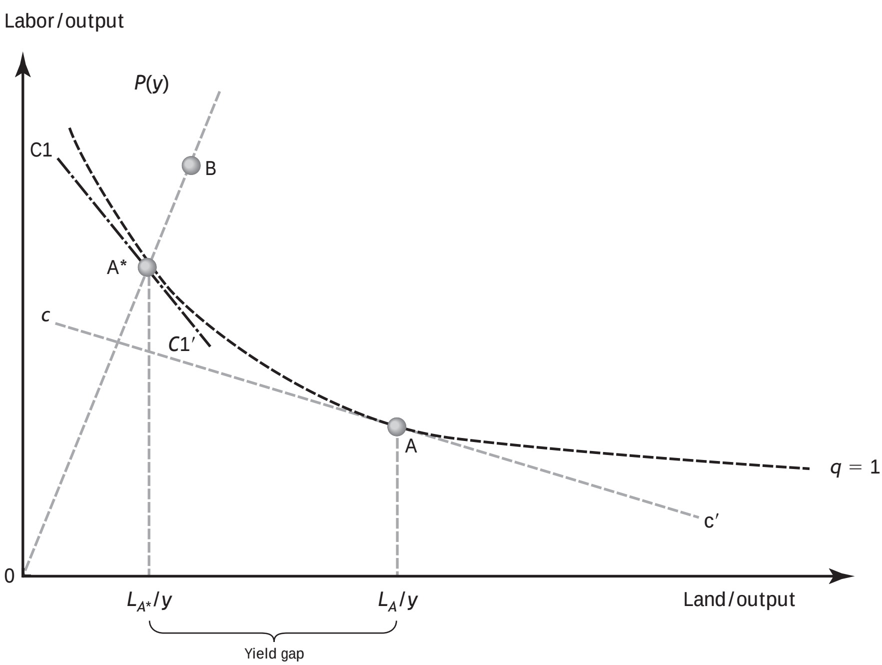
Ideally, to explore the technical potential to expand the output of different agricultural products, we should apply the concepts just discussed using known production functions for different crops and locations and comparing actual inputs used and the output resulting from the production process with inputs needed to obtain the same amount of output in the production function.[3] However, there is no available information that allows us to conduct this analysis for more than 40 crops and livestock activities in West Africa. This would imply information on the actual use of inputs by crop and the output obtained in different environments, along with similar information on the technological frontier or potential output given available knowledge on production technologies. Instead we need to rely on partial productivity measures indicating the amount of output of different activities obtained per hectare of land use in the case of crop and per head of animal stock in

[3] In practice, the production function giving efficient combinations of inputs to obtain a certain output is generally not known and must be estimated econometrically or using data envelopment analysis.

the case of livestock (we will refer to both measures as "yields"). The use of these indicators imposes a significant constraint on measure potential output expansion. This can be seen in Figure 4.2.

Like Figure 4.1, Figure 4.2 shows the unit isoquant of the technology representing the efficient combinations of inputs. This isoquant cannot be observed because of data limitations. What we observe is only one point at the isoquant (frontier) representing the recommended combination of land and labor from the experimental station (point A*). We also observe point A representing the average production unit, which in this example is both technically and allocatively efficient given the relative land and labor prices. Comparison between yields of A* and A (on the horizontal axis) would result in a yield gap equal to (y/L_{A^*}-y/L_A). This yield gap clearly does not measure the potential expansion of output given that unit A cannot improve efficiency. What A can do is increase yields, moving up through the isoquant toward A*, but then it becomes allocative inefficiency, and there is no incentive for A to adopt the recommended combination of inputs. The yield gap could measure potential expansion of production when A is inefficient and produces within $P(y)$ and not at the frontier. However, if the potential yield is not obtained

Figure 4.2 Yield gaps and efficiency



Source: Authors.

at the point of allocative efficiency, the greater the difference between the input combination in A* and A, the more the yield gap will overestimate the potential. Thus, the best case for the yield gap to be an adequate approximation of potential output expansion occurs when (1) the observed average yields are obtained by using an input combination similar to the one used in the reference technology A* and (2) this combination is allocatively efficient. This is the case of point B in Figure 4.2, where prices are now represented by c_1-c_1•. But in this particular case the difference in yields results from differences in efficiency, and the yield gap is a good indicator of potential output expansion.

The previous discussion relates yields and yield gaps to mainstream concepts in microeconomics, assuming that producers allocate resources to maximize profits or minimize costs based on market prices. However, this does not necessarily reflect the situation in West Africa, where we do not necessarily expect households to behave as profit maximizers. Household behavior and the factors that determine it are explained in a conceptual framework based on the “household model” (Singh, Squire, and Strauss 1986). This model attempts to explain the behavior of a household that is jointly engaged in production and consumption, making decisions about the level of output, the demand for factors, and the choice of technology, labor supply, and commodity demand (Bardhan and Udry 1999). Since publication of the paper by de Janvry, Fafchamps, and Sadoulet (1991), the introduction of elements from New Institutional Economics has allowed the development of a framework that assumes the presence of transaction costs affecting exchanges in developing countries that determine a wide margin between low selling price and high buying price.

Under this framework, optimization occurs in a context of selective market failures that “severely constrain households’ ability to respond to price incentives and other external shocks” (de Janvry, Fafchamps, and Sadoulet 1991). These market failures result in nonseparability of consumption and production decisions at the household level. Market failures could occur in output, input, capital, land, and labor markets and could result from transaction costs due to distance and poor infrastructure, high marketing margins, imperfect information, risk, poor supervision, lack of incentive, and transport and communication costs. It is this occurrence of market failures that causes households to deviate from the input combinations implied by input price ratios (Sadoulet and de Janvry 1995).

In sum, the yield gap as a measure of potential to increase output is fundamentally limited and will be inaccurate if the input combination of the reference technology at the frontier is significantly different from the one used at present (Capalbo and Vo 1988). This is what we expect to happen in the case of West Africa given that normally recommended input combinations do not necessarily reflect the relative prices of inputs. Yield gap estimates would actually reflect the potential to expand output if (1) we assume that a policy change would bring relative input prices closer to point A* or, equivalently, that production unit A is allocatively inefficient and needs to move toward A* to become efficient or (2) producer A is actually inefficient (as B is in Figure 4.2). However, and because of market failures affecting decisions at the household level, even if governments remove price distortions, farmers' expected utility optimization subject to the constraints they face will yield input combinations different from those suggested in our discussion about the economics of yield gaps. In addition, as discussed later, the maximum obtainable yield is derived from the crop modeling results of Fischer, van Velthuizen, and Nachtergaele (2002), which assume certain levels of inputs and management conditions. Even though one can acknowledge that the choice of production system is related to relative factor prices, this remains an approximation, and it is not clear that the model represents any optimization under farmers' conditions.[4] For all these reasons, it is likely that the yield gaps calculated in the paper represent an overestimate of the gap that can be realistically closed even if governments implement price reforms and improve infrastructure and agricultural support services. With these caveats in mind, along with the limitations of our approach, we proceed to define and analyze yield gaps observed in West Africa.

Definition and Measurement

Penning de Vries, Rabbinge, and Groot (1997) define yield gaps as the difference between the potential yield and the average yield a farmer currently achieves. This yield gap indicates, in a quantitative way, the increase in yield that can be obtained over the current yield levels under specifically defined management practices (Bindraban et al. 1999).

Different measures could be used to estimate potential yield. The agronomic yield potential—defined as the yield obtained on experimental stations with no physical, biological, or economic constraints; using the best known techniques; applying sufficient inputs to stimulate crop growth to the maximum; and eliminating all pre- and postharvest losses—is the maximum achievable yield and reflects the knowledge frontier and best known management practices at any given point in time (Penning de Vries, Rabbinge, and Groot 1997).[5] The yield gap is then estimated comparing the potential yield with

[4] We thank the editor and reviewers for pointing this out.

[5] For example, the exploitable yield potential is the yield obtained with no physical or biological constraints with the goal of maximizing profits. The exploitable yield is lower than the agronomic yield potential given that it is constrained by economic considerations (output and input prices).

yields obtained using current farming practices in areas with similar agroecological conditions (for example, climate, physical and chemical soil characteristics, water availability).

The yield gap reflects mainly differences in management practices (for example, the amount of fertilizer used, land preparation, time of the year of different practices) under similar agroecological conditions. For example, the national average yield is not an appropriate indicator of farm-level performance because it is an average across agroclimatic zones, soil types, crop ecologies, crop types, and technologies. For this reason, it is important to obtain average yields from homogenous agroecological conditions, similar to those used to measure potential yields, and also under similar production systems (technologies).

Yield gaps have at least two components. The first of these cannot be narrowed, is not exploitable, and mainly owes to factors that are generally not transferable, such as the environmental conditions and some of the built-in technologies that are available at research stations or experimental farms. The second component arises when farmers use amounts of inputs and cultural practices different from the ones needed to achieve the agronomic yield potential (Duwayri, Tran, and Nguyen 2000) and is mainly the result of differences in management practices. The differences in management practices, on the other hand, could result from deficiencies and lack of knowledge of the production technology, or it could reflect economic constraints given that, for instance, the level of fertilizer used by producers could maximize profits, not yields. In this case, and as discussed by Pingali and Heisey (1999), efforts to narrow the yield gap without considering economic aspects may be counterproductive and may actually result in inefficient allocation of inputs, reducing farmers' incomes as shown in Figure 4.2. In other words, a large yield gap implies that farmers did not fully adopt the existing technologies because they were not packaged appropriately or because economic conditions made them unattractive. A small yield gap, on the other hand, indicates that the available technologies are almost fully used.

With advances in information technology and spatial analysis techniques, a different approach to measure yield gaps is now available, offering important advantages over the traditional measure using research station yield estimates. These advantages are apparent when estimates are needed at the country or the regional level, in regions where agroecological conditions different from those at the experimental station prevail. Yield gaps can be determined with this approach by estimating yield potential using detailed spatial information on soil associations (including soil water-holding capacity, slope, depth, and texture) and climate (radiation, temperature, rainfall) to model the response of different genetic materials simulating growth on a daily basis for the duration of a growing period. Of all the factors that affect crop performance, the most important are the efficiency of the use of radiation, the availability of water and nutrients, factors contributing to the soil-water balance, and those affecting soil fertility (Bindraban et al. 1999). The yield gaps can be estimated by comparing these estimated values with those observed in different regions and conditions or by simulating production of the same crops under farming conditions.

Examples of this approach have been presented by Bindraban et al. (1999), Rockström and Falkenmark (2000), and Fischer et al. (2001), to name a few. The study by Bindraban et al. used global datasets on climate and soil at a grid cell resolution of 5 × 5 minutes to determine land quality indicators for SSA, expressing the indicator as a yield gap. The yield gap indicates in a quantitative way the increase in yield over the current yield levels that can be obtained under specifically defined management practices using deterministic growth crop models. The gaps are estimated for optimal, water-limited, and nutrient-limited management conditions. Annual potential yields increase from zero at higher latitudes (in the Sahara) to as high as 25 tons per hectare near the equator. This growth is caused by the increase in growth period and the number of crops that can be grown on an annual basis.

Rockström and Falkenmark (2000) focus on the determination of yield gaps and the opportunities for yield increase in rainfed agriculture in dry climate regions. The model used addresses the effects on crop yields of partitioning rainwater into runoff, plant-available soil water, and water for deep percolation, along with other technical variables.

The work by Fischer et al. (2001) is the most relevant to this study because we use their estimates of potential yields for different crops in West Africa as the potential yield to estimate yield gaps. The study by Fischer et al. presents a comprehensive global assessment of the world's agricultural ecology. These authors developed an agroecological zone (AEZ) approach using a GIS-based modeling framework that combines land evaluation methods with socioeconomic and multiple-criteria analysis to evaluate spatial and dynamic aspects of agriculture. Results of the AEZ assessment are estimated by grid cell and aggregated to national, regional, and global levels, providing a standardized framework for the characterization of climate, soil, and terrain conditions relevant to agricultural production. In this context, Fischer et al. used crop modeling to identify crop-specific environmental limitations under assumed levels of inputs and management conditions, obtaining output time series of attainable crop yields for all major food and fiber crops.[6] The AEZ

[6] The key components of the database applied in the AEZ methodology include the following: the FAO Digital Soil Map of the World and linked soil association and attribute database; a global elevation and derived slope distribution database; the global climate dataset of the Climate

assessments were carried out for a range of climatic conditions, including a reference climate, individual historical years, and scenarios of future climate based on various global climate models. Farming technology was considered at three levels: a high level of inputs with advanced management, an intermediate level of inputs with improved management, and a low level of inputs with traditional management. We will return to the data and results of Fischer et al. to explain the methodology used in this study.

Yield Gap Estimation

To be able to determine potential production expansion of different crops based on yield gaps, we need to obtain yields from similar production systems in homogenous agroecological conditions across the region. In this section we proceed to define yield potential, current yield, and the main aspects of the methodology we use to estimate current yields in this study.

Yield Gap and Yield Potential

We first define yield gap and its components, potential and actual yields, as used in this study. The *yield gap* for a particular crop is defined as the potential yield minus the actual average yield obtained for that crop at the pixel level under homogenous agroecological and economic conditions.[7] Correspondingly, *potential yield* is defined as "the yield of a cultivar when grown in environments to which it is adapted, with nutrients and water non-limiting and with pests, diseases, weeds, and lodging and other stresses effectively controlled" (Evans and Fischer 1999).

From an agronomist's perspective, the defining factors of crop yield potential are cultivar choice (genetic potential, resistance, tolerance, and stability) and local agroecological conditions such as climate, soil, and sun radiation. The purpose of crop management improvement is mainly to reduce abiotic stressors such as lack of moisture, poor soil fertility, and frost and biotic stressors such as insects, pests, and fungi. We use potential yield estimation from the global agroecological zone project (Fischer, van Velthuizen, and Nachtergaele 2002) introduced in the previous section.

Actual Yields and Yield Gaps in Homogeneous Agroecological Zones

As discussed in Chapter 3, information on production and yields of different crops is, in most cases, available only at national or aggregated subnational

Research unit of the University of East Anglia, with annual data from 1901 to 1996; and distributions in terms of 11 aggregate land-cover classes derived from a global 1-kilometer land-cover dataset. Estimates from population distribution and densities at a spatially explicit subnational level for each country are from a global population dataset for 1995.

[7] The pixel size is an area of 5×5 minutes, which is about 9×9 square kilometers.

levels such as for regions or districts. Such geographically coarse data are unable to reflect important variations within countries and are insufficient for the estimation of yield gaps for different agroecological conditions as intended in this study. Thus, to obtain information on actual yields we use an innovative approach that takes advantage of several sources of information to fill such data gaps. This approach uses the SPAM, presented in Chapter 3, to disaggregate production data from large reporting units to the pixel level (You and Wood 2006; You et al. 2007). We also use information on potential yields at the pixel level (from Fischer, van Velthuizen, and Nachtergaele 2002) to obtain spatially disaggregated yields gaps. These yield gaps are then aggregated at the development domain level, our basic spatial unit of analysis, to obtain yield gaps in homogeneous agroecological conditions and in areas with similar economic conditions and similar constraints and opportunities for development.

Estimated Yield Gaps and Potential for Agricultural Production Expansion

Table 4.1 reports calculated average yield gaps based on the assessment of potential yields by Fischer et al. (2001) and our own estimates of average yields in the different development domains and production systems. Although we report only averages at the regional level, the standard deviations capture the variation in yields and yield gaps across countries, AEZs, and distinctive farming systems. Evidently, the potential to experience a two- to threefold yield increase among some of the basic food staples is possible if more farmers can access and efficiently use the available stock of knowledge and technologies.

Among staple crops, sorghum and millet have the potential to realize average yield gains of up to three times their current levels. Rice has the potential to experience a doubling of current yields. Cassava, another important staple in the region, can also realize significant gains, up to 50 percent on average, although this can be significantly higher in the less humid regions, where intercropping is less intensive (see Nweke, Spencer, and Lyman 2002).

According to our estimates of yield gaps, we conclude that there is a vast potential to expand agricultural production in West Africa. The yield gap for most crops could be reduced to obtain yields closer to the potential achievable yield by appropriately using improved crop varieties, the recommended levels of fertilizers, and adequate management of nutrients, water, and pests and diseases. At this point we could ask several questions: Is this knowledge really available? Is there historical evidence of technology development and availability of this technology in the region? If this is the case, why have these technologies not been adopted?

In what follows we look at the evidence on technology availability and the impact that its use could have on yields and use this information as a qualita-

Table 4.1 Descriptive statistics of current and maximum potential yields among rainfed cropping systems in the CORAF region

		Actual or current yield		Maximum potential yield		
Crop type/item	*N*	Mean	Standard deviation	Mean	Standard deviation	Yield gap (potential/current)
Cereals						
Maize	39	1.24	(0.6)	3.40	(1.1)	2.7
Rice	31	1.49	(0.6)	2.78	(0.6)	1.9
Millet	35	0.72	(0.3)	2.43	(0.8)	3.4
Sorghum	33	0.84	(0.3)	2.75	(0.8)	3.3
Root crops						
Cassava	32	9.15	(5.4)	14.0	(5.4)	1.5
Potatoes	20	6.11	(3.3)	28.4	(10.6)	4.7
Sweetpotatoes	30	8.67	(7.1)	15.3	(10.3)	1.8
Pulses						
Beans	12	0.54	(0.2)	1.14	(0.4)	2.1
Oil crops						
Groundnuts	32	0.83	(0.3)	1.35	(0.6)	1.6
Soybeans	14	0.79	(0.3)	1.50	(0.9)	1.9
High-value crops						
Bananas	23	6.08	(3.0)	27.4	(16.1)	4.5
Cotton lint	19	1.29	(1.3)	3.82	(2.8)	3.0

Source: Authors' calculations using data from Fischer et al. (2001), averaged across the agroecological zones and farming systems among all CORAF countries.

tive check of our yield gap estimates. We look for this evidence in four areas: improved and high-yield varieties, water, fertilizer, and biotic constraints. Because the evidence collected supports the potential for growth found in our yield gap estimates, we end this chapter with a discussion of the poor results in terms of yield growth in the past, as well as future prospects.

Technology Availability

As discussed in the introduction to this chapter, the technical possibilities of closing the gap depend on the availability of improved crop varieties and on knowledge of the optimum use of water, fertilizer, and control of pests and diseases. We look separately at the information on availability in these different areas, and we also discuss technical problems and knowledge of livestock production and potential yield gaps. Note that we only introduce the discussion of livestock yield gaps and growth possibilities in this section, given that no information is available with which to conduct a spatial analysis of yield gaps similar to the one done for crops.

Crops

Improved Varieties

R&D investment in West Africa is low compared with investment efforts in countries with well-developed and successful institutions for innovation in agriculture such as Brazil, China, India, and South Africa. Nevertheless, and according to Maredia, Byerlee, and Pee (1998), the investment in technology development and transfer activities made in the region since the 1970s is not negligible. These authors assert that between 1961 and 1991, the number of agricultural researchers in government institutions increased from 1,576 to almost 6,800, with an average expenditure in R&D of $162,000 (in 1985 purchasing power parity dollars) in 1961, decreasing to $101,000 in 1991. They also claim that there is increasing evidence of the availability of improved varieties of major foodcrops to farmers in Africa, as well as increased food production in regions where adoption has occurred and high returns to research investment.

Maredia, Byerlee, and Pee (1998) conclude that the effects of agricultural research in West Africa can no longer be denied and, as evidence for their claims, they refer to "outstanding success stories of technological change in food crop production in West Africa," such as widespread adoption of improved, higher-yielding maize open pollinization varieties (OPVs) and the availability of semidwarf rice varieties for irrigated regions and early-maturing cowpeas.

Similarly, in an analysis using recorded yield gaps in smallholder agriculture in a sample of five SSA countries including Ghana and Nigeria, Larsson (2004) finds that in potentially dynamic areas, the majority of farmers achieve yields far below those possible to obtain under present agroecological conditions. Based on these results, Akande et al. (2004, 254) conclude: "Appropriate technology is largely available 'on the shelf.' . . . Technologies (high-yielding varieties, drought tolerant and pest resistant seeds, fertilizer, etc.) are available and peasants want them."

More evidence is provided by the InterAcademy Council (IAC 2004), which refers to the "dramatic" responses of sorghum, millet, rice, and maize to improved technology and to potential yields of these crops that are several times greater than the actual average yields observed in West Africa. Hybrid sorghums achieve yields exceeding 6 tons per hectare, and top yields of more than 10 tons per hectare are reported. IAC (2004, 75) concludes that "technology already 'on the shelf' has the potential to enhance land productivity in Africa once adapted and fine-tuned to location specific situations."

The research results for particular crops are encouraging. Maize shows improvements in research over the past two decades that have resulted in the release of a steady stream of new and improved OPVs. From 1965 to 1997, public maize research programs, with active research collaboration and exchange of germplasm with the International Institute of Tropical Agriculture (IITA) and the International Center for Maize and Wheat Improvement, released a total of 186 maize varieties in West Africa, while the private sector released 81 varieties (Manyong, Makinde, and Ogungbile 2002). In 1998, 37 percent of the total area of maize in 11 West and Central African countries was planted with improved varieties (Manyong, Makinde, and Ogungbile 2002). This rate of adoption is comparable to the estimated figures of 42 percent in Asia and 39 percent in Latin America. Especially notable is the rapid adoption of improved maize varieties in the savanna areas of West Africa, particularly Nigeria, and in important maize-growing regions of Ghana, DRC, Mali, and Senegal (Byerlee and Heisey 1996; IAC 2004).

Information on the yields obtained from the use of improved varieties differs. According to Manyong, Makinde, and Ogungbile (2002), a comparison of yields obtained in 1998 shows that the yields of improved varieties adopted in West Africa were, on average, 45 percent higher than the yields of traditional varieties in that year. Morris et al. (2007) report yield gains for OPVs of about 14–25 percent over local varieties in tropical areas. In addition to the yield gains, yield stability has been enhanced by the release of disease-resistant varieties, especially those that have resistance to the maize streak virus, which has become a major disease of maize in Africa, affecting 60 percent of the maize area in recent years (Bosque-Pérez 2000). In some cases, resistance to streak virus is the main explanation for the yield superiority of improved varieties over local ones (Low and Waddington 1991).

Most of the research on rice done by the region is devoted to cultivar development activities. Despite the limited regional resources invested annually in varietal improvement, 197 improved varieties had been released by the year 2000, and more than 122 were targeted to be released before 2005, with 8 varieties per year released since 1980 (Dalton and Guei 2003a).

Similar numbers of these new varieties have been released for the irrigated and the rainfed ecologies, but the adoption rates for the different ecologies differ dramatically, with the highest levels of adoption observed in irrigated lowland production systems.[8] All the available area in Senegal, 96 percent in Mali, 93 percent in Côte d'Ivoire, and 80 percent in Nigeria are planted with modern

[8] The upland and lowland rainfed systems are the most important in terms of area, with 43 and 35 percent, respectively, of total area planted with rice in West Africa. The irrigated areas in the humid and Sahel regions cover 12 percent of the total area, while deep water and mangrove rice production occupy a smaller area along major rivers and on the southwestern coast of the region (Dalton and Guei 2003a).

varieties. On the other hand, greater variation in adoption can be found in rainfed systems. In lowland rainfed ecologies, 65 percent of the area in Ghana and 55 percent in Guinea are cultivated with modern varieties. The areas of other countries with modern varieties are all below 40 percent. The lowest level of adoption of modern varieties is verified in rainfed upland ecologies, where only Nigeria shows a high level of adoption, with 67 percent of its available area under improved varieties (Dalton and Guei 2003b).

The explanation for the differences in adoption across ecologies is that the irrigated ecologies are the most homogenous and the most similar to Asian production systems and have benefited from the introduction of Asian semi-dwarf varieties. The lack of adoption in rainfed upland systems is attributed to development programs that have not produced varieties that outperform local cultivars (Dalton and Guei 200b). Overall, the adoption of improved rice varieties is estimated to have occurred in about 55 percent of the total rice area in West Africa.

Despite this effort, average rice yields are still low in West African countries. Work by the Africa Rice Center (WARDA) estimates that the yield gap in rice cultivation is as high as 5 tons per hectare in some regions (observed under experimental field conditions). According to Matlon, Randolph, and Guei (1998), the gap between the current average yields realized in farmers' fields and the potential yields is estimated at more than 2 tons per hectare in irrigated humid ecosystems. One study estimates that the yield advantage of simply adopting improved varieties (whether rainfed or irrigated) can be as great as 1.2 metric tons per hectare (see Dalton and Guei 2003a). IAC (2004) asserts that there are promising research avenues to address current biophysical factors that explain the observed yield gap at present. These include the development of low-cost water management, weed-competitive and nutrient-responsive rice varieties, and site-specific soil fertility management.

Cassava is a crop largely grown by poor farmers who use few purchased inputs. This crop requires inputs to be used over a long period of time and for a wide variety of pests and diseases because of its long production cycle (Johnson, Masters, and Preckel 2006). Breeding efforts have focused on substituting biological adaptation for purchased inputs, especially pesticides and fungicides. The number of improved cassava varieties with material from IITA and the Centro Internacional de Agricultura Tropical released in West and Central Africa up to the year 2000 was 113. The area of cassava planted with improved varieties ranged from 31 to 19 percent in Cameroon, Ghana, DRC, Nigeria, and Sierra Leone. In Nigeria and DRC, yields of improved varieties are almost 50 percent higher than those obtained with traditional varieties (Maredia, Byerlee, and Pee 1998). According to IAC (2004), with improved technologies, the yield can increase 5 to 10 times the present average. The yield gap has not narrowed in the past decade due to a lack of investment to improve soil fertility, the absence of supplementary irrigation, and the incidence of various diseases and pests, which cause considerable depression in actual yields (IAC 2004).

Unlike in the cases of maize, rice, and cassava, the potential to expand sorghum and millet production in West Africa is disputed. A report from the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) claims that sorghum and millet research has had no impact in West Africa (CGIAR/TAC 1994), highlighting that the world's most urgent food production problems lie in drought-prone areas such as those of the Sahelian zone of Africa, where sorghum and millet are the staple foodcrops. In 1986 TAC had recommended that the level of effort on sorghum be increased immediately and that the main effort continue to be directed at SSA, where research needs and opportunities were greatest, to bring research support for sorghum (and millet) to a level comparable to that for maize, for rapid development of suitable varieties and other technologies. On the other hand, recent evidence from Sanders, Ramaswamy, and Shapiro (1996) and Vitale and Sanders (2005) presents a more optimistic outlook. These authors argue that technology introduction and demand expansion have been less successful for sorghum and millet because of their low price elasticity of demand, which presents a serious constraint on the intensification process in the short run, resulting in low yields and very limited use of inorganic fertilizers. Increased adoption in the future could result from a demand-driven expansion of the area under improved varieties as a consequence of the shifting dietary demands for meat (especially chicken) that result from urbanization and income growth.

Rai et al. (1999) claim that high-yield varieties have begun to be adopted in some West African countries (for example, Cameroon and Chad), although data on the area under improved varieties are available for only a few countries and show low numbers. In Mali, the area under improved varieties of sorghum reached 29 percent in 1995. In Nigeria, this area was 29 percent in Kaduna in 1996–97 but only 3 percent in Jigawa. Similar numbers have been obtained for millet in Mali.

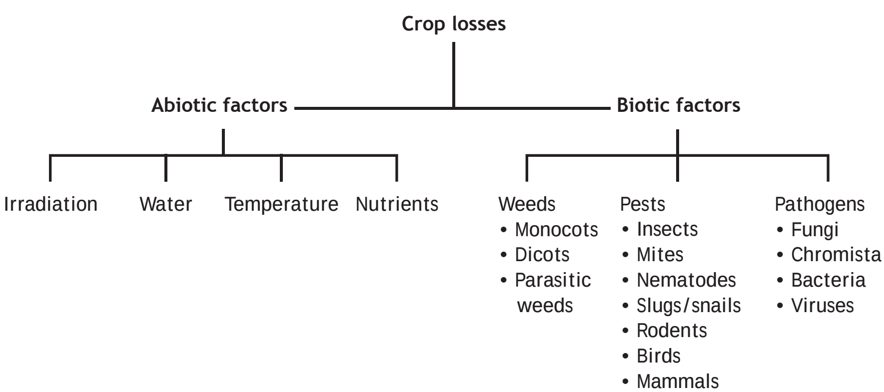
Under the dry conditions of Sahelian countries such as Niger, improved millet varieties are estimated to increase yields by 22 percent, or about 200–500 kilograms per hectare (Mazzucato and Ly 1994). At the extreme, *Striga*-resistant sorghum varieties are estimated to increase yields by 59 percent in the *Striga*-affected regions of Africa.

Associated Crop Yield Losses Due to Biotic and Abiotic Constraints

From a purely agronomic perspective, the diversity in biophysical conditions and their associated production constraints (in terms of both biotic and abiotic factors) contributes to significant yield losses in each cropping system. Figure 4.3 summarizes the typical abiotic constraints as radiation, water, temperature, and nutrients. Biotic constraints, on the other hand, include weeds, pests and insects, and pathogens. Knowledge of how to reduce the incidence of these losses is available, and it normally requires the use of chemicals—fertilizers, insecticides, herbicides, and so on—all inputs that African smallholders are ill positioned to afford. Unable to combat an infestation, a majority of smallholder farmers frequently suffer both pre- and postharvest losses.

As highlighted earlier, because smallholder agriculture is mostly rainfed, yield loss due to water deprivation is by far the most critical limiting factor in the Sahel and in the northern semiarid regions of Coastal countries (for example, Côte d'Ivoire, Ghana, and Nigeria), as illustrated by Figure 3A.1. Although the rest of West and Central Africa receives sufficient rainfall amounts, the distribution and timing of rain events are not always predictable and thus pose a risk for achieving optimal yields. In the case of nonirrigated upland or lowland rice, for example, the most critical time is during the main stages of growth, from panicle initiation to heading (just before flowering). Lack of sufficient soil moisture at this stage will significantly limit yields. This is of concern given that nearly 60 percent of rice production in SSA is concentrated in the rainfed uplands and lowlands (Defoer et al. 2004). Estimates of the exact yield losses are difficult to determine, but some have noted that, due to both inadequate rainfall and poor access to irrigation in recent years, rice yields may have declined significantly, from a high of 7 tons per hectare to 3 tons per hectare (Balasubramanian et al. 2007). In examining the yield gaps between actual and maximum attainable levels of

Figure 4.3 Biotic and abiotic factors that affect crop losses



Source: Oerke (2006).

cassava, Fermont et al. (2009) also attribute the lower than expected yields to erratic rainfall. They claim that nearly 30 percent of the unachieved yield in trials can be explained by a lack of rainfall during the critical 9- to 12-month period of growth.

Water alone is not useful if soils do not have sufficient levels of nutrients to spur crop growth. As noted before, the extreme diversity in soil properties even at a local level can affect performance, including the degree to which farming practices help replenish the fertility of cultivated land (for example, through the use of fallow, mixed-crop, and livestock systems; shifting cultivation; or application of organic or inorganic fertilizer). For example, an analysis of upland rice production systems showed a high level of yield sensitivity to soil fertility differences alone (Defoer et al. 2004). For maize, Wopereis et al. (2006) show average yields varying between 1.8 and 3.2 tons per hectare as a result of differences in soil fertility alone. Focusing on the use of organic fertilizers, their study compared yields between the outfields and infields of individual farms in Togo. This example highlights the traditional practice of depositing organic household wastes and livestock manure in fields closer to the homestead, which enriches the infields and contributes to high variability in crop yields even at the farm level (Tittonell et al. 2008). As a result, many researchers have advocated using more organic sources located on a farm, especially when faced with high input costs for inorganic fertilizers. The potential gains from organic fertilizer use alone can be substantial. In a study of potential rice yields in four agroecological zones of West Africa, Becker et al. found that 20–43 percent of the observed yield gap between farmer-managed and researcher-managed rice plots could be explained by simple on-farm nutrient management alone without the application of inorganic fertilizers or herbicides (Becker et al. 2003). However, because organic fertilizer materials are sometimes needed for other uses, such as for construction and fodder, use of inorganic fertilizers may be more appropriate and even viable under these circumstances (Shapiro and Sanders 1998).

Among biotic constraints, weeds are especially problematic during the growing season. Herbicides are costly and frequently beyond the means of resource-poor farmers. Therefore, manual weeding is most common, typically taking up the majority of the time farmers invest in crop production. In the event that farmers are able to purchase herbicides, their application rates are below the recommended level or they are applied beyond the stage when they are most effective. For rice, for example, production losses from weeds can be as high as 40 percent (WARDA 1999), while improved weed management techniques can potentially increase yields by another 20 percent (Becker et al. 2003). For cassava, weed management has been shown to be responsible for 23–32 percent of the yield gap, and more efficient management can add nearly 5 tons per hectare to yield improvement (Fermont et al. 2009).

In tropical agriculture, crop infestation by pathogens can cause serious crop losses. For example, the genus *Striga* (*Striga* spp.) is responsible for significant yield losses in cereal grains throughout West and Central Africa. Although there have been some advances in breeding since the 1980s, *Striga* still infests nearly 17 million hectares in Western Africa, by far the largest area affected in Africa (Evenson and Gollin 2003). The worst-hit countries, as shown in Table 4.2, are mostly in the Sahel, experiencing yield losses for sorghum, millet, and maize of up to 50 percent (Gressel et al. 2004).

Aside from pathogens, animal pests and insects can also devastate crops. Stem borers are the most common pests to infect cereals growing cereals in SSA and can cause yield losses of between 20 and 40 percent in maize and sorghum (Gressel et al. 2004).

An extensive summary of statistics and evidence on the extent of crop yield losses from both biotic and abiotic stressors in West and Central Africa has been recorded by Oerke et al. (1994) and compiled in a database by CABI (2005). This information shows that overall yield losses average up to 60 percent in the region, or 10–15 percent each from weeds, pests, viruses, and pathogens, respectively. Figure 4.4 illustrates the range of yield losses by crop. Altogether, the losses contributed to a US$10 billion loss in the value of output between 2000 and 2004 (CABI 2005). Simply eliminating yield losses, therefore, could have a huge impact on agricultural performance and growth in the region.

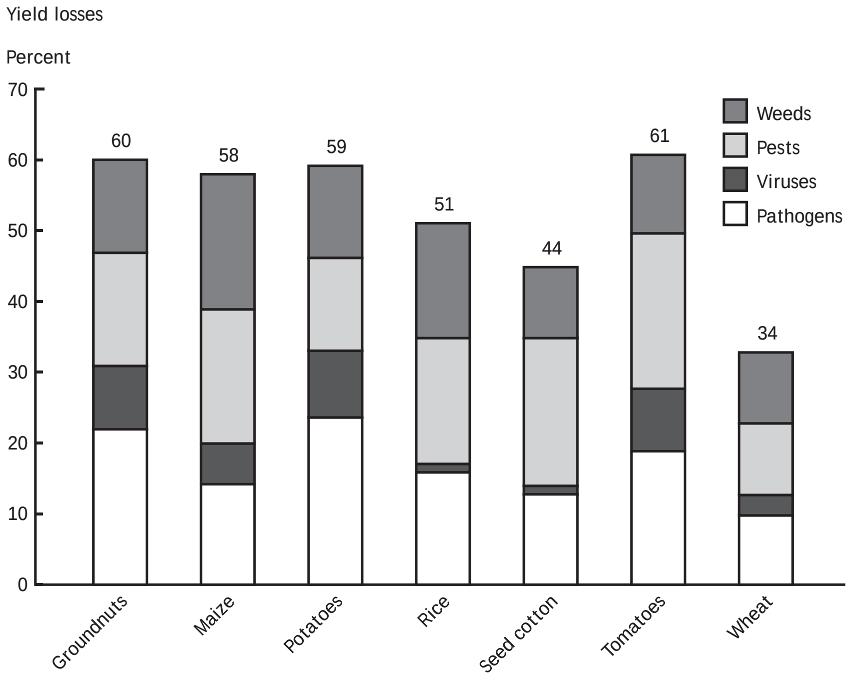
Table 4.3 presents a summary of potential yield gains from closing the gap between actual practices and improved crop technologies in West and Central Africa. For example, applying improved seeds and fertilizer in areas with high

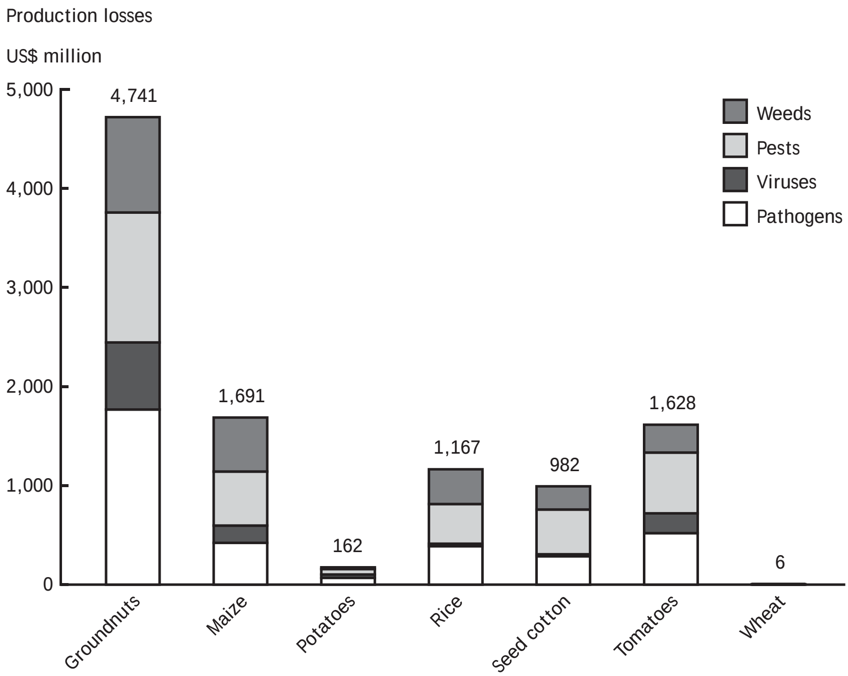
Table 4.2 West and Central African countries with the highest cereal production losses due to *Striga* (includes sorghum, millet, and maize), 2004

Country	Estimated yield losses (%)	Yield loss (thousands of metric tons)
Burkina Faso	35–40	710–820
Ghana	35	170
Mali	40	580
Niger	40–50	930–1,160
Nigeria	35	3,750
Togo	35	70

Source: Gressel et al. (2004).

Figure 4.4 Simple average yield and value of production losses due to biotic stress in West Africa, 2005





Source: Calculated by authors from CABI (2005).

Table 4.3 Select examples of potential yield gains from improved crop technologies in West and Central Africa

Crop / agricultural potential (high, medium, low, irrigated)[a]	Traditional technology (kg/ha)	Modern technology (kg/ha)	Yield gain (ratio of modern/ traditional technology)	Type of modern technology	Country	Source
Cassava						
High	12.9	21.9	1.7	Improved seed, with fertilizer	Benin	Carsky and Toukourou (2005)
High	13.41	19.44	1.4	Improved seed	Nigeria	Nweke (2004)
High	13.6	24	1.8	Fertilizer	Benin	Zinsou et al. (2004)
High	–	15.8	1.2	Cropping management	Benin	Zinsou et al. (2004)
High	–	17.8	1.3	Improved seed	Benin	Zinsou et al. (2004)
High	–	16.4	1.2	Improved seed, with fertilizer	Benin	Zinsou et al. (2004)
High	–	20.2	1.5	Cropping management and improved seed	Benin	Zinsou et al. (2004)
Medium	10.8	18.5	1.7	Fertilizer	Benin	Zinsou et al. (2004)
Medium	–	20.1	1.9	Cropping management	Benin	Zinsou et al. (2004)
Medium	–	20.9	1.9	Improved seed, with fertilizer	Benin	Zinsou et al. (2004)
Medium	–	14	1.3	Cropping management and improved seed	Benin	Zinsou et al. (2004)
Rice						
Irrigated	3.36	3.81	1.1	Improved weeding and irrigation	Côte d'Ivoire Coastal	Becker et al. (2003)
Irrigated	3.63	4.92	1.4	Improved weeding and irrigation, with fertilizer	Côte d'Ivoire Coastal	Becker et al. (2003)

Irrigated	5.41	—	—	Improved weeding and irrigation, with animals (land prep)	Mali	Becker et al. (2003)
Irrigated	3.85	4.87	1.3	Improved weeding, irrigation, with tractor (land prep)	Senegal	Becker et al. (2003)
Irrigated	3.85	5.69	1.5	Improved weeding and irrigation, with fertilizer and tractor (land prep)	Senegal	Becker et al. (2003)
n.a.	—	4.982	—	Improved seed, with fertilizer	Ghana	Somado, Guei, and Keya (2008)
n.a.	—	3.95	—	Improved seed, with fertilizer	Guinea	Somado, Guei, and Keya (2008)
n.a.	—	4.27	—	Improved seed, with fertilizer	Mali	Somado, Guei, and Keya (2008)
n.a.	3.9	4.8	1.2	Improved weeding	Mauritania	Haefele et al. (2001)
n.a.	3.9	5.7	1.5	Improved weeding, with fertilizer	Mauritania	Haefele et al. (2001)
Maize						
n.a.	2.1	4.04	1.9	Fertilizer	Togo	Wopereis et al. (2006)
n.a.	—	6.13	—	Fertilizer	Ghana	Pingali (2001)
Sorghum/millet						
Low	0.832	1.531	1.8	Fertilizer	Mali	Aune and Bationo (2008); Aune, Doumbia, and Berthe (2007)
Low	0.21	0.469	2.2	Fertilizer	Mali	Aune and Bationo (2008); Aune, Doumbia, and Berthe (2007)

Note: n.a. means not available; — means that there is no corresponding yield for the particular combination of crop and potential.
[a]Agricultural potential refers to the length of growing period (LGP) as presented in Figure 3A.1. For rice, it is primarily irrigated.

agricultural potential has been shown to increase cassava yields by 20–80 percent. Maize, sorghum, and millet appear to be even more responsive, with yields almost doubled by adding sufficient doses of fertilizer. The potential to increase rice productivity under irrigation seems to be smaller, as expected, but a 50 percent increase in yields is feasible with weed control, fertilizer, and use of a tractor for land preparation.

In sum, the evidence in the literature appears to show that technologies exist to mitigate the threat of crop losses from both biotic and abiotic stressors through improved cropping management practices, adoption of improved seeds (high-yield varieties or those resistant to certain pathogens and viruses), use of organic and inorganic fertilizers to improve soil nutrients, irrigation, and so forth. The results, of course, depend on how well farmers can access and adopt more efficient and intensive production practices to rapidly close current yield gaps over time.

Livestock

As mentioned before, because of the constraints that the environment imposes on livestock production in the region, we can observe a clear spatial stratification of production systems, with pastoral grazing systems found mostly in the northern part of the region, mixed crop-livestock systems in the subhumid unimodal rainfall zone, and specialized intensive livestock periurban systems (for example, poultry production) around major cities along the coast. Our focus here is on pastoralist and mixed (agropastoralist) systems in which the main livestock activity is the raising of cattle and small ruminants (sheep and goats).

Pastoral grazing systems in the Sahel are based on the migration of herders in accord with seasonal rainfall patterns, with the drier part of the year spent in the higher-rainfall semiarid zones. Pastoralists practice semisubsistence production of millet and cowpeas, but their principal activity is herd management. Agropastoralists, meanwhile, raise crops during the rainy season, as do traditional crop farmers in the mixed systems, but maintain much larger herds. Three main options are available to agropastoralists to keep livestock, according to Delgado (1989). The first option is the ownership of cattle that are entrusted year-round to transient cattle herders. This is the option that predominates at present in West Africa. Using this option, farmers benefit through meat price speculation but lose the use of by-products such as milk and manure. The second option is cattle fattening, whereby farmers buy cattle at the end of the cropping season, feed the animals with high-energy feeds and farm-produced roughage, and sell them when prices are highest at the end of the dry season. The key element that makes this second option feasible is the low opportunity cost of household labor outside the cropping season. Finally, the growing-out option involves keeping or breeding cattle year-round on the smallholder's farm for dairy production or oxen draft cultivation.

The possibilities for increasing productivity in livestock production are in part related to the role that animals play in the livelihoods of livestock holders. The use of new technologies becomes an option for livestock holders when animals are used as production capital. This implies the reduced importance of other roles of livestock, such as being a means of saving or a reserve of value and insurance for the household. This normally occurs when financial and insurance services become available to households and when a growing demand for livestock products makes production attractive. As this is increasingly the case, intensification of livestock production in West Africa will require an expansion of mixed systems together with technical options to improve nutrition, reduce the incidence of diseases, and increase the genetic potential of the animals. In what follows we look at the prospects for intensification and productivity enhancement in livestock production in West Africa. But before doing this, we need to briefly discuss the economic factors that drive these trends and changes.

Economics of Livestock Keeping in West Africa

According to Delgado (1989), the main economic issue in mixed farming in West Africa is the evolution of the opportunity cost of land and labor used in crop and livestock activities. We follow Delgado to describe the main characteristics and economic drivers of the pastoralist and mixed systems.

Where arable land is in short supply, growth in agricultural output requires a more intensive use of labor per unit of land and increased input in terms of soil amendments, fertilizers, and improved seeds compared with traditional technology.[9] These increase the profitability of keeping cattle on a farm year-round for the maintenance of soil fertility through reincorporation of animal dung and green manures (made easier with oxen draft cultivation), making mixed farming more attractive over time as the agricultural population density increases.

In areas where land scarcity is not yet a problem or where there is a rise in the cost of labor, intensification will depend on the distribution of labor demand through the year and on peak-period labor requirements. If the higher opportunity cost of labor occurs primarily in the peak agricultural season, dry-season feeding and oxen draft strategies are also favored. However,

[9] Delgado highlights that smallholder farming systems involving cattle kept year-round on the farm are found primarily in countries with relatively scarce arable land, such as the Ethiopian and Kenyan highlands, which shows that mixed farming is a practice that permits higher labor input per unit of land in a profitable manner.

the reverse is the case if the opportunity cost of labor is also high during the dry season. In that case, other things equal, relatively high labor costs unambiguously favor cattle entrustment. A high opportunity cost of capital, on the other hand, unambiguously harms mixed farming and, in particular, oxen draft cultivation.

Changes and trends in output prices also affect the evolution of production systems. Although according to Delgado (1989) increased returns to cropping do not affect the opportunity cost of land in land-abundant economies, they negatively affect mixed farming and raising cattle on the farm through labor allocation. On the other hand, high returns to crops increase the attractiveness of oxen draft power. Finally, an increase in beef producers' revenues is beneficial to livestock owners in general, although it probably discourages oxen draft cultivation because there is a greater incentive to roll over oxen capital into beef sales.

Trends in Livestock Production

The population of West Africa, in particular the urban population, has grown rapidly in the past 40 years and is expected to continue growing. The result has been an increase in demand for cereals and pulses (which produce crop residues for livestock) and a much increased urban demand for livestock products. In response to this increase in demand, producers expand their cultivated area to maintain per capita crop output. As a consequence, fallow periods for maintaining soil fertility on cropland decline or disappear in many semiarid areas, and pasture land is put under crop cultivation. Continuing population growth eventually reduces farm sizes as land becomes limited in quality as well as quantity as the fallow system breaks down and cropping is extended onto the less fertile lands previously used for grazing. The resulting decline in yields reinforces the process, limiting land supply further, while potential returns to more intensive production practices increase (Tiffen 2004).

One of the reasons for this rapid population growth seen in many semiarid areas is lower human and animal disease pressure than that found in humid zones and the improved disease control across rainfall regimes. Higher population density increases land demand and permanent farming settlements in the higher-rainfall zones around traditional water sources, resulting in property rights conflicts between traditional herders and crop farmers and making traditional pastoralism more difficult (Hiernaux 1994; Shapiro and Ehui 2004). Simultaneously, grazing land has diminished, and crop residues are becoming a more important element of livestock raising, favoring the development of more intensive systems.

As a result of this process, agricultural production is being forced toward both intensification and expansion in relation to increased human and livestock populations (Kristjanson et al. 2005). Among the results of such pressure is the increased integration of crop and livestock production enterprises (McIntire, Bourzat, and Pingali 1992; Tarawali et al. 2004), which results in the expansion of the farmed area, with a growing number of animals living in the enlarged farming zone and a smaller percentage in the exclusively pastoral zone.[10]

Technology Needs and Availability

The present trends showing the increasing importance of mixed systems and intensification in West Africa, as discussed earlier, are not guaranteed to continue in the future. According to Shapiro and Ehui (2004), with no markets for livestock products and no technologies available that make it profitable to incorporate and replenish soil nutrients and increase water availability, mixed systems and livestock intensification will wither with the exhaustion of soil fertility. Over time, human population in the mixed-system regions is likely to decline; migration of most men from these areas began several years ago (Sutter 1984; Painter 1986; Shapiro and Sanders 2004). Ultimately, as the opportunity costs of farmers increase outside of agriculture, they will leave the farms and an extensive livestock production system will be developed.

Shapiro and Ehui (2004) highlight the importance of the profitability of crop fertilization in the development of an intensive crop-livestock system in the region. The possibility of substituting fodder for expensive fertilizers is an option to increase soil fertility and the quantity and quality of feed. Options for improved but low-cash-input livestock activities include crop rotation or intercropping with forages, resulting in better feeding of animals as well as improved soil fertility management. Such low-cash-input systems, which include legumes, would limit, if not entirely eliminate, the need for purchased inputs (Shapiro and Ehui 2004). Development of production systems using cover crops in rotation with cereals or cash crops is already occurring in West Africa.[11]

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[10] Tiffen (2004) exemplifies this trend with the case of Nigeria where cultivation has also spread into the less densely populated Middle Belt. Population growth and its impact on the environment reduced the incidence of trypanosomiasis, allowing mixed farming and holding animals in the farm all year round. By 1992, almost half of Nigeria's cattle population was kept in this region, with declining importance of pastoralist systems

[11] Two cover crops already in use are *mucuna* (*Mucuna pruriens*) and *stylo* (*Stylosanthes hamata* or *guianensis*). In Nigeria, cattle with access to *stylo* in the dry season produced more milk, lost less weight, had shorter calving intervals, and had a better rate of calf survival. Goats showed reduced weight losses of nonpregnant adults grazing *stylo* pasture than natural pasture. In Côte d'Ivoire, cross-breeds fed on *stylo*-based pastures produced very high milk yields compared to those managed using the traditional method using native pastures (Tarawali et al. 1999).

Together with increasing soil fertility and improving water availability, reducing the risk of diseases, improving the methods for preserving and processing meat and other livestock products, improving the nutritive content and storage of crop residues, and improving breeding techniques are other technological developments needed to increase productivity and market opportunities (Tiffen 2004).

The basis for increasing yields for meat or milk production (output per head of animal stock) is to increase the production of individual animals (increase milk production per milking cow or achieve faster and more efficient conversion from feed to meat) and to increase off-take rates (increase the proportion of "productive" animals in stock, milking cows or the proportion of animals that are sold or consumed each year). To this end, production systems need to increase fertility rates, reduce mortality, and reduce the time it takes to prepare an animal for the market or to increase the production period of milking cows. This can be done with improved genetics, nutrition, and animal health in a more commercially oriented system. We do not have specific data for West Africa, but studies in East Africa (see Fernandez-Rivera, Okike, and Ehui 2001) show that productivity increases of 20 percent in beef production could be achieved by improving feed quality and health management in mixed systems with local breeds. The total impact on the livestock sector will depend on the assumptions about the extent of adoption of this technology. Substantial improvements can be achieved by improving animal genetics, as shown by the case of cross-bred milking cows in the highlands of Kenya.

After reviewing the evidence of technology availability for crops and livestock, we conclude that there is a gap between potential and actual production in West Africa resulting from the limited stock of knowledge available, as reviewed in this section, and from the low yields obtained by farmers at present. The gap could be closed, at least in part, through wider use of the existing stock of knowledge and technologies, implying the use of improved agronomic practices, adoption of stress-resistant crop varieties, and appropriate use of chemicals for pest, disease, and weed control. Results show that countries in the Sahel can benefit from high growth in agriculture if the yield gap in cereal production is reduced in the next 10 years. Similarly, Coastal and Central countries could benefit from increased productivity of cereals and also roots and tubers.

In the case of livestock production, the path to intensification appears to be to respond to a growing population and higher population densities by acknowledging the growing importance of mixed crop-livestock production systems. Here the evidence on available technology is spare, and we could find no analysis of the impact on livestock productivity. In any case, the possibilities for these mixed systems to expand depend first on the transformation of the livestock sector, which is predominantly pastorialist, to a system that produces livestock in mixed crop-livestock systems. Gains in productivity appear to be linked at least in part to improvements in crop technology, such as increasing yields through fertilization, greater and better-quality crop residues, and the availability of cheaper feed and supplements.

It is important to notice, as mentioned earlier, that there is a gap between potential and actual production in West Africa. This is different from saying that there is a potential to expand production based on this gap. Evidently, conventional technologies that address some of the production constraints observed in West Africa have not always been adopted widely. Is it possible, then, to narrow this gap? What strategy should be used to do so? Although the goal of this study is not to answer this question but rather to look at the yield gap and estimate the economic impact of reducing this gap (assuming that it can be reduced), in the remainder of this chapter we briefly look at some of the answers to this question given by previous studies to put our results in the context of the economic and social constraints affecting technical change in the region.

Technical Change in West Africa

Are technical change and intensification of agricultural production in West Africa possible in the near future? If technologies are available and knowledge has been accumulated over the years on genetic improvement of major crops and the use of inputs in different environments, why is it that intensification is not occurring? In this section we discuss possible answers to these questions, looking at hypotheses offered by researchers in the past and some of the evidence supporting their assertions. However, this is not intended to be an exhaustive or detailed literature review of this topic, given that, as explained in Chapter 1, the identification of how actual adoption of new technologies can be brought into effect through policies, investment, and strategies is beyond the scope of our study. Rather, the goal of this section is to frame our analysis of growth priorities in the context of the discussion of the factors affecting change in agriculture, its likelihood, and the possible paths to be followed by the region in pursuing the intensification of its agricultural sector.

Several hypotheses about the reasons behind the poor performance of the agricultural sector in SSA have been offered starting in the 1980s. A useful summary of this subject is presented by Crawford et al. (2003). These authors summarize the different explanations of and approaches to this problem as follows:

- *Government can solve the problem.* In the 1960s and 1970s, donors and SSA governments alike focused on increasing agricultural production by attempting to copy Asia's Green Revolution. This led to heavy reliance on input subsidies, government-provided services (marketing, infrastructure, extension, research), and the establishment of input and commodity marketing parastatals.
- *Government is the problem.* The lack of results in terms of agricultural intensification and the problems with financial sustainability of the previous approach and the macroeconomic crises that followed shifted the approach to development in the opposite direction. Structural adjustment programs were implemented to create a more economically sound basis for stimulating agricultural productivity and economic development, leading to the dismantling of parastatals and the end of commodity and input subsidies.
- *Others are trying to fill the gap.* Expectations that the private sector would jump in to occupy the spaces left by a government in retreat were not fulfilled. A wide range of responses followed, focusing on different aspects of the new problems created by the reduced government participation. Crawford et al. (2003) mention two main problems—the decline in the use of inputs, particularly fertilizers (Bumb and Baanante 1996; Gordon 2000), which raised concerns about negative impacts on soil fertility and reduced productivity, and "market failures," especially in the supply of credit—as requiring alternative systems for delivering inputs and credit to small farmers (Dorward, Kydd, and Poulton 1998). Also recurring are references to failure of the research system and lack of available technologies, failure of extension, or both; failure of input markets, including seed and fertilizer markets; lack of infrastructure; and so on. In this context, there followed recommendations for renewed government support of input promotion programs; some asked for the return of subsidies (Lele, Christiansen, and Kadiresan 1989; World Bank 1994; Reardon et al. 1999) while others proposed a wide range of interventions capable of increasing supply, reducing costs, and increasing demand without resorting to subsidies (FAO 1994; Donovan 1996; Larson and Frisvold 1996; IFDC 2001; Kherallah et al. 2002). According to Crawford et al. (2003), citing White and Eicher (1999, 279): "The flaws in this approach (high costs, lack of coordination and continuity, problems of scaling up) started to manifest themselves by the late 1990s."

Other factors frequently cited in the literature as affecting agricultural intensification have been lack of infrastructure, limited supply of inputs, and limited supply of new technologies. For instance, Ndjeunga and Bantilan

(2005, 99) find that "productivity gains in sorghum and millet have been limited by low performing varieties, poor functioning institutions which are supposed to supply and deliver technologies at low costs, poor functioning credit, fertilizers and seed markets, missing markets and poor road infrastructure." For these authors, the possibility of increasing productivity depends on investment in road infrastructure to reduce transport costs and on providing an enabling environment for the development of input and product markets. They believe that scientists should simultaneously continue to develop technologies that could be adopted by farmers for the purpose of increasing productivity and design institutional arrangements that will facilitate technology transfer to farmers. Not much is said about what kinds of technologies farmers will adopt or what kinds of institutional arrangements should be most appropriate for technology transfer.

Similarly, the World Bank (2007) attributes low agricultural productivity to a lack of "Green Revolution" technology, one that combines improved crop varieties with adequate water supply, pest control, and fertilizer. The reasons for the lack of technology availability identified by the World Bank are the lack of infrastructure, markets, and supporting institutions; the broader mix of crops grown in the region; and the area's agroecological complexities and heterogeneity (World Bank 2007).

The argument about agroecological complexities has also been frequently cited as a major explanation for the lack of intensification in SSA's agriculture. For Sachs and Warner (1997, 335), poor economic policies, in particular lack of openness to international markets, have played an important role in the slow growth, and they add that "geographical factors such as lack of access to the sea and tropical climate have also contributed to Africa's slow growth." Pardey et al. (2007) also argue that the differences between African and high-income countries make it difficult to exploit technological spillovers. Even more important, Pardey et al. show that the differences in agroecological resources within Africa are startling, making very difficult the possibilities of regional spillovers.

Where do we go from here? Some recent studies appear to be heading in the direction of better understanding the socioeconomic conditions and structural problems faced by African societies, proposing a wider view of the problem. We summarize some of these views.

One of these views is presented in a publication edited by Djurfeldt et al. (2005). The authors develop a model of the Green Revolution, arguing that "the Green Revolution is too narrowly defined when seen as a package of technology" (Djurfeldt et al. 2005, 5). The perspective they develop is less centered on technology than on defining the Green Revolution "as a state-driven, market-mediated and small-farmer based strategy to increase national self-sufficiency in food grains in a string of Asian countries, from the 1960s onwards." For these authors, the Green Revolution is one possible approach to the process of the intensification and modernization of agriculture. In other words, the Green Revolution is a smallholder-based process led by a state that pursues a clear geopolitical goal (that of food self-sufficiency and industrialization), with markets playing a fundamental role in different parts of the chain. According to Djurfeldt et al., this model is supposed to be used not as a normative precept but rather as an explanation of the process.

The policy implications of this model are significant. First, this view implies that although well-functioning markets are essential for the process of change to work, they are not sufficient. It also implies that governments need to establish ownership over their agricultural policies and that donors need to assist them in achieving that goal (Djurfeldt et al. 2005, 4). The authors also mention that governments have played a key role in developing commodity chains and emphasize that the notion of commodity chains driven by different actors is a very useful concept in understanding the process. They claim that small farmer–based agricultural growth is an efficient means of poverty reduction and that agricultural policies in Africa have seldom been small farmer based, as this model requires. Finally, excess reliance on grain imports does not help the process of intensification, and the bottom line is that it is better for governments to protect their farmers against the import of low-priced grains and use the room that the World Trade Organization provides for protection in poor countries (Djurfeldt et al. 2005).

Djurfeldt et al. (2005) stress that the argument that Green Revolution technologies are not applicable in SSA is a myth with serious consequences such as underinvestment in agricultural R&D and dismantling of extension services. They also argue that Boserup's (1965) thesis that the conditions for intensification have always been associated with a closed land frontier and with the pressure of a growing population is interesting but that the factors Boserup mentions are not necessarily those that lead intensification. For Djurfeldt et al. (2005), growing demand and urbanization rather than population pressure explain this process in some African countries.

Other views that differ from some of the traditional approaches that mainly focus on technology supply and constraints by natural resources are those of Karshenas (2001), Collier and Dercon (2009), and Woodhouse (2008). In their view, one of the key factors explaining the poor performance of African agriculture is the low productivity and high cost of labor, and they argue that rather than focusing on agriculture, an economywide approach is needed because the possibility of increasing labor productivity depends on migration from agriculture to other sectors in the economy and on the availability of labor-saving technologies in agriculture. These authors offer different explanations of the effect of high labor costs on intensification.

Karshenas (2001) explains the low labor productivity in SSA's agriculture in terms of the predominant agrarian structures in the region, which resulted from the very low population densities. In the extensive farming system of postcolonial SSA, smallholder agriculture was based on shifting cultivation, and the main constraints on output expansion were labor and labor-augmenting technological possibilities. The poor development of labor markets in SSA has been due to the rural population's ease of access to land as a reflection of the existing agrarian relations. The consequence of this has been higher wages and an intensive use of land, which has caused more land to be incorporated into production from a large stock of unused land. An increasing population and a limit to the incorporation of land into production or a change in agrarian structures (as in South Africa) would induce the use of labor-saving technologies with high capital intensity (as in Asia), increasing labor productivity.

In contrast to the situation in SSA, with its relative abundance of land, Asia's intensive farming system was constrained by land availability and the need for land-augmenting technological possibilities. These formed the main constraints on growth, while producers had access to an abundant supply of wage labor at low relative wage rates. The differences between Asia and SSA are reflected in the high rates of fertilizer and irrigation use (labor-intensive, land-saving technology) in Asia in contrast to SSA in 1965 at the start of the Green Revolution (Karshenas 2001).

However, the expected higher capitalization of African agriculture has yet to occur, and the low input-use ratios for SSA are therefore also indications of low investment and undercapitalization. Labor productivity is similar in Asia and SSA, but land productivity is eight times higher in Asia. The problem of undercapitalization in West Africa can be seen in Figure 2.5, which compares labor and land productivity in West Africa with that in South Africa, India, and Brazil. Despite very low levels of labor/land ratios, South Africa managed to establish a highly mechanized and commercialized farming sector with a predominant use of wage labor and high levels of labor productivity through forced eviction of its indigenous agricultural population and colonization of new lands. These strategies also generated surplus labor residing in labor camps and labor reserve towns, which solved the labor shortage problem of the nonagricultural sector. The process of capitalization in South Africa's agriculture was not simply the result of capital availability but rather the result of forced transformation of agrarian relations and generation of surplus labor. The possibilities of introducing labor-saving technological change in agriculture should be considered an important part of the definition of, and growth prospects for, labor-constrained economies (Karshenas 2001).

Similarly, Woodhouse (2008) argues that labor productivity and labor shortages are the key determinants of future growth, stating that there is no increase in labor productivity without migration from rural areas, access to land and labor mobilization, and development of urban economies. According to Woodhouse, agricultural innovation has focused on improving the productivity of natural resources (for example, land, assuming that additional "smallholder" household farm labor has zero opportunity cost) when the critical factor is actually labor productivity. In part for this reason, capitalization of agriculture in SSA is low, and labor shortages remain a widespread constraint. As a consequence, labor migration continues to form a key element of agricultural development: zones of high productivity and growing market access are frequently sites of immigration, and immigrants' success in profiting from these agricultural opportunities may depend on their ability both to negotiate access to land with "native" landholders and to mobilize labor, sometimes through transnational migrant networks. Conversely, labor emigration may create labor shortages, even in areas with population densities as high as 1,000 people per square kilometer, such as western Kenya (Place et al. 2007), making labor shortage a binding constraint on farming innovation in households too poor to hire the extra labor needed.

Collier and Dercon (2009) also put labor productivity at the center of the problems of African intensification, arguing that rapid growth in labor productivity is what is needed for large-scale productivity growth. However, the focus on smallholder production of past policies and development strategies has been constraining agricultural intensification in several regions because smallholders and the institutions that support and sustain them are weak agents for labor productivity growth in Africa. The reason is the existence of economies of scale in the process of technical change. These economies of scale result mainly from four factors: the learning process involved in technology adoption; the risk implicit in the process; the need to finance the process and provide access to capital; and the need to organize the logistics of trading, marketing, and storage.

Collier and Dercon (2009, 5) argue that knowledge is "a classic scale economies activity replete with externalities," and this makes the process too costly for smallholders, while large organizations may be able to diffuse knowledge much more cheaply, effectively, and quickly. Innovation also implies experimentation and trial and error and, as a result, there is a strong incentive to wait until others have tried innovations. This is a public goods problem that results in underinvestment in the public good, because no one wants to pay the costs but everyone wants to reap the benefits. Larger farms are in a much better position to internalize this process.

The need for collateral to fund investment and the limitations of smallholders in gaining access to credit are well known. But for Collier and Dercon (2009), the problem of access to capital is not only a problem of collateral but also one of institutionalization and reputation, making large farms more likely to regularly gain access to finance even in the face of shocks. Finally, Collier and Dercon believe that problems of thin and underdeveloped markets in poor countries are usually assigned to high transaction costs, poor infrastructure, and capital constraints for investment by traders. Although they recognize these problems, they argue that the main problem is the presence of scale economies in retailing (for example, the emergence of supermarkets), which make inadequate the traditional promotion of the smallholder model of commercialization involving large numbers of small traders. These increased scale economies in retailing call for a more realistic approach to the problem, and these authors argue that the incentives from long-term contracts and the need for standardization and certification can lead to large dynamic efficiency gains, as seen in the cases of India and other transitional economies where vertical coordination and integration are accelerating and can result in high returns.

Finally, it is worth mentioning a new phenomenon, a product of the 2008 food crisis that represents a new dimension of demand that affects African agriculture and is discussed by Collier and Dercon (2009). During that crisis, export bans imposed by governments of food-exporting countries exacerbated the rise in world prices, motivating some food-importing countries to try to "lock up" some major source of supply. China led the way with a multibillion-dollar plan to develop agricultural assets in Africa, and it was followed by Qatar, Abu Dhabi, Saudi Arabia, Daewoo Logistics of South Korea, and Heilberg, which acquired 400,000 hectares in Southern Sudan in a deal with the warlord and deputy commander of the Southern army (Collier and Dercon 2009). Collier and Dercon argue that this option is not the way to promote commercial agriculture in Africa. The reasons include the long-term (99-year) leases used for these deals, which they consider inappropriate because there is no credible basis for such long-term commitments. Also, these deals create a huge entity that would inevitably be a monopsonist in local factor markets, the resulting organizations would be too large to be normal commercial entities, and, most important, the processes by which leases have been secured are not competitive.

These latest views on the problem of intensification in African agriculture point to the need for a more complex model to understand the factors behind

Africa's low productivity and growth. We finalize this chapter by pointing to some of the implications of these views.

One of the main problems is the neglect of labor scarcity in Africa as a key constraint on technical change. First, research on agricultural innovation has favored increases in land productivity, assuming that additional "smallholder" household farm labor has an opportunity cost of zero. Because Green Revolution technology increases the labor requirements for fertilizer and irrigation management and for harvest, the cost of the additional demand for labor may be a factor limiting the adoption of more productive technology (Woodhouse 2008).

Second, in contemporary Africa, capitalization of agriculture is low, and labor shortages remain a widespread constraint on agriculture. In this situation, labor migration is key for agricultural development and generation of the opportunities for migration and employment. This migration could be facilitated, for example, by the provision of public goods such as water resources that would lead to improved agricultural opportunities, invariably characterized by immigration from less productive rural areas and increasing competition for land, typically involving the development of informal land markets. It could also be encouraged by the development of nonagricultural activities and increased demand for agricultural products. These ideas suggest that the "smallholder productivity revolution" in African agriculture cannot progress without growth of productivity and employment in the nonagriculture economy and public-sector investment in agricultural productivity improvement (Woodhouse 2008).

Finally, the results of our review of available technologies and yield gaps appear to show that despite relatively small investment in R&D in West Africa, some results have been obtained, in particular in the development of new crop varieties, with a relatively high level of adoption in some cases, as seen in previous sections. If this is the case, as Woodhouse (2008, 273) asserted, "We find ourselves in the realm of 'infrastructure, markets and supporting institutions,' rather than in that of 'ecological complexity.'" According to these arguments and some of the evidence available, the path to intensification, then, should be one creating conditions for capitalization of agriculture, which includes migration and increasing employment opportunities, development of labor and land markets, and public investment in labor-saving technologies and public goods, facilitating adoption of new technology.

CHAPTER 5

Growth Potential for West and Central Africa

Information presented in the previous chapter shows that there is a potential for West African agriculture to attain higher yields simply from adopting (or adapting) some of the existing technologies for different crops. Assuming that the estimates are close approximations to the realities on the ground, average yields at present are consistently below the maximum potential for most of the major crops and for the majority of countries in West Africa, signaling an important opportunity for the region to realize greater productivity growth in the future.

In this chapter we delve deeper, examining and comparing the potential effects of narrowing these yield gaps on overall economic growth and farm income within the framework of an ex ante economic model simulation. The model provides a way to quantify certain economic criteria useful for ranking future alternative priorities for agricultural investments, including the contribution to overall growth and poverty alleviation and economic benefits by crop. Finally, by employing the economic analysis at the regional and multi-country levels, we highlight both regional and country-specific priorities.

The analysis proceeds as follows. First, we define the growth scenarios to be simulated using the EMM model. Second, we use the EMM model for West Africa to quantify the economic implications of these alternative growth scenarios for African agriculture beyond a "business-as-usual" scenario. We also use the analysis of these scenarios to prioritize both agricultural and nonagricultural subsectors by evaluating the potential contributions of these subsectors to future AgGDP and GDP growth rates.

Alternative Growth Scenarios

To further build on the understanding of strategic opportunities for agricultural development in West Africa, this section considers alternative scenarios of agricultural growth to be implemented using the EMM model, focusing on the subsequent implications of the changes simulated in these scenarios for overall economic growth.

Business as Usual

The "business-as-usual" scenario uses recent growth trends in crop and livestock production to project agricultural growth into the future. This scenario serves as a marker against which we evaluate alternative agricultural growth scenarios defined later.

One of the most prominent indicators of the challenge currently facing West African agriculture is the low growth within key agricultural subsectors. Consider the growth rates for three agricultural commodity groups: staples, cash crops, and livestock products. These commodity groups combined account for at least three quarters of the AgGDP of the majority of countries in West Africa. Table 5.1 reports the growth rates of key agricultural subsectors over the past five to eight years for countries in the three subregions (the Coastal, Central, and Sahel regions) of Africa. Given the current constraints on West African agriculture, what becomes clear from the growth rates in Table 5.1 is that a business-as-usual path will not lead to significant growth or reductions in poverty.

Yield Gap and Potential Productivity Growth

For the purpose of our study, we adopt two alternative scenarios for closing the calculated yield gaps within each development domain. The first focuses on simply reducing yield losses due to biotic stress as a shorter-run and less ambitious policy alternative for accelerating agricultural productivity in the region. The second alternative introduces a longer–run, more ambitious strategy, one that requires significant investments to achieve maximum attainable yields. This goes beyond simply eliminating stress-induced yield losses, also considering the efficient use of existing technology inputs (for example, improved high-yield varieties, application of fertilizers and chemicals, and mechanization) within each development domain.

We complement these two scenarios with a third and final scenario, the most optimistic and ambitious of the three, in which we assume the same high-yield growth rates of the second scenario together with improvements in market access. This scenario is intended to help absorb a rapid increase in output by integrating markets more fully within and across countries in the region.

Growth Scenario 1: Recovering Yield Loss Due to Biotic Constraints

This scenario estimates the yield loss due to biotic constraints by crop and development domain. Assuming that the yield targets will eventually be reached within the next 10 years, we calculate the annual growth rates of crop yields for each domain within each country by comparing the yield target with the projected yield in 2015 in the business-as-usual scenario. A summary

Table 5.1 Production growth rate (percentage) employed in the base run, based on trends of 1998 -2004

Region/country	Cereals	Roots	Pulses and oilseeds	Vegetables and fruits	Cocoa	Cotton	Other high-value crops	Livestock	Processed foods
Coastal									
Guinea	2.27	2.88	3.93	2.61	3.38	3.03	2.36	3.78	4.17
Sierra Leone	1.85	3.33	3.42	4.98	2.56	0.00	3.68	2.31	3.65
Côte d'Ivoire	1.81	2.67	4.08	4.81	2.43	3.84	2.76	2.23	5.08
Ghana	3.09	3.74	4.87	3.68	3.26	2.64	3.14	4.26	5.52
Togo	3.21	3.12	4.49	3.41	5.73	2.65	4.03	2.26	3.72
Benin	4.03	4.29	3.92	6.41	2.08	3.17	2.22	2.83	5.93
Nigeria	3.09	4.01	3.03	2.95	2.17	5.04	7.10	2.95	4.69
Sahel									
Burkina Faso	3.07	3.26	3.17	3.38	—	4.24	2.92	3.99	4.72
Chad	3.42	3.21	3.17	2.85	—	2.28	2.68	2.19	3.58
Gambia	3.16	2.92	2.55	4.32	—	3.35	2.84	4.17	4.78
Guinea-Bissau	2.41	3.10	2.54	3.31	—	3.75	3.13	3.21	3.91
Mali	3.57	3.45	3.41	3.69	—	4.56	2.95	4.31	4.68
Mauritania	2.59	2.26	4.07	3.61	—	0.00	2.88	2.70	6.28
Niger	3.18	2.00	3.75	2.74	—	2.00	0.00	3.01	4.97
Senegal	3.07	3.10	2.41	5.93	—	3.97	0.00	1.96	2.67
Central									
Cameroon	2.92	3.05	3.06	3.48	3.62	2.62	3.60	3.52	3.92
Central African Republic	3.08	2.08	4.02	2.48	2.59	3.12	2.91	2.40	4.11
Gabon	2.47	2.96	2.44	2.70	3.47	0.00	2.43	2.48	3.64
Congo, Republic of	2.18	2.68	2.75	2.77	2.28	0.00	2.65	2.01	2.50
Congo, Democratic Republic of	2.27	2.54	2.74	3.08	2.68	2.53	3.80	2.20	2.54

Source: Authors' estimation from FAO (various years).
Note: — means crop is not produced in this country.

Table 5.2 Targeted annual rate of growth (percentage) in crop yield in a yield loss -recovering scenario, 2006-15

Region/country	Cereals	Roots	Pulses and oilseeds	Vegetables and fruits	Cocoa	Cotton	Other high-value crops	Livestock	Processed foods
Coastal									
Guinea	3.65	3.44	5.03	3.18	3.75	4.08	2.83	4.93	5.28
Sierra Leone	3.16	3.92	4.30	5.72	3.49	0.00	4.61	3.57	4.66
Côte d'Ivoire	3.10	3.19	5.33	6.57	2.45	5.21	0.00	3.42	6.06
Ghana	3.85	4.29	5.90	4.46	3.48	3.88	3.82	5.54	6.51
Togo	4.00	3.59	5.65	4.45	6.49	3.14	3.89	3.46	4.84
Benin	4.85	5.01	4.96	7.45	2.13	4.38	0.00	3.98	6.96
Nigeria	4.07	4.71	4.19	3.45	2.52	6.04	4.27	4.13	5.72
Sahel									
Burkina Faso	3.82	3.84	4.19	4.34	—	5.35	4.82	4.96	5.72
Chad	3.83	3.67	4.17	3.87	—	3.50	4.85	3.58	4.93
Gambia	4.12	3.47	4.07	6.04	—	4.48	0.00	5.47	6.10
Guinea-Bissau	3.63	3.51	3.58	3.93	—	4.87	3.46	4.30	5.04
Mali	4.85	3.76	4.33	4.35	—	5.44	5.05	5.74	6.12
Mauritania	4.24	2.45	4.44	4.03	—	0.00	0.00	3.38	6.91
Niger	3.65	2.52	4.55	3.14	—	2.78	4.84	4.55	6.13
Senegal	4.06	3.54	3.86	6.69	—	5.09	4.63	2.97	3.57
Central									
Cameroon	3.68	3.89	4.27	4.59	3.86	3.77	4.19	4.94	5.21
Central African Republic	3.91	2.53	5.09	3.08	2.67	4.31	3.30	3.87	5.48
Gabon	3.75	3.64	4.11	3.30	3.51	0.00	3.13	3.95	4.93
Congo, Republic of	3.73	3.32	3.89	3.30	2.72	0.00	3.22	3.63	4.09
Congo, Democratic Republic of	3.63	3.19	3.86	3.80	3.43	3.81	4.29	3.56	3.91

Source: Authors' estimation from FAO (various years).
Note: — means crop is not produced in this country.

of average national growth rates for different groups of crops is reported in Table 5.2. These represent the weighted average of national average growth rates of the individual crops included in each group and development domain and are incremental yield growth rates with respect to the base-run rates.

Growth Scenario 2: Catch Up to Maximum Yield Potential

Targeted annual growth rates for this scenario are presented in Table 5.3. These growth rates are defined by the yield gaps calculated from the SPAM analysis described in Chapter 3. As in the first growth scenario, it is assumed that the target yield in Scenario 2 will eventually be reached in the next 10 years, which allows us to define the annual growth rate of each crop's yield at the domain level within each country.

In the case of livestock, adequate data for growth projections are not available. To capture the growth contribution of the livestock sector, an important source of growth in many West African countries, we estimate growth in the livestock sector based on a comparative assessment of its performance in different countries as well as growth in crops, assuming that growth in livestock activities will follow productivity increases in cereals. Growth in agriculture must be supported by income increases in both agricultural and nonagricultural sectors. Thus, additional growth in nonagriculture is also estimated in the growth scenarios.

Growth Scenario 3: Catch-Up to Maximum Yield Potential with Improved Market Access

Despite the significant gains that can be achieved from reducing biotic constraints and catching up to the maximum yield potential, West African agriculture still faces considerable barriers based on market and trade access. The first two alternative growth options were based on the assumption that current trade policies and market conditions will not significantly change. But without improvements in market conditions and reductions in intra-regional trade barriers, the increased supply of agricultural products may depress prices and reduce farm incomes. Thus we use the multimarket model to further simulate a situation in which trade barriers from inefficient trade policies and inadequate infrastructure are reduced. Productivity growth assumptions for the agricultural sector are the same as those employed in the second growth scenario; that is, growth in agriculture is realized mainly through catching up to the yield potential. Reduced price gaps due to improved market and trade conditions are modeled by exogenously lowering trade margins between domestic producer prices and border prices. Reductions in trade margins also indicate the potential for productivity improvements in the trade sector. To capture this, we exogenously increase the service

Table 5.3 Targeted annual rate of growth (percentage) in crop yield in catch-up to the potential yield scenario, 2006–15 average

Region/country	Cereals	Roots	Pulses and oilseeds	Vegetables and fruits	Cocoa	Cotton	Other high-value crops	Livestock	Processed foods
Coastal									
Guinea	6.21	4.24	6.21	4.22	5.40	5.69	5.15	5.10	5.78
Sierra Leone	7.47	6.24	6.81	8.73	7.12	0.00	9.39	4.26	6.01
Côte d'Ivoire	5.73	4.39	7.27	10.00	4.08	6.75	0.00	3.73	6.58
Ghana	5.28	5.43	6.91	6.58	5.47	8.10	6.29	6.46	7.53
Togo	4.98	4.16	7.44	7.01	9.75	5.54	7.53	3.75	5.18
Benin	5.70	5.83	6.07	9.87	2.40	6.04	0.00	4.87	7.41
Nigeria	6.29	5.58	6.28	4.79	4.46	6.89	5.38	4.77	6.64
Sahel									
Burkina Faso	5.03	5.44	5.04	6.49	—	6.54	8.87	5.38	6.06
Chad	4.07	3.83	4.48	5.86	—	3.76	9.33	3.70	5.11
Gambia	5.25	4.47	6.19	9.85	—	7.87	0.00	5.57	6.40
Guinea-Bissau	5.75	3.56	3.59	4.04	—	4.87	3.44	4.26	5.05
Mali	6.76	4.34	5.09	5.95	—	6.65	9.62	5.80	6.46
Mauritania	7.34	2.84	4.97	5.07	—	0.00	0.00	3.42	7.04
Niger	4.23	3.93	5.47	4.69	—	4.21	9.26	5.01	6.65
Senegal	6.40	5.26	7.50	9.19	—	10.96	8.67	3.82	3.81
Central									
Cameroon	3.68	3.89	4.27	4.59	3.86	3.77	4.19	4.94	5.21
Central African Republic	3.91	2.53	5.09	3.08	2.67	4.31	3.30	3.87	5.48
Gabon	3.75	3.64	4.11	3.30	3.51	0.00	3.13	3.95	4.93
Congo, Republic of	3.73	3.32	3.89	3.30	2.72	0.00	3.22	3.63	4.09
Congo, Democratic Republic of	3.63	3.19	3.86	3.80	3.43	3.81	4.29	3.56	3.91

Source: Authors' calculations.
Note: — means crop is not produced in this country.

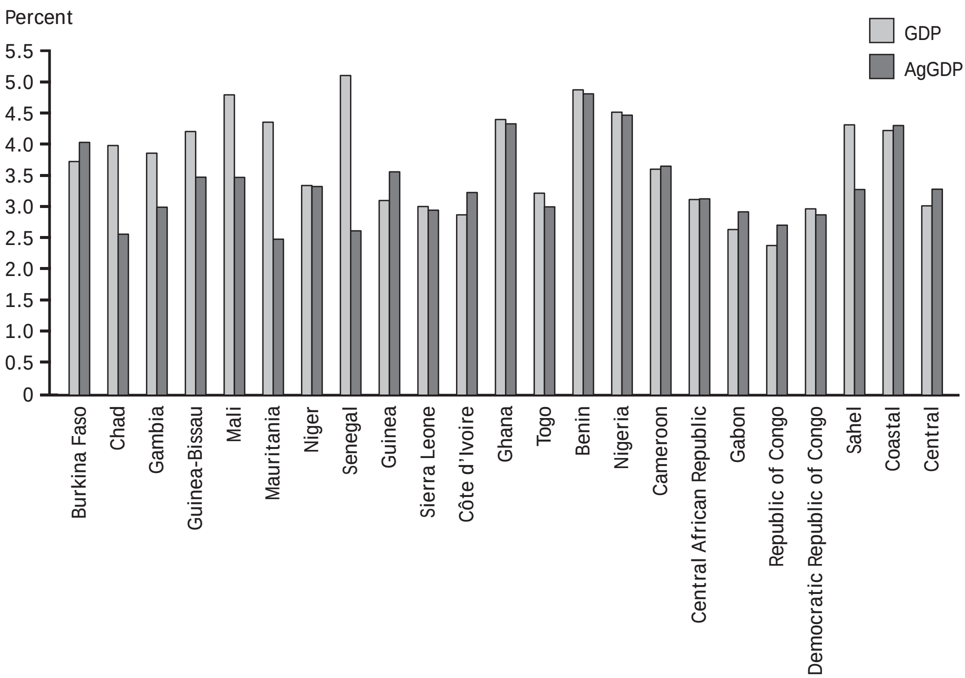
sector's productivity to match reductions in trade margins. Results of the different scenarios follow.

Results and Projections

Considering past growth rates along with recent growth rates in agricultural processing sectors and two nonagricultural subsectors, we use the multimarket model to project economic growth forward to 2015. The projected annual growth rates for AgGDP and overall GDP are reported in Figure 5.1.

The results suggest that without changes in the historical growth rates, AgGDP growth rates would fall below the 6 percent required by CAADP and overall economic growth would stay at a similarly low level. With most West African countries experiencing population growth rates of 2–3 percent, this means that per capita AgGDP would fall below 1 percent (or even decline) in 13 of the 20 West African countries. Ghana and Nigeria have the highest per

Figure 5.1 Projected rates of AgGDP and overall economic growth in the base run, 2006–15 average



Source: Economywide multimarket model simulation results.
Note: AgGDP means agricultural gross domestic product; GDP means gross domestic product.

capita AgGDP growth rates, at close to 2.0 percent per year, and only three other countries could potentially reach a growth rate of 1.5 percent.

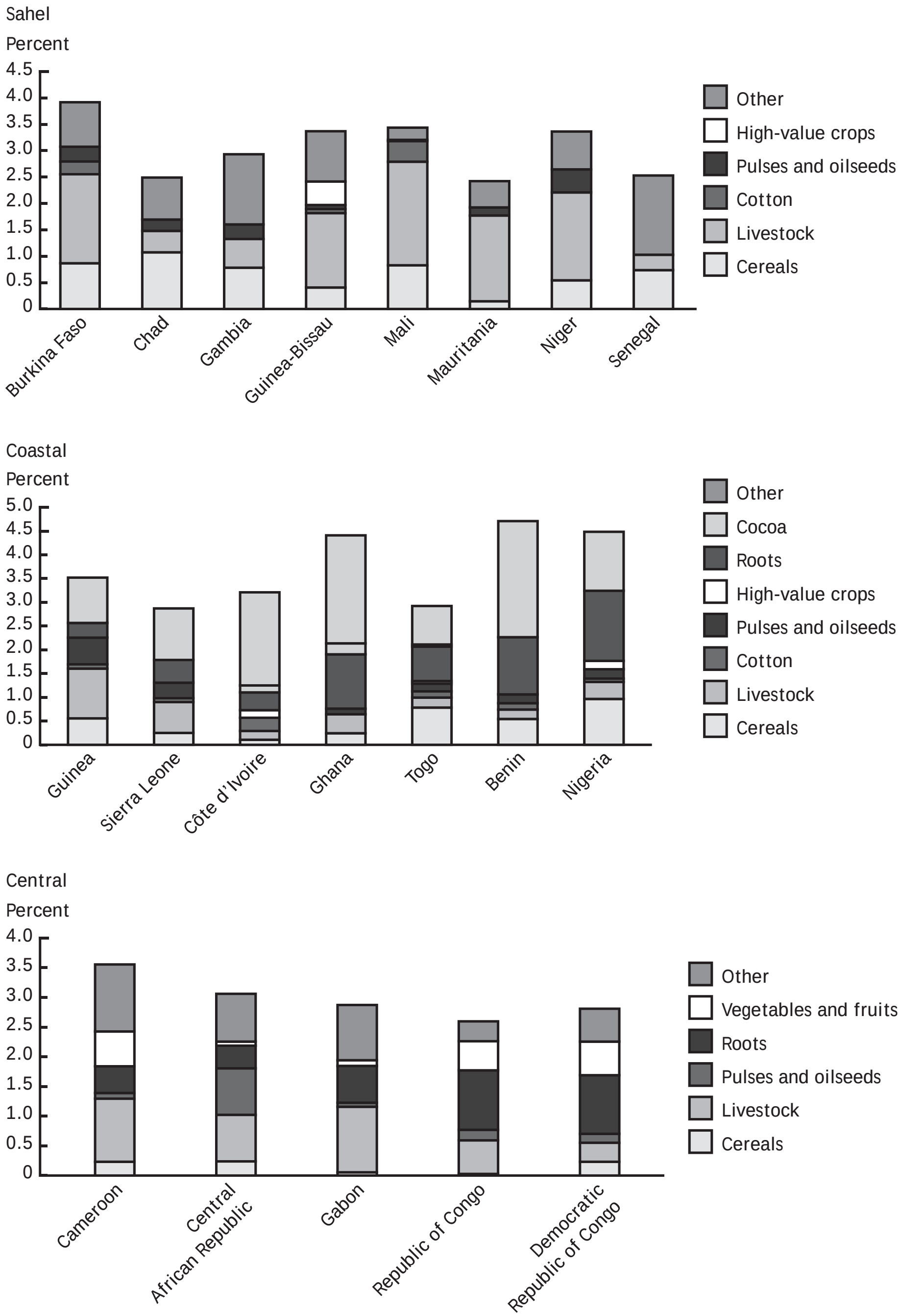
What do simulation results tell us about the projected contributions of the different subsectors to total AgGDP in a business-as-usual scenario? Two main results are worth mentioning (Figure 5.2). First, cereals' contribution to growth is projected to be low in all countries, which, given the shares of cereals in GDP, means that growth rates are projected to be very low. Only in Nigeria would cereals eventually contribute 1 percentage point to AgGDP growth, and they would make a contribution close to this value in Burkina Faso and Chad. If West Africa continues along its current growth path, there will be a widening gap between the supply of and demand for cereals. Projections show that the shortfall in supply would increase to 22 million metric tons by 2015—some 80 percent greater than in 2003. This figure represents 27 percent of the total regional demand. The widening gap between supply and demand would make it impossible for most countries to meet the MDG goals of increased nutrition and food security.

Second, the potential of traditional export crops to drive AgGDP growth in the region, if they continue to grow at historical growth rates, is low because of the low shares of export commodities in total agricultural income. While cotton and cocoa are the most important export crops and sources of foreign exchange earnings in the region, their contribution to total AgGDP growth is small when domestic markets and farmers' own consumption are taken into account. This holds true even when considering cotton's contribution to AgGDP in Benin and Mali and cocoa's contribution in Côte d'Ivoire and Ghana.

Growth Impact of Closing the Yield Gap in Agriculture Productivity

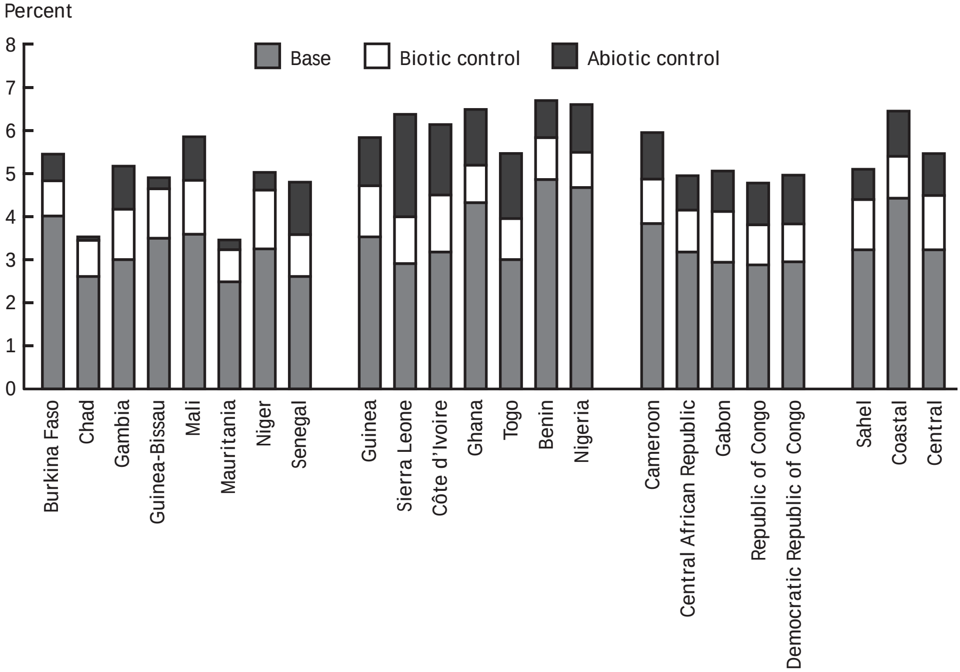
Based on the aforementioned description of the three growth simulations and using the multimarket model to project these growth rates forward to 2015, the annual growth rates for AgGDP and overall GDP in the first two growth scenarios are reported in Figure 5.3, which also illustrates the clear differences these three scenarios show in terms of agricultural growth. Growth from recovering current yield losses (by overcoming biotic constraints) could contribute to an additional 1 percent annual AgGDP growth in the next 10 years for many West African countries. Even with this additional growth, rates in most West African countries will still be far below the 6 percent target set by CAADP. However, by catching up to the agroclimatically attainable yield potential through intensification and the use of best practices, 8 of the 20 West African countries included in the study (Benin, Côte d'Ivoire, Ghana, Guinea, Nigeria, Sierra Leone, Cameroon, and Mali) can come close to reaching the 6 percent target. Among these 8 countries, 6 are located within the Coastal region, while Cameroon is in the Central region and Mali is in the

Figure 5.2 Subsectors' contribution to the AgGDP growth rate in the base run, 2006–15 average



Source: Economywide multimarket model simulation results.
Note: AgGDP means agricultural gross domestic product.

Figure 5.3 Projected average annual growth rate of AgGDP in different scenarios, 2006–15



Source: Economywide multimarket model simulation results.
Note: AgGDP means agricultural gross domestic product.

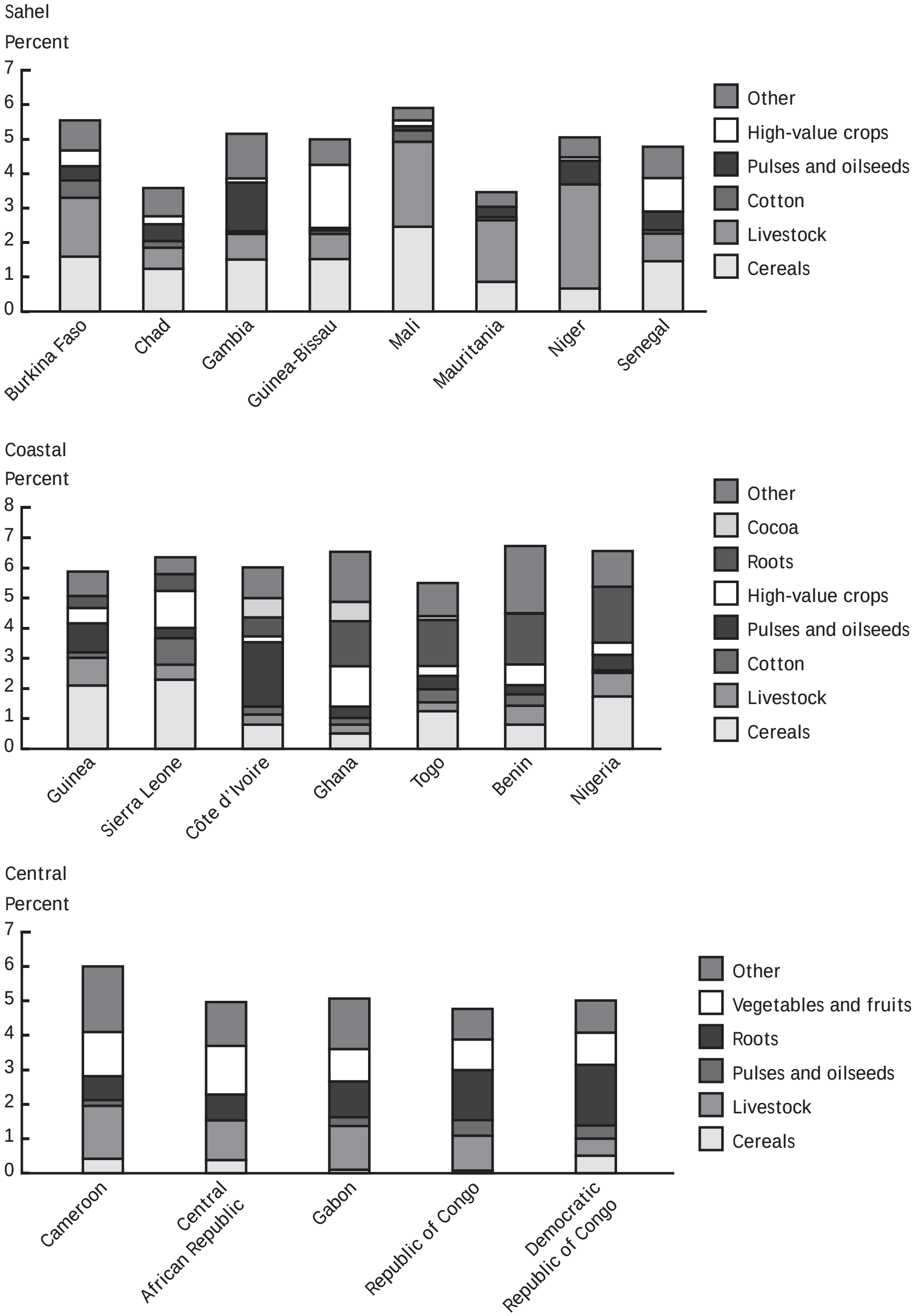
Sahel. There are also 10 countries in which annual AgGDP will grow at close to 5 percent or more, and only 2 Sahelian countries, Chad and Mauritania, for which projected annual growth in AgGDP will be under 4 percent.

The contributions of different subsectors to total agricultural growth that can result from attaining their yield potential using intensification and best practices (Scenario 2) will vary across countries due to social and economic conditions, agroecological potential, and different agricultural production structures (Figure 5.4).

A first conclusion from the results shown in Figure 5.4 is that staple crops such as cereals and root crops could contribute a large share of AgGDP growth in the region. However, the importance of other subsectors varies depending on whether countries are in the Sahel or on the coast.

In most countries in the Sahel region, livestock and cereals are the subsectors explaining most of the projected AgGDP growth. Export crops such as cotton explain about 10 percent of growth. Demand for livestock and cere-

Figure 5.4 Projected shares of subsectors' contribution to AgGDP growth from attaining yield potential using intensification and best practices, 2006–15



Source: Economywide multimarket model simulation results.
Note: AgGDP means agricultural gross domestic product.

als tends to grow as incomes rise and at proportionately greater rates. Such growth in demand allows for sustained productivity growth without significantly negative price effects and thus results in higher overall real income levels. In most Sahelian countries, livestock could contribute more than 28 percent of total growth. In only three countries (Chad, Gambia, and Senegal) is the contribution of livestock projected to be below these values. The cereal subsector's contributions to total agricultural growth are projected to be in the range of 24–41 percent for seven of the eight Sahelian countries, excepting Niger, in which cereal growth should contribute 13 percent of total agricultural growth.

In the Coastal countries, the subsectors that could contribute significantly to total growth are much more varied than those in most of the Sahelian countries discussed. The most important subsectors in terms of their contribution to growth are root crops, traditional export crops such as cocoa, and nontraditional export crops, and other high-value crops also seem to be important.

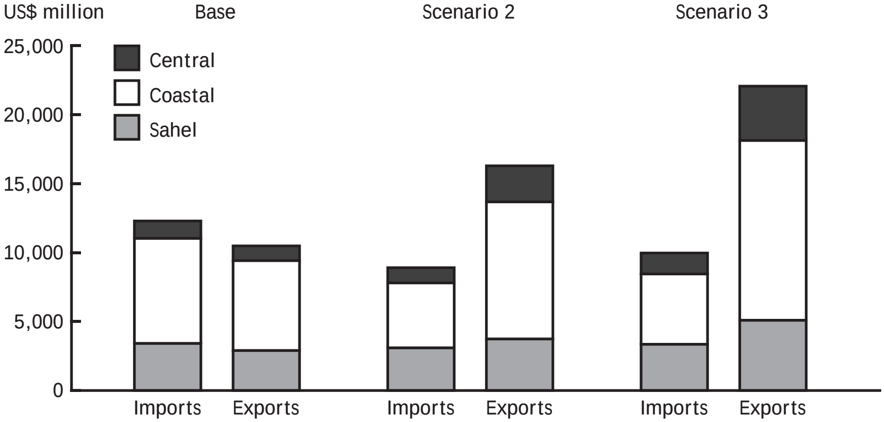
For example, root crops are projected to contribute about 23–30 percent of agricultural growth in Ghana, Benin, Togo, and Nigeria and 9–10 percent of growth in Sierra Leone and Côte d'Ivoire. Cocoa could contribute around 10 percent of total agricultural growth in its major exporting countries (Côte d'Ivoire and Ghana). Nontraditional exports and other high-value crops could contribute more than 17 percent of AgGDP growth in Ghana and more than 35 percent in Côte d'Ivoire.

Countries in the Central subregion, with the exception of Cameroon, have relatively low agricultural potential (at the national aggregated level). In this environment, livestock and root crops seem to be the most important sources of growth in the region. Livestock could contribute 19–23 percent of agricultural growth in four of the five Central region countries, excepting DRC, while root crops could contribute 10–35 percent of total agricultural growth in the five Central region countries.

Agricultural Growth and the Impact on Trade

Figure 5.5 summarizes potential agricultural export and import outcomes by 2015 as projected by the model. Compared to the business-as-usual scenario, catching up to yield potential in agriculture (Scenario 2) could result in US$6 billion more in agricultural exports for the region as a whole as total regional agricultural exports rise to US$16.4 billion. This is significantly more than the US$10.6 billion projected to be gained in the business-as-usual scenario by 2015. With respect to imports, the model projects that by 2015 agricultural imports will fall from US$12.4 billion in the base run to US$9.0 billion in Scenario 2.

Figure 5.5 Projected total agricultural exports and imports by 2015

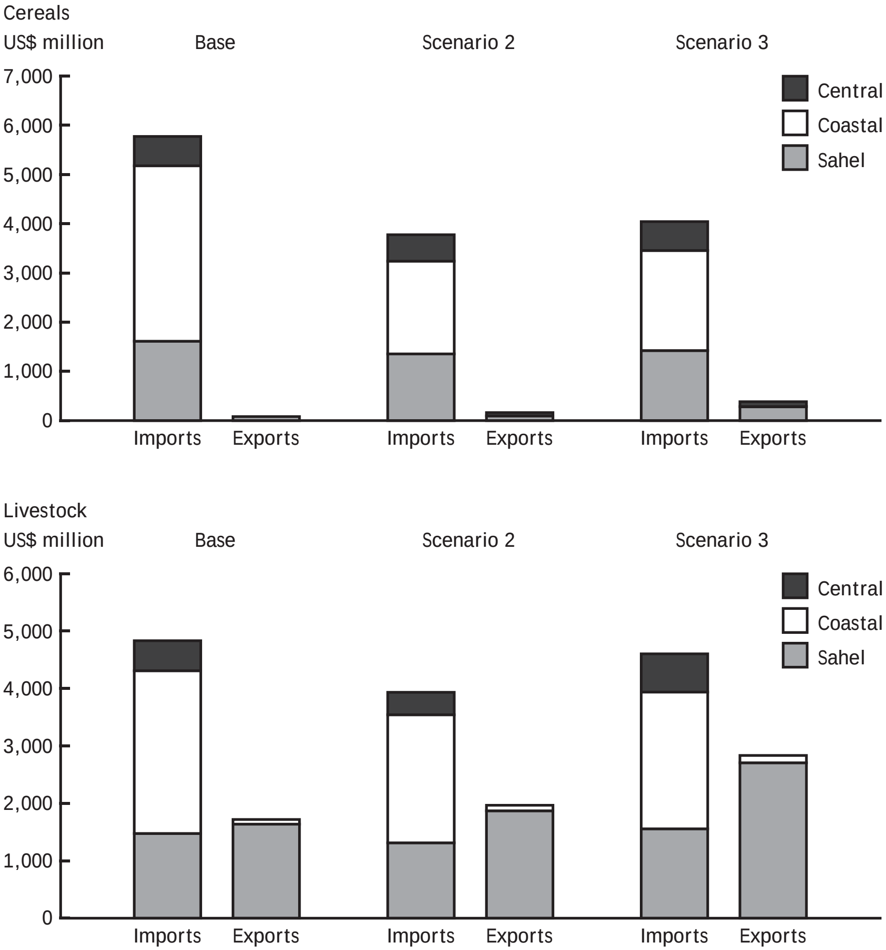


Source: Economywide multimarket model simulation results.

If growth in agricultural productivity were further supported by improved market conditions and trade policies (Scenario 3), West Africa's total agricultural exports would rise to US$22.1 billion, while its total agricultural imports would increase only modestly, to US$10.1 billion, by 2015. These results show that improved market conditions along with increased agricultural productivity can increase West African countries' competitiveness, although, constrained by the lack of intraregional bilateral trade data among West African countries, our analysis cannot distinguish between intraregional and interregional trade. However, increasing trade and improvements in the region's international competitiveness would likely result in the substitution of global imports by intraregional imports. We focus on trade in cereals and livestock, the two subsectors with the highest intraregional trade potential, to illustrate this argument (Figure 5.6).

If growth follows a business-as-usual path, cereal imports are projected to reach US$5.7 billion by 2015, and the three subregions in West Africa will continue to be cereal-deficient regions with low numbers of cereal exports (Figure 5.6, top panel). With enhanced productivity growth in agriculture, cereal imports are projected to decrease in West Africa, even though demand will significantly increase with income growth. About US$280 million in cereal exports could be generated through improving market and trade conditions in the region, but cereal imports would also increase compared to the import levels in a growth scenario without market improvements. Thus, it is reasonable to believe that cereal exports could easily find markets in the region given that Nigeria will import US$2 billion in cereals in the same scenario.

Figure 5.6 Projected cereal and livestock exports and imports by 2015



Source: Economywide multimarket model simulation results.

In the case of livestock, although exports are significant in the base run (US$1.7 billion), imports (US$4.8 billion) are projected to total more than exports by 2015. Among the three subregions, the Sahelian region is a net exporter, while the other two regions are net importers. With enhanced productivity, livestock imports will decline, but exports will increase only modestly, indicating market constraints in the livestock-exporting countries (Figure 5.6, bottom panel). However, if productivity growth is supported by improvements in market and trade conditions, livestock exports will increase to US$2.8 billion, of which US$1.8 billion will be exported from Sahelian countries. Although livestock imports will fall slightly, to US$4.6 billion, imports will still be greater than exports for the region due to more than US$1.4 billion in imports by Nigeria.

Figures 5.7 and 5.8 summarize the export and import structure of the three subregions as well as West Africa as a whole. It appears that West Africa's export structure will become more diversified with growth in agricultural productivity and improvements in market and trade conditions. In the base run, traditional exports including cocoa and cotton account for 47.8 percent of West Africa's total agricultural exports, a structure similar to that found in current trade. Agricultural productivity growth, together with improvements in market and trade conditions, will increase the export opportunities of other commodities. Thus, as observed in Figure 5.7, exports of cocoa and cotton in total agricultural exports will fall to 29 percent, while exports of high-value products (fruits, vegetables, and processed food) will increase from 36 to 43 percent of total exports. Also, crops such as cereals, roots and tubers, and oilseeds will increase their share in exports from 0.1 and 0.7 percent to 6.6 and 8.9 percent, respectively. On the import side (Figure 5.8), improved productivity and reduced transaction costs will result in a reduction of the importance of cereals and in an increased share of livestock products in total imports.

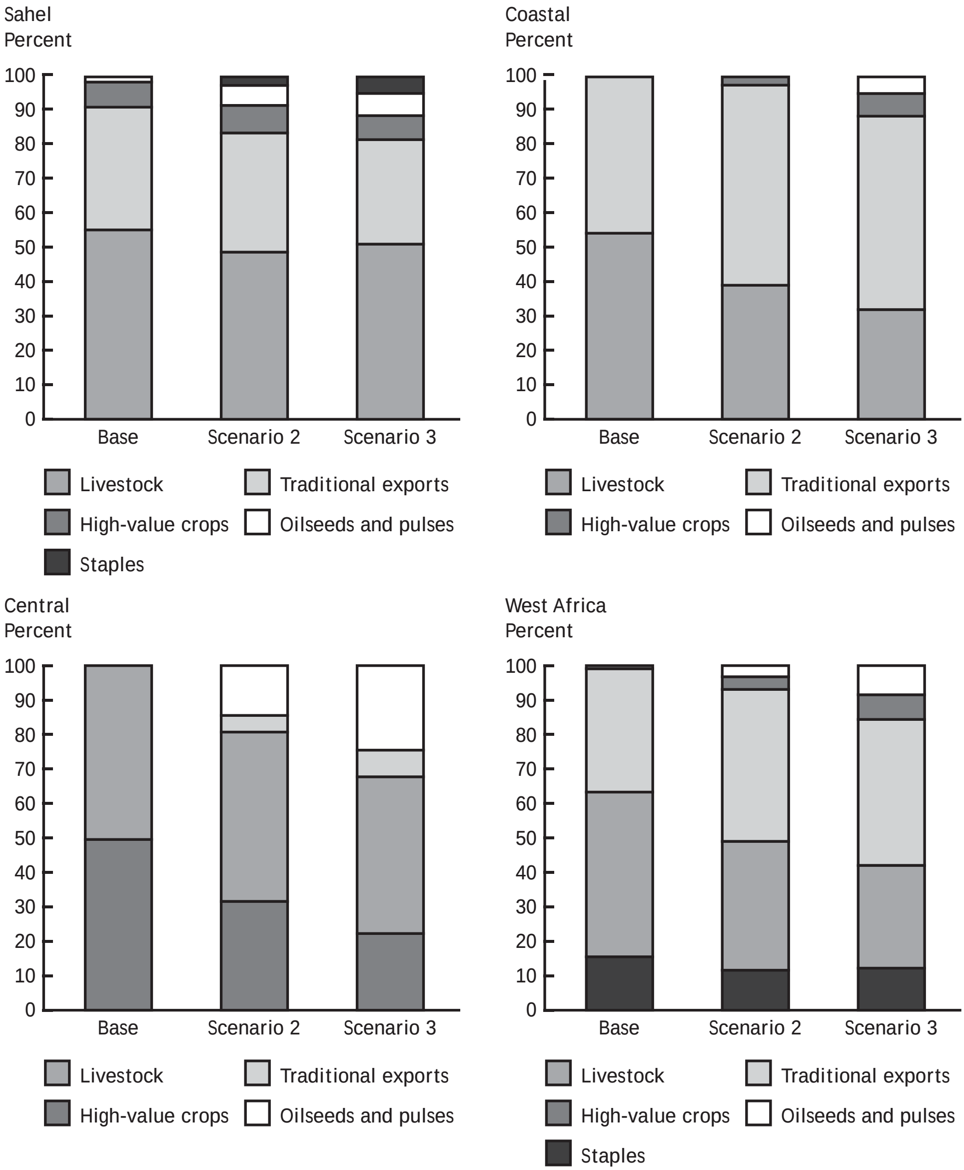
Changes in the structure of exports in subregions show a similar pattern. However, changes in Coastal and Central regions are more pronounced than in the Sahel, reflecting the higher agricultural potential of these regions. With increased productivity, high value products will displace traditional exports and become the major agricultural export item in the Coastal region. The Central region can become an exporter of staple crops with a substantial reduction in the share of traditional export crops.

Discussion

In this section we summarize some of the results of our study and discuss their implications for the region. The first of these results is the evidence from the estimated yield gaps of the high potential for agricultural growth in West Africa. Despite the limitations of our approach, the existence of these gaps appears to be supported by an extensive literature pointing out success stories in the production of new varieties, mostly in staple crops, as well as a significant rate of adoption of these improved varieties. This evidence appears to show at least two things: first, that there is a high potential for agriculture in West Africa, and second, that there is accumulated knowledge in the region that has not been fully adopted by producers.

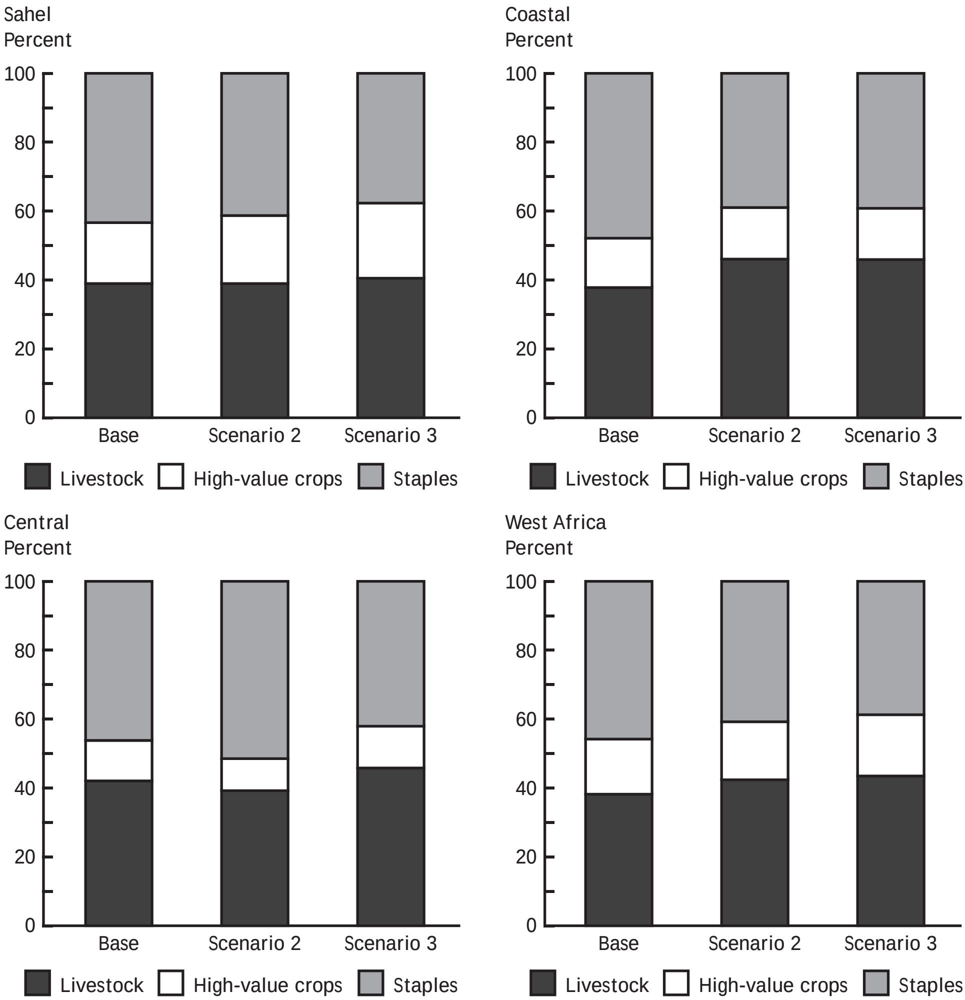
A first implication of this result is that hypotheses that point to the diverse and extreme agroecological conditions in West Africa as one of the

Figure 5.7 West Africa's agricultural export share in different scenarios, 2015



Source: Economywide multimarket model simulation results.

Figure 5.8 West Africa's agricultural import share in different scenarios, 2015



Source: Economywide multimarket model simulation results.

main factors explaining the lack of agricultural development do not appear to hold. Agricultural potential seems to be high even in the Sahel if the region uses underused resources for irrigation. Some of the literature reviewed for this study also points to a similar conclusion. If this is the case, we are in "the realm of 'infrastructure, markets and supporting institutions,' rather than in that of 'ecological complexity,'" as Woodhouse (2008, 273) asserted. This is important because assumptions made in the past about the low potential for agriculture resulted in reduced investment in R&D and extension, with negative consequences for the sector and for growth possibilities in several countries (Djurfeldt et al. 2005, 4).

In the realm of markets, infrastructure and institutions, the focus needs to turn on labor constraints, the capitalization of agriculture and the development of labor and land markets as a necessary condition for intensification if we take at face value some of the recent approaches analyzing this problem in Africa. This implies an economywide approach looking at urbanization, demand growth, and migration as creating opportunities for investment in agriculture.

Another implication of this study results from the importance of growth in staple crops and livestock to accelerate growth in the region. In particular, the literature reviewed shows that the development of livestock production in the Sahel is linked to the possibilities for migration and the expansion of mixed systems. This possibility, according to Shapiro and Ehui (2004), depends on the availability of technology to increase soil fertility for the production of sorghum and millet. Targeting the development of these technologies appears to be a priority for agriculture in the Sahel, together with further developments in rice production. On the other hand, Coastal countries have more options and possibilities, from improvements in cassava, maize, and rice production to diversification into high-value and export crops.

Our results also provide some insights regarding the importance of regional integration. Growth possibilities in the production of staple crops and livestock result from a more open region that facilitates trade and movement of goods across countries. A point of contention is the relevance for the region of the implications of the Green Revolution model as emphasized by Djurfeldt et al. (2005). These authors believe that governments have to play a key role in developing commodity chains and also in reducing the competition of local farmers with imported grain to facilitate the process of intensification. In this case, developing commodity chains and limiting imports of staples should apply at the regional rather than the country level.

Finally, and also in the area of regional integration, implicit in our approach is the need to think further about the possibilities of regional collaboration in agricultural R&D and the potential of regional spillovers. The study by Pardey et al. (2007, 65) points to the startling variability in terms of agroecological resources between regions in Africa, in particular between countries in the same region, stating that "the technological distance among countries within the continent suggests that geographic proximity may not necessarily translate into spillover potential, and so regional cooperative agreements may not be the most efficient way to capitalize on spillovers." The detailed spatial information on regional agroecologies presented in this study confirms the high variability in terms of these conditions that can be found within and between countries. However, the approach to the analysis of agricultural potential used in this study looks at the region not by country but by agro-ecological zone, with the idea that regional research should be organized targeting the development of technologies for similar conditions across countries. The potential for spillovers is not between countries but within similar agroecologies across countries, which is precisely what is behind the idea of a regional approach in this report.

CHAPTER 6

Conclusions and Policy Implications

The primary purpose of this report is to identify a set of alternative development priorities that tap into the potential for agricultural productivity growth in crop and livestock production and cut across West and Central Africa in order to achieve economywide growth goals in the region. To identify these priorities, we adopt a modeling and analytical framework that involves the integration of various economic and statistical tools, which results in a number of unique advantages. First, our approach is spatial and differentiates areas that are similar with respect to agroecological and market conditions within West Africa. This allows us to identify yield gaps that determine the growth potential of different agricultural products for areas with similar conditions. Second, our approach maintains an economywide perspective through the use of a multimarket model complemented by a single-commodity, multiple-region, partial equilibrium model. These models incorporate information on yield gaps defined in the spatial analysis together with information on agricultural and nonagricultural production, consumption, prices, and trade to simulate ex ante the economic effects of closing these yield gaps.

On the other hand, our results should be considered with caution given the limitations of our approach and data constraints. First, the yield gap is fundamentally limited as a substitute for efficiency measures of potential to increase output. The potential gap depends on the efficiency with which households combine all of their outputs and inputs, and yields capture this only in the case of inefficient households whose inefficiency is measured in terms of their combination of inputs and outputs. Moreover, the previous statement is true if we assume profit maximization by the household and by the combination of inputs in the new technology. However, this cannot be assumed in our study mainly for two reasons. First, because of market failures affecting decisions at the household level, profit maximization is not likely to reflect the behavior of households in West Africa. Second, the maximum obtainable yield is derived from the crop modeling results of Fischer et al. (2001), which assume certain levels of inputs and management conditions that do not necessarily result from profit maximization behavior in West Africa. For all these reasons, it is likely that the yield gaps calculated in this report represent an overestimate of the gap that can realistically be closed. These limitations of our approach should be kept in mind when looking at the main conclusions and findings of our study.

The results that emerge from this integrated spatial and economywide approach point to a rank of production activities at the country and regional levels that must be prioritized in order to stimulate productivity growth and achieve overall growth and poverty reduction goals in West Africa. These results indicate that the greatest agriculture-led growth opportunities in West Africa reside in staple crops (cereals and roots and tubers) and livestock production. The potential impact of these products is explained mainly by their relatively large share in total agricultural production; their large growth potential, as suggested by the analysis of yield gaps, in particular for staple crops; and the large and growing demand for these commodities within the region.

The contribution of different staple crops and livestock production to agricultural growth and to the income of agriculture producers varies across countries and major zones due to different agroecological, physical, and socioeconomic conditions. When looking at the different regions, we find that the agricultural subsectors projected to contribute the most to agricultural growth in the Sahel are livestock and cereals. This is primarily because of the significant potential to expand production given the observed yield gaps for these products, the sheer size of these sectors in the economies of most Sahelian countries, the comparative advantage of the Sahel for livestock production in West Africa, and the fact that demand for livestock products tends to grow at proportionately greater rates as incomes rises.

In the Coastal countries, the subsectors with a potential to make a significant contribution to total growth are much more varied than those in the Sahel. Despite this diversity, the projected contribution to total growth from staple crops like cassava, yams, and cereals seems to be relatively more important than that of other subsectors. In the case of Central Africa, livestock and root crops are likely to be the most important sources of growth in the region. Traditional export crops, such as cotton and cocoa, could make a significant contribution to growth in their major exporting countries (cotton in Mali and cocoa in Côte d’Ivoire and Ghana), while nontraditional exports and other high-value crops could be important sources of growth in some Coastal countries.

Our subsector analysis strongly indicates that the countries of the region could greatly benefit by pooling their resources to find common solutions to problems of technology adaptation and diffusion for particular agroecologies and development domains. According to our results, there is scope for greater regional cooperation in research and extension given the extent to which technologies and farming practices are applicable within domains and agroecological zones and across national boundaries, leading to a greater likelihood of widespread adoption and impact in the region.

Our results also point toward the need to strengthen regional agricultural markets exploiting opportunities for greater regional cooperation and harmonization to stimulate the productivity growth of prioritized activities. Regional markets would play a strategic role in expanding demand opportunities for producers of staple crops and livestock in different countries, facilitating subregional production specialization and contributing to export diversification. West Africa as a whole is a net importer of cereals and livestock products, and our analysis shows that if agricultural productivity growth were further supported by improved policies and market conditions, trade in these products would increase in the region. These changes would likely result in the substitution of global imports by intraregional trade and could contribute to the diversification of agricultural exports in some West African countries. The creation of such trade, and its diversification, would help agricultural growth and could also reduce the risk from concentrating on a very small number of agricultural export commodities.

In the case of livestock, intensification appears to be related to migration and expansion of the mixed crop-livestock system of production. Availability of technologies to increase soil fertility and crop residues would eventually play a key role in making this intensification feasible. Conversely, traditional export crops, such as cocoa and cotton, will continue to play important roles in West Africa’s agricultural growth. However, there are possibilities for market diversification by increasing the production of high-value crops in Coastal countries.

Finally, a regional strategy to promote agricultural growth will need to enhance linkages between agricultural and nonagricultural sectors to facilitate migration and develop labor and land markets to encourage investment in agriculture. In areas where transport costs and other structural factors prevent local economies from reaching outside sources of demand for local products, the strongest links between agricultural and nonagricultural sectors could spring from the production and consumption of nontradable commodities. These areas would play an important role in expanding the production of rice and coarse grains given that there is a higher growth potential for these crops in areas with low market access and low population density. In these areas, the availability of processing technologies and improved varieties suitable for feed appears to be important to strengthen links between production and consumption, complementing increased productivity in grain production. In areas with good market access, the priority will be to develop or improve links between agricultural production and agroindustries (for example, processed foods, feed, and intermediate products). An example of a crop with possibilities to expand in areas with good market access is cassava in the Coastal countries. Due to its short shelf life, better processing technologies, improved varieties (for agroindustry and biofuel), and the development of links to agroindustries will be critical to improve the overall productivity of this crop in order to compete in regional and international markets.

We conclude that there is a vast potential to expand agricultural production in West and Central Africa. A first implication of our results is that hypotheses that identify the diverse and extreme agroecological conditions in West Africa as one of the main causes of the lack of agricultural development do not withstand scrutiny. Evidence in the literature shows that there are technologies adapted to regional conditions, including improved varieties, improved crop management practices, recommended levels of fertilizer, and adequate management of nutrients, water, and pests and diseases. Adoption of these technologies could reduce the yield gaps for most crops. A second implication of our study is that staple crops and livestock have the highest potential to accelerate growth in the region. Targeting the development of staple crops such as sorghum and millet and of livestock technologies appears to be a priority for agriculture in the Sahel, together with further developments in rice production. On the other hand, Coastal countries face a wider set of options, from improvements in cassava, maize, and rice production to diversification into high-value and export crops. Finally, assuming high agricultural potential in West and Central Africa, closing the current yield gaps over the coming years through improved agricultural production depends mostly on developing conditions that allow farmers to access and adopt more efficient practices. An improved environment for agriculture will require developing infrastructure, markets, and supporting institutions. In turn, this will require an economywide strategy that considers trends in urbanization, demand growth, and migration so as to define investment priorities and create opportunities for investment in agriculture. Assumptions made in the past about the low potential for agriculture in the region resulted in reduced investment in R&D and extension, with negative consequences for the sector and for growth possibilities in several countries. Such consequences must be avoided by future development policies.

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West and Central African nations face major obstacles to achieving the Millennium Development Goal of cutting poverty and hunger in half by 2015, not least among them the fragile state of their agriculture. Although most regional economies depend on agriculture for employment, national income, and export revenues, farm productivity tends to be low, owing to relatively little use of chemical fertilizers, improved seeds, and other modern technologies. *Yield Gaps and Potential Agricultural Growth in West and Central Africa* responds to this problem by identifying potential areas of growth in the agricultural and livestock sectors. Using data on the soil, water availability, and weather in different parts of West and Central Africa, the authors find significant gaps in different locations between the potential and actual yield of various agricultural products. They then use an economywide multimarket model to simulate the future economic effects of closing these yield gaps. In coastal nations, crops such as cassava, cereals, and yams have the greatest yield gaps, whereas, in the Sahel, livestock, rice, coarse grains, and oilseeds (groundnuts) have more room for growth. Although identifying these yield gaps does not guarantee that they can be closed, it does provide a focus for development efforts in the region. The authors conclude, moreover, that if such efforts involve transnational cooperation in agricultural research, marketing, and other areas, they could produce significant benefits across West and Central Africa. This study's findings will be of interest to policymakers, researchers, and others concerned with African development.

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