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Agricultural Intensification in Africa

A Regional Analysis

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ABSTRACT

A renewed optimism in recent years about the possibility of an Asian-style Green Revolution taking root in Africa seems to be based on the assumption that rapid population growth will result in declining labor costs and growing land constraints, generating economic conditions similar to those in Asia. It is argued that such changes should lead to the adoption of labor-intensive technologies and increased fertilizer use, particularly in densely populated areas. This optimism explains in part the resurgence of input subsidy programs in Africa, which has arguably been one of the region's most important agricultural policy development in recent years. In 2011, 10 African countries spent roughly US$1.05 billion on fertilizer subsidies. What is the evidence so far for this optimistic case? This study assesses the patterns of agricultural intensification in 40 African countries looking at the role fertilizer plays in the process. We propose a set of indicators that uses information on available agricultural land and land suitability to measure intensity of land use in agricultural production. Results show that half of the countries in our sample, those with low population density, have followed a land-abundant intensification path with growth driven by new land incorporated to crop production and increased cropping intensity through the reduction of fallow periods and increased double cropping. For these countries, fertilizer appears to be an instrument for land expansion, with little impact on land productivity. High-population-density countries, on the other hand, show a substantial contribution of land productivity to output growth and a positive correlation between land productivity and fertilizer use but with high variability in the use of fertilizer across countries. These results seem to be related to production systems and agroecology, as countries where root and tree crop systems are dominant demand lower levels of fertilizer than countries with cereal-based systems. Results also show that agroecological conditions for the expansion of a package of high-yielding cereal varieties and fertilizer using intensive labor are limited given that only 18 percent of total available land in the region is better suited for cereals than for root and tree crops, and that low population densities in regions with advantages for cereal production do not make the technology attractive unless it is complemented by capital investments that increase labor productivity. The best possibilities of success for the fertilizer-and-labor-intensive technology package are in Ethiopia, Kenya, Uganda, and Malawi, countries with more than 60 percent of potential agricultural land in favorable agroecologies with high population densities.

Keywords: Africa, agricultural intensification, fertilizer use, technical change

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ABBREVIATIONS AND ACRONYMS

A_h	harvested land
AI	agricultural intensity index
A_r	arable land
CII	crop intensity index
CPA	crop potential area or the stock of land suitable for crop production
LII	livestock intensity index
PA_{adj}	potential agricultural area or quality-adjusted total available land
SK	animal stock measured in cow equivalents.
TPA	total agricultural potential area or the total stock of agricultural land in the country
Y_c	crop output
Y_{lv}	livestock output
YT	total agricultural output

1. INTRODUCTION

A confluence of factors has in recent years generated renewed interest in agriculture and spurred the early stages of the Green Revolution in Africa. According to Pingali (2012), the combination of continued food deficits, increasing reliance on food aid and food imports, soaring populations, growing land scarcity, rapidly growing urban demand, and an improved macroeconomic environment has reintroduced agriculture as an engine of growth in the policy agenda. Adding to this favorable environment for agriculture, new studies provide tangible evidence of the increasing availability of improved varieties of major food crops to farmers in Africa, increased food production in regions where adoption has occurred, and positive returns to research investment. The widespread adoption of improved maize, wheat, and rice varieties in Africa since the early 1990s is especially noteworthy (Maredia, Byerlee, and Pee 2000).

Morris et al. (2007) advance another argument for a more intensive use of fertilizer and Green Revolution technologies in Africa south of the Sahara (SSA). According to those authors, the expansion of the agricultural frontier and the opening of less favorable soils for cultivation could lead to a disaster in the long run, given the difficulty of restoring tropical soils to productive capacity without nutrient replenishment. They conclude that the improvements in soil fertility needed to boost agricultural productivity growth, improve food security, and raise rural incomes will require substantial increases in fertilizer use with adoption of improved land husbandry practices (121). This explains in part the resurgence of input subsidy programs in Africa, which according to Jayne and Rashid (2013, 547) "has arguably been the region's most important agricultural policy development in recent years." In 2011, 10 African countries spent roughly US$1.05 billion on fertilizer subsidies (29 percent of their public expenditures on agriculture).

The renewed optimism about an Asian-style Green Revolution taking root in Africa seems to be based on the assumption that rapid population growth on the continent will result in declining labor costs and growing land constraints, generating economic conditions similar to those in Asia. Under such reasoning, such conditions will lead to the adoption of labor-intensive technologies and greater fertilizer use, particularly in densely populated areas with relatively low labor costs and high returns to a more intensive use of land.

A more pessimistic view is offered by studies that argue that the optimist case for the Green Revolution in Africa overlooks the structural and agroecological characteristics of African agriculture that have resulted in the failure of policies pushing land-saving technologies in the past. For example, Woodhouse (2009) argues that despite rapid population growth, the performance of African agriculture is still largely limited by the high cost and low productivity of labor. Furthermore, vast areas of agricultural land in many African countries are still under low population pressure. According to Binswanger and Pingali (1988), one-third of all SSA countries will still have extensive rural areas with low population densities in 2025 despite rapid population growth, and shifting cultivation will still be the most common system of farming in those countries.[1] The remaining two-thirds of SSA countries are mostly natural-resource-rich countries where labor costs could remain high even in areas of high population density as a result of structural characteristics that produce rapid urbanization even at low levels of agricultural intensification (Gollin, Jedwab and Vollrath 2013). In other words, land and labor endowments across Africa are diverse (Headey and Jayne 2014; Chamberlin, Jayne, and Headey 2014) and if resource-rich economies are structurally different from labor-abundant economies in Asia, population growth will not necessarily transform resource-rich African economies into labor-abundant, low-labor-cost economies.

Adding to structural economic differences, diversity in land endowments in Africa and agroecological differences between Africa and Asia could be important in explaining differences in fertilizer use and intensification patterns. For instance, favorable agroecological conditions for cassava production in SSA have increased the importance of cassava as a food security crop, resulting in

[1] Jayne, Chamberlin and Headey (2014) show that, as of 2010, 70 percent of the rural population in SSA is clustered on 20 percent of the rural arable land, indicating that 80 percent of the rural arable land remains sparsely populated by the remaining 30 percent of the rural population.

production expansion through the reduction of fallow land. Generally, cassava can give reasonable yields in soils of low fertility and is thought to require less labor per unit of output than most other major staples; in fact, expansion of cassava production in Africa appears to be leading to greater labor productivity in the region (Hillocks 2002). Increasing cassava production could be a profitable alternative to intensive cereal production when labor still imposes significant constraints to production expansion.

What is the evidence so far for the optimistic case of an African Green Revolution? What role did fertilizer and increased use of inputs and labor per unit of cultivated land play in agricultural growth in recent years? The goal of this study is to assess the patterns of agricultural intensification in 40 countries in SSA. To do this we use the conceptual framework developed by Boserup (1965) and Ruthenberg (1980) to look at the patterns of intensification in SSA at present, their evolution in recent years, and the changes in output composition and input use associated with different intensification patterns. In particular, we look at the use of fertilizer and the role it played in the different intensification paths followed by SSA countries. We also discuss implications of the observed patterns for growth and policymaking.

The study is organized as follows. Section 2 presents the conceptual framework and Section 3 develops a series of indicators, based on the conceptual framework of Section 2, to measure intensification. Results and analysis of recent intensification trends and patterns are presented in Section 4, and Section 5 focuses on intensification and fertilizer use. Section 6 discusses findings and concludes.

2. CONCEPTUAL FRAMEWORK

The term *agricultural intensification* has been used extensively in the agricultural and development literature with different meanings and in different contexts. Most often, it is used at the farm level referring to the process of increasing labor and inputs per hectare of agricultural land. For example, Tiffen, Mortimore, and Gichuki (1994, 22) defined intensification as "increased average inputs of labor or capital on a smallholding, either cultivated land alone, or on cultivated and grazing land, for the purpose of increasing the value of output per hectare." The key idea here is that intensification is a process that results in increased output per unit of land as a consequence of intensive use of inputs and labor (per unit of land). Most often, the term *intensification* is used to refer to the intensive use of chemical inputs and improved crop varieties or other yield-enhancing practices leading to increased output per hectare, as in the case of the Asian Green Revolution, the best-known and most-studied example of intensification in this context. Other technologies, such as mechanization, that do not lead to a rise in output per hectare are not considered to contribute directly to intensification as they contribute very little to land productivity (Carswell 1997). In this context, the alternative to agricultural intensification is *extensification,* or the expansion of production into previously uncultivated areas. This may also require increased inputs, investments, and labor as in the case of intensification; however, and unlike intensification, this increased use of inputs will not result in higher output or input per unit of land. In other words, under this approach, intensification is synonymous with increased land productivity.

This is not the meaning of agricultural intensification that is relevant for this study. Defined in this way, the concept of *intensification* is narrowed down to a technical or agronomic process without social or economic meaning. Instead, we follow Boserup (1965) and Ruthenberg (1980), who understood intensification as the process of relative changes in the availability of land, labor, and capital driven by population growth and by the higher returns to farming that arise with improvements in market infrastructure and farmgate price increases. Intensification as defined by Boserup refers to the stock of available land whether that land is under cultivation or not. A more intensive use of such stock occurs when new land is placed under cultivation, when the length of the average fallow period is shortened, and when land under cultivation is used more intensively, requiring increasing levels of inputs, labor, or capital per unit of land.

The importance of relative resource abundance as a determinant of intensification and technological change paths has been part of the economics of technological change since the 1970s, when Ruttan, Hayami, and Binswanger (Hayami and Ruttan 1971, 1985; Binswanger and Ruttan 1978) formulated a model of induced technological change in which the development and application of new technology is endogenous to the economy. According to this model, the direction of technological change in agriculture is induced by changes (or differences) in relative resource endowments and factor prices. Because of the relatively high prices of less abundant resources, alternative agricultural technologies are developed to facilitate the substitution of relatively scarce (hence, expensive) for abundant (hence, cheap) factors.

More recently, Acemoglu (1998, 2002, 2007), contributing to what is today known as the directed technological change literature, provides a characterization of how the bias of technology will change in response to changes in factor supply. According to Acemoglu (2007), an increase in the supply of a factor always induces a change in technology biased toward that factor. This result implies, for example, that land scarcity will lead to technological changes biased against land (land-saving technologies). The directed technological change literature also discusses the relationship between scarcity of different factors and technological change. Acemoglu (2009) shows that labor scarcity induces technological advances if available technology is strongly labor saving. In contrast, labor scarcity discourages technological advances if the technology is strongly labor complementary. Also according to Acemoglu (2009), wage increases above the competitive equilibrium have similar effects to labor scarcity.

Adoption patterns of different inputs and practices will depend on the benefits one should expect from various types of agricultural innovations under different factor-scarcity regimes, and such benefits could be measured in terms of the reduction in the unit costs of production that result from adopting the innovation. The greater the reduction in unit costs, the higher the demand for and the higher the probability of adopting the innovation. As highlighted by Binswanger (1986, 470), innovations that do not reduce input requirements per unit of output of those factors that are scarce or expensive will not be easily adopted. From society's point of view, those innovations will have a low value.

How do different types of innovation contribute to unit cost reduction in land- or labor-scarce environments? To discuss this we need Binswanger's (1986) classification of innovations that groups them according to how they use land, labor, and inputs as (a) yield-increasing and (b) labor-saving innovations.[2] Yield-increasing innovations fall into three types: (1) input-using innovations such as fertilizer and pesticides; (2) stress-avoiding innovations based on genetic resistance or tolerance to pests, diseases, or water stress; and (3) husbandry techniques such as better land preparation or intensive mechanical weeding. Labor-saving innovations include the use of machines, draft animals, implements, and herbicides.

All three types of yield-increasing innovations reduce the area required to produce one unit of output, reducing not only land costs but also the cost of all inputs that are used proportional to the area saved. The difference between them is in how they use inputs in the remaining area. For example, the use of chemical inputs increases input costs substantially. In contrast, the use of resistant varieties results in the extra cost of new seeds, which is normally low. Crop husbandry techniques have a small impact on input costs but increase the costs of labor or machinery, or both.

Adoption of yield-increasing innovations such as fertilizer must be cost-efficient, which means that the increase in fertilizer cost must be less than the reduction in land cost and in the cost of inputs, which are proportional to the area saved. When land area can be easily expanded, yield-increasing innovations result in minimal savings in land costs. The only major saving is in the labor in land preparation, planting, and weeding on the area saved. For these innovations to be adopted, the increased cash costs of inputs or higher labor costs must be less than the value of labor savings alone. Among the yield-increasing innovations, the most likely to be adopted in land-abundant areas are those reducing environmental stress as the cost of improved seed is negligible.

Labor-saving innovations, on the other hand, do not usually reduce area and have very little, if any, effect on yields. For such innovations to be adopted, the labor savings need to be larger than the extra machine or herbicide costs. Since labor saving is the most important benefit, the value of these innovations rises with rising wages, meaning that the benefit of labor-saving technologies is a rising function of the wage rate but is not strongly dependent on land values or preexisting technology levels (Binswanger 1986). The implications for technology adoption in land-abundant regions are clear. Farmers in such regions demand labor-saving innovations. They also demand crops that enable them to produce more food or a higher gross return for a lower labor input.

Population Pressure and Technological Change

The tension caused by increasing scarcity of resources (for example, population growth) stimulates technological change to save those resources as well as new institutions that support such change. It is argued in the case of Africa that incentives for induced innovation have been created by population pressure on limited land resources (Otsuka and Place 2014). According to Boserup (1965) an agrarian community has a fixed territory and an array of discrete techniques that use land with different intensities consisting of five different categories: forest fallow, bush fallow, short fallow, annual cropping, and multiple cropping. Each successive category represents an intensification in the Boserupian sense of the use of land (Darity 1980). With low population densities, farmers cultivate the land for a few years, moving on to another patch when fertility diminishes, leaving the land for several years to recover its natural fertility. With increasing population density, communities using a particular production technique experience decreasing output per capita. When population growth depresses average output sufficiently to lower the community's standard of living, more labor is allocated to production to bring new land under

[2] Binswanger's (1986) classification also includes quality-increasing innovations, which are not discussed here.

cultivation or shorten the fallow period, or both, so land is cultivated for longer periods until annual cropping and later multiple cropping become the rule. A more intensive use of land reduces the rate of natural replenishment of the available land, so to preserve land's productivity the community needs to switch over to a new technique. As land is now scarce, its value rises and farmers find it cost-effective to use manure or chemical fertilizer to maintain soil fertility and low-cost irrigation can become economic.

At the core of Boserup's model is the notion of technological change induced or impelled by a "critical" population density. Turner and Fischer-Kowalskic (2010) claim that the simple account of agricultural intensification provided by Boserup's model offered a powerful set of ideas in opposition to the prevailing neo-Malthusian ideas of the time applied to agricultural development. Boserup challenged Malthus's proposition that the relatively slow growth in the food ceiling served as the upper limit for the more fast-paced potential growth in population. She reversed the causality, arguing that increases in population pressure trigger the development or the use of technologies and management strategies to increase production commensurate with demand and that over the long run, this process transforms the physical and social landscapes.

Turner and Fischer-Kowalskic (2010) assert that Boserup's thesis remains important today to the various subfields contributing to sustainable development. Its foundations have been tested and critiqued, generating a vast literature exploring the roles of environment, gender, social capital, household composition, tenure, off-farm employment opportunities, and state policies, among other factors on agricultural intensification under different land pressures (for example, Brookfield 1972, 2001; Dorsey 1999; Turner and Brush 1987; Angelsen 1999; Carr 2004; Morrison 1996; Lambin, Rounsevell, and Geist 2000; Stone 2001; Turner and Ali 1996).

It is important to consider also that population pressure does not inevitably lead to technological change, as Boserup (1965) acknowledged. Population pressure is a necessary but not a sufficient condition since different communities might be faced with different technological elasticities due to differences in soils and climates, differences in the distribution of land between types of uses, and different external influences. All of those considerations could make communities with essentially the same population characteristics emerge with different production techniques. Regardless, for Boserup, population pressure must be present to precipitate a move toward more intensive uses of the land (Darity 1980).

Some recent literature has relaxed the assumptions imposed in Boserup's scheme, revealing the conditions leading to Boserupian, Malthusian, or other outcomes (Malmberg and Tegenu 2006; Pascual and Barbier 2006; Place and Otsuka 2000; Tachibana, Nguyen, and Otsuka 2010; Gray and Kevane 2001; Reenberg 2001; Stone 2001; Turner and Ali 1996; Demont et al. 2007). This literature assumes that population growth results in increasing hardship in meeting the prevailing standard of living, causing the community to opt for more intensive agriculture or other paths not necessarily requiring intensification as long as those paths allow it to maintain or improve its living standards.

For example, Demont et al. (2007), working with a survey of farms in northern Côte d'Ivoire, found that the Boserup and Malthus theses coexist rather than compete. They observed that in an initial stage, demographic pressure engenders Malthusian mechanisms (degradation of the environment and decline of profitability of the ancient production system) leading to migration and, hence, Malthusian population control. They show that as long as the option to migrate is kept open, Malthusian population control will generally dominate Boserupian mechanisms of induced innovation. However, in the long run it is expected that the saturation of sparsely populated regions will induce intensification and mechanization across farming systems. They also found that taking into account an urbanization level of 45 percent, the agrarian transition in Côte d'Ivoire will be induced not only by local demographic pressure but also by the increase of urban food, feed, and fiber demand and the development and expansion of marketing systems.

Another example is the case of Bangladesh discussed in Turner and Ali (1996). Analyzing the evolution of agriculture from 1950 to 1986, they found complementary episodes of Boserupian and Malthusian response. According to those authors, over the entire period, induced intensification proceeded in a Boserupian path marked by several thresholds, each of which had the potential to spin off into a Malthusian path. The first threshold was reached in the 1960s and was averted by the adoption of high-yield-variety technologies. The second threshold in the 1980s was overcome by a shift to crops with high market values, especially market gardening in more favorable locations. Yet another threshold was reached in the 1990s when economic and policy barriers to irrigation technologies impeded production in food staples and the poor state of transportation infrastructure inhibited most villages from moving into market gardening. Eventually, barriers to various technologies, such as low-lift pumps, were reduced, and their increased use throughout Bangladesh led to yet another spurt in land productivity through increased dry-season cultivation. Turner and Ali concluded that the discussion has thus moved beyond a simple Malthus–Boserup debate, demonstrating how both positions might be supported depending on where in the intensification process the analysis is undertaken or on the temporal scale of analysis employed. On the other hand, those authors indicate that the processes that divert intensification into the involution and stagnation paths are less well-developed conceptually and that a better grasp of such processes is required for a fully developed theory of agricultural change among smallholders.

Market-Driven Technological Change

Population pressure is not the only factor causing intensification. As Stone (2001) argues, farmers take steps to use land more intensively for various reasons other than population pressure or land shortage. For example, market incentives can induce farmers to intensify in the absence of land shortage (Turner and Brush 1987; Netting, Stone, and Stone 1989). Even in low-density areas, farmers facing a growing demand, arising largely from newly accessible markets, will want to produce more, which will increase demand for land and spur more intensive land use. An important difference between this market-driven growth model and the Boserupian population-pressure-driven growth model is that in the former, favorable market conditions could accelerate the incorporation of new land to production and accelerate intensification, introducing intensive use of chemical inputs with high-yielding varieties even in low-population-density regions. Moreover, the density threshold at which there is significant demand for fertilizer can be quite low provided other favorable conditions exist (Goldman and Smith 1995). The implications are that natural-resource-rich countries on a market-driven intensification path will demand agricultural innovations with strong labor-saving components rather than the land-saving technologies that were promoted in Asia under the Green Revolution. Binswanger (1986) reminds us that in Thailand, a country that has traditionally had an open land frontier, remarkable agricultural growth has come from area expansion and that fertilizer use levels and adoption of high-yielding varieties have been below that in other Asian countries.

Even if we accept that market-driven intensification in Africa could result in demand for labor-saving rather than land-saving innovations, we could still assume that labor supply in agriculture will continue to grow due to population pressure, reducing labor costs in land-abundant countries and creating conditions for the adoption of labor-intensive technologies at least in high-density areas. In other words, labor-intensive technologies could still be promoted in natural-resource-rich countries if we focus on high-population-density areas where farms are small, incomes are low, and a high proportion of the rural poor live.

A first problem with this reasoning is that it does not consider the fact acknowledged by Boserup that population pressure is not a sufficient condition for intensification, as discussed earlier. For example, Goldman (1993) and Goldman and Smith (1995) argue that constraints to innovation could also appear in very dense areas when there is little potential to increase farm sizes. If no land is available for expansion, the additional wealth that agricultural investment and new technology can generate is limited and nonagricultural activities may then be preferable to investment in agriculture.

A second problem with this approach is that it seems to assume that high-density areas in resource-rich countries behave like closed Boserupian models, where population pressure increases labor supply, generating labor surpluses that farmers use to increase output through the introduction of land-saving, labor-intensive technologies as the excess labor has no other employment opportunities. As it happens, farmers do have other options, as shown by Demont et al. (2007) in the already mentioned case of Côte d'Ivoire, when the possibility to migrate is kept open. Also, Schultz (1964) developed a critique of labor surpluses in agriculture as postulated by Lewis (1954), arguing that numerous case studies of the agricultural sector in less-developed societies showed that the output of the traditional sector falls when labor was withdrawn from the agrarian sector. One of these studies by Hansen (1969), looking at agriculture in Egypt, a country with one of the highest population densities in the world, found that small farmers are brought to a high level of employment by the substantial opportunities for obtaining employment outside their own farm, on other farms and outside agriculture. Hansen concludes that the active labor market observed in Egypt is difficult to reconcile with the idea of surplus labor and zero productivity of labor as a general phenomenon. If, in fact, a country with the population density of Egypt had no rural labor surpluses, it is at least unlikely that resource-rich countries in SSA will conform to the surplus labor model.

High labor costs appear to be a structural characteristic of resource-rich economies as a consequence of a different agricultural transformation path when compared with the path in labor-abundant economies. One of the explanations for this persistence of high labor costs most commonly found in the literature relates to Dutch disease, a phenomenon that arises when a strong upswing in the world price of the export commodity leads to increased purchasing power and increased demand for urban goods, real appreciation of the local currency, and an increase in the relative price of nontradable goods. The result of such changes is a shift of labor, pulled by the more attractive returns in the export commodity and in the nontraded goods and services and a "push" of workers into urban areas.

Gollin, Jedwab and Vollrath (2013) develop a model that formally explains urbanization without industrialization and the persistence of high labor costs despite rapid population growth in Africa. One of the implications of natural resource rents is that natural-resource-rich economies do not experience a stage of labor abundance with low labor costs in agriculture, as was observed in Asia. What is observed instead, as Gollin, Jedwab and Vollrath describe, is rapid urbanization resulting in "consumption cities" that are made up primarily of workers in nontradable services, surrounded by rural areas with high population density. These high-population-density rural areas either produce semisubsistence agriculture while diversifying into nonfarm activities (services) or specialize in high-value crops. In addition, interspersed with these high-population-density rural areas are vast areas of relatively low population density dedicated to the production of export crops and semicommercial agriculture. Multiple cropping and intensive use of chemical fertilizer associated with cereal production could be an option in high-population-density areas if it can compete with production in low-density areas, and if returns to family labor in this activity are higher than other farm and nonfarm activities that seem to be more attractive for smallholders. For example, in many countries natural resources favor production of cassava and other noncereal staples that give higher marginal returns to labor than intensive cereal production. These developments stand in contrast to the Asian case of labor-abundant economies, where we observe the typical substitution of industrial labor for agricultural labor resulting in "production cities" that produce tradable goods (manufacturing).

Drawing on the foregoing discussion, we approach the data using Boserup's model as the conceptual reference to look at intensification in SSA's agriculture. Her framework proves useful in at least two ways. First, it helps us to understand the process of intensification and the relationship between land abundance, technology, inputs, and labor intensity. Second, by linking relative abundance of labor and land to input use and intensity, it helps in understanding the demand for different technologies in regions with different degrees of population pressure on land.

3. INTENSIFICATION INDICATORS

Several indicators have been proposed to measure intensification in agricultural production. Some of the most used indicators try to capture the intensity of land use by looking at the length of the cultivation and fallow periods. One of the most commonly used indicators is the ratio *R*, calculated as the ratio of the length of the cultivation period to the total length of the cycle of land utilization, defined as the length of the cultivation period plus the length of the fallow period (Ruthenberg 1980). When *R* is less than 33, the corresponding system is classified as shifting cultivation or long-fallow agriculture. An *R* value between 33 and 66 is used to indicate a short-fallow, semipermanent cultivation. When *R* is greater than 66, the system is classified as permanent cultivation with either single cropping or various degrees of multiple cropping. Cropping intensity measures the intensity of land use under cultivation as the ratio between gross and net cropped area, varying from 100 to 200 if there is complete double cropping.

Information to estimate these indicators is not always available, especially when comparing agriculture sectors across countries. On the other hand, such indicators present only a fragmented view of the process of intensification and its changes across time. For the purpose of this study, we propose an indicator to measure intensity of agricultural production at the sectoral level that can be decomposed into a set of other indicators reflecting the level of intensification reached by a particular country and the factors driving intensification.

Our overall intensification indicator (intensity index) is the ratio between total agricultural output and total stock of agricultural land in a country, including both land under cultivation and land not incorporated to production. This measure reflects the intensity of use of the available land in a country and implies that intensification could be increased by simply incorporating new land to production or reducing the fallow period, or could also result from a more intensive use of land under cultivation. Given the different nature of their production process, we decompose this index into crop and livestock intensity indexes as follows:

$$AI = \frac{YT}{TPA} = CII \times LII = \frac{Y_c}{TPA} + \frac{Y_{lv}}{TPA}\,, \tag{3.1}$$

where *AI* is the agricultural intensity index, *YT* is total agricultural production, *TPA* is total agricultural potential area, or the total stock of agricultural land in the country, *CII* and *LII* are, respectively, the crop and livestock intensity indexes, and Y_c and Y_{lv} are crop and livestock outputs, respectively.

We further decompose *CII* as follows:

$$CII = \frac{CPA}{TPA} \times \left[\frac{A_r}{CPA} \times \frac{A_h}{A_r} \times \frac{Y_c}{A_h}\right], \tag{3.2}$$

where *CPA* is the crop potential area, or the stock of land suitable for crop production, so that *CPA/TPA* is a measure of quality or potential of agriculture in the country and determines the contribution of crop intensification to overall agricultural intensification. The first term in parentheses is the ratio between arable land (A_r) and total land suitable for agriculture, which could be thought of as an indicator of land abundance. The second term in parentheses is the ratio of harvested land (A_h) to arable land (A_r), which is an indicator that could be used as a proxy for crop intensity as normally defined, the ratio of gross and net cropped area. The last term Y_c/A_h reflects land productivity and measures crop output per hectare of harvested land. We expect that in high-population-density countries, Y_c/A_h would contribute the largest share to crop intensification. On the other hand, we expect that crop production in low-density countries would increase through a combination of more land being incorporated to crop production and a more intensive use of that land (for example, increasing double cropping).

Finally, the livestock production intensity index has two components:

$$LII = \frac{Y_{lv}}{SK} \times \frac{SK}{TPA}\,, \tag{3.3}$$

where SK is animal stock measured in cow equivalents. Comparing this with the crop index, SK/TPA is the equivalent to land being incorporated to livestock production, while Y_{lv}/SK, output per animal, is a productivity measure. Intensification in livestock production at low levels of population density is expected to occur through increases in SK/TPA with no major changes in animal productivity. Increased animal productivity would require more inputs per animal, similar to what is needed to increase yields in crop production. Note that at this level of aggregation, output per hectare of harvested land could increase as the result of more intensive use of labor and inputs without changes in crop composition, or as the result of changes in the crop mix without changes in inputs or from a combination of both. The same reasoning applies to changes in output per animal in stock as the stock composition could change.

We use data for 40 SSA countries from the Food and Agriculture Organization of the United Nations (FAO 2013), which provides national time-series data from 1961 to 2011 for the total quantity of different agricultural inputs and output. Total agricultural output is the value of gross agricultural production expressed in constant 2004–2006 US dollars including crop and livestock production. Inputs include labor, measured as total economically active population in agriculture, fertilizer (metric tons of nitrogen, potash, and phosphates used measured in nutrient-equivalent terms), animal stock including cattle, sheep, goats, pigs, and chicken aggregated as total number of livestock units,[3] and capital calculated by FAO at average 1995 prices including on-field land improvements (irrigation channels, soil conservation works, flood control structures, and so forth), plantation crops, and machinery and equipment.

Three different measures of land from FAO are used: (1) *arable land,* which is land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than five years);[4] (2) *harvested area,* which is the area from which a crop is gathered;[5] and (3) *total agricultural land,* which is total land being used in production and results from the sum of arable land and pasture land, which is land used permanently (five years or more) to grow herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

Data on the stock of agricultural land (TPA and CPA as defined previously) and land suitability were provided by IFPRI's Spatial Production Allocation Model for all countries in SSA at the pixel level and were aggregated to be used at the country level in this study (see You et al. 2014). Total agricultural land is identified according to topographic characteristics, length of growing period and annual rain, and so forth, and classified according to its suitability for agricultural production in six categories:

- S1 = Land very poorly suited for pasture and at best poorly suited for rainfed crops
- S2 = Land poorly suited for pasture and at best poorly suited for rainfed crops
- S3 = Land suited for pasture and at best poorly suited for rainfed crops
- S4 = Land suited for rainfed crops and pasture possible
- S5 = Land well suited for rainfed crops and pasture possible
- S6 = Prime land for rainfed crops and pasture possible

Land variables in equations 3.1 through 3.3 are defined as follows: potential agricultural area, or the total stock of agricultural land, is TPA = S1 + S2 + S3 + S4 + S5 + S6; and potential crop area is CPA = S4 + S5 + S6. Information on determinants of fertilizer use in Section 5 was obtained from different sources, including FAO (2013), Heston, Summers, and Atten (2012), and World Bank (2014).

[3] Conversion factors for livestock units are as follows: 1.1 for camels and buffalo; 1.0 for cattle; 0.3 for pigs; 0.15 for sheep and goats; and 0.01 for poultry.

[4] The abandoned land resulting from shifting cultivation is not included in this category.

[5] If the crop under consideration is harvested more than once during the year as a consequence of successive cropping, the area is counted as many times as harvested. On the contrary, area harvested will be recorded only once in the case of successive gathering of the crop during the year from the same standing crops.

4. AGRICULTURAL INTENSIFICATION: PRESENT LEVELS AND TRENDS

To shed light on the effect of population density on the intensity of output production and input use, we sort countries by their population density in 1995 (the beginning of the period covered in this study) and define four groups, each containing the same number of countries, with group 1 (G1) including countries with the lowest levels of population density and group 4 (G4) including those with the highest population densities. Table 4.1 presents the values of population density and different measures of output per hectare. The first measure uses total available agricultural land; the second measure uses the same area but adjusted by quality (number of hectares equivalent to land well suited for crop production); and the last measure employs actual agricultural land used in production. Estimates of output per hectare are presented for the 40 countries included in the analysis. We will refer to the quality-adjusted total available land as potential agricultural area (PA_{adj}). The measure of population density used here is calculated as total rural population divided by PA_{adj}.

Table 4.1 Population density and output per hectare of agricultural area (average values for 1995–2000)

Quantile	Country	Population density	YT/TPA	YT/TPA_{adj}	YT/A_r
G1	Central African Republic	0.047	12	14	122
	Namibia	0.068	5	19	8
	Botswana	0.078	3	16	6
	Gabon	0.104	51	68	34
	Zambia	0.115	11	14	32
	Angola	0.117	11	16	16
	Congo	0.127	17	20	18
	Chad	0.139	13	29	23
	Mozambique	0.183	21	23	31
	Liberia	0.198	26	40	95
G2	Sudan	0.202	30	56	44
	Mali	0.239	22	63	52
	Mauritania	0.257	9	65	9
	Madagascar	0.263	42	63	61
	Equatorial Guinea	0.294	25	34	95
	Cameroon	0.297	83	96	269
	Côte d'Ivoire	0.329	160	177	235
	Benin	0.360	150	158	540
	Congo, D.R.	0.364	33	39	130
	Zimbabwe	0.373	53	86	127
G3	Tanzania	0.412	49	62	105
	Guinea	0.448	42	84	73
	Burkina Faso	0.448	61	73	152
	Niger	0.503	21	85	36
	Senegal	0.515	57	98	111
	Ghana	0.516	173	184	264
	Somalia	0.606	22	187	31
	Togo	0.611	128	148	190
	South Africa	0.659	82	324	95
	Sierra Leone	0.675	36	66	89
G4	Guinea-Bissau	0.759	77	158	106
	Gambia	0.980	84	130	152
	Swaziland	1.005	150	324	196
	Nigeria	1.065	260	341	301
	Ethiopia	1.128	22	56	67
	Uganda	1.181	226	267	339
	Kenya	1.190	71	198	138
	Malawi	1.463	168	222	287
	Burundi	4.189	294	526	321
	Rwanda	5.571	400	910	521

Source: Elaborated by authors.

Notes: TPA = total potential agricultural area. TPAadj is TPA adjusted for quality: equivalent hectares of land well suited for rainfed crops and pasture possible (crop suitability index (CSI): 50–80 and pasture suitability index (PSI) > 0). Output is in 2004–2006 US$ constant prices.

The first thing to notice is that the highest population pressure on agricultural land in SSA occurs in East Africa (Burundi, Rwanda, Kenya, Uganda, Ethiopia), Nigeria and small Gambia and Guinea-Bissau in West Africa, and Malawi and Swaziland in southern Africa. On the other end of the ranking of countries, Group 1 (G1) includes countries with forest-based agriculture (Congo, Central African Republic, and Gabon), semiarid countries with a very low population density (Botswana, Chad, and Namibia), and large southern countries with high agricultural potential (Angola, Mozambique, and Zambia). The intermediate groups (G2 and G3) are composed mostly by West African countries including also southern African countries (South Africa, Zimbabwe, and Madagascar), plus eastern African Sudan, Tanzania, and Somalia. Among these two groups, Sierra Leone with a population density of 0.68 has the highest population density. On the other extreme, Sudan is the country with the lowest population density (0.20).

According to the figures in Table 4.1, and despite some expected variability in part explained by land quality, our measure of output per hectare of potential agricultural land is clearly related to population density as shown in Table 4.2. Correlation values in the last two rows of the table show that the expected relationship between population density and production per hectare holds, and it is highly significant for the measures using potential area. Average values of output per hectare seem to show evidence of the existence of population density thresholds for intensification given the differences in output and input per hectare between G4 and all other groups. Output per hectare of potential agricultural area is three times larger in G4 ($175) than in G2 and G3, which show almost the same values ($61 and $67, respectively). There are also large differences between G1 ($17) and all other groups.

Table 4.2 Population density and output per hectare of different measures of agricultural area by quantile of population density and correlation values

Variable	Population density	*YT/TPA*	YT/TPA_{adj}	YT/A_r
Quantile				
G1	0.12	17	26	39
G2	0.30	61	84	156
G3	0.54	67	131	114
G4	1.85	175	313	243
Correlation between population density and averaged values, 1995–2000	1.00	0.985	0.99	0.872
p-value		0.015	0.010	0.128
Correlation between population density and pooled country-year values	1.00	0.81	0.88	0.65
p-value		0.000	0.000	0.000

Source: Elaborated by authors.

Notes: *TPA* = total potential agricultural area. TPA_{adj} is *TPA* adjusted for quality: equivalent hectares of land well suited for rainfed crops and pasture possible crop suitability index (CSI): 50–80 and pasture suitability index (PSI) > 0). Output is in 2004–2006 US$ constant prices. Average values for the use of inputs per hectare show no clear patterns across groups of population density (Table 4.4). Fertilizer and capital use per hectare of *CPA* is much lower in G1, but no clear pattern exists between the other three groups. For example, fertilizer and capital use per hectare is highest in G3, and no large differences are observed between G4 and G2. The normally used measures of fertilizer per hectare of arable land show almost no differences in the use of fertilizer and capital between G2, G3, and G4 and relatively small differences between those groups and G1 if we compare them with the differences observed when *CPA* is used. Correlation coefficients in the last rows of Table 4.4 confirm the large variability in the use of fertilizer for similar levels of population density. Only the measures that use *CPA* show the expected sign, although correlation is low (0.18 and 0.23 for fertilizer and capital, respectively). The measures using arable land show very low and insignificant coefficients, as is the case for fertilizer, or significant but negative coefficients in the case of capital.

How does intensity in the use of inputs relate to population density? Table 4.3 shows values of population density, fertilizer, and capital per hectare of different measures of agricultural area. Values for intensity of input use show greater variability at similar levels of population density than output per hectare. Without considering South Africa, which is an outlier in this sample, maximum observed values of fertilizer per hectare of *CPA* are between 8 and 9 kilograms. Only 4 of the 10 countries in G4 appear among the group of countries using the highest levels of fertilizer (Malawi, Kenya, Swaziland, and

Ethiopia). Other high-density countries in G4, like Nigeria, Gambia, and Burundi, use less fertilizer per hectare of *CPA* than countries with much lower population pressure like Senegal, Côte d'Ivoire, Mauritania, Togo, and Benin. Similar variability for similar levels of population density is observed in the use of capital. Rwanda, the country with the highest population density in SSA, uses less fertilizer than Sudan, while Uganda, another highly populated country, shows one of the lowest levels of fertilizer use in in the region.

Table 4.3 Population density and inputs per hectare of different measures of agricultural area (average values for 1995–2000)

Quantile	Country	Population density	Fertilizer/ *CPA*	Capital/ *CPA*	Fertilizer/ A_r	Capital/ A_r	Fertilizer/ $A_{r\,adj}$	Capital/ $A_{r\,adj}$
G1	Central African Republic	0.047	0.010	0.012	0.222	0.253	0.380	0.433
	Namibia	0.068	0.017	0.048	0.203	0.584	0.455	1.308
	Botswana	0.078	0.748	0.057	13.244	0.983	32.479	2.411
	Gabon	0.104	0.121	0.136	0.617	0.695	1.227	1.382
	Zambia	0.115	0.926	0.036	15.782	0.609	28.666	1.106
	Angola	0.117	0.072	0.056	1.161	0.905	2.291	1.786
	Congo	0.127	0.444	0.033	7.786	0.588	14.340	1.083
	Chad	0.139	0.390	0.036	3.731	0.345	6.476	0.599
	Mozambique	0.183	0.139	0.036	2.143	0.551	3.358	0.864
	Liberia	0.198	0.051	0.069	0.558	0.747	1.256	1.680
G2	Sudan	0.202	0.607	0.152	3.433	0.860	5.929	1.484
	Mali	0.239	1.634	0.124	8.859	0.673	17.596	1.337
	Mauritania	0.257	3.070	0.473	5.831	0.900	14.858	2.294
	Madagascar	0.263	0.317	0.271	3.076	2.630	5.779	4.941
	Equatorial Guinea	0.294	0.001	0.481	0.003	1.800	0.006	3.228
	Cameroon	0.297	1.602	0.129	5.559	0.446	8.886	0.713
	Côte d'Ivoire	0.329	2.989	0.236	11.656	0.919	19.750	1.557
	Benin	0.360	3.954	0.110	16.612	0.463	26.705	0.745
	Congo, D.R.	0.364	0.047	0.040	0.522	0.445	0.901	0.768
	Zimbabwe	0.373	8.397	0.056	48.586	0.327	98.968	0.666
G3	Tanzania	0.412	0.503	0.142	2.863	0.806	5.198	1.463
	Guinea	0.448	0.329	0.096	1.133	0.333	2.342	0.688
	Burkina Faso	0.448	1.810	0.054	9.520	0.288	16.982	0.513
	Niger	0.503	0.525	0.400	0.344	0.262	0.744	0.566
	Senegal	0.515	2.919	0.137	8.900	0.419	18.485	0.869
	Ghana	0.516	0.773	0.150	2.814	0.544	4.498	0.870
	Somalia	0.606	0.434	2.506	0.496	2.861	1.411	8.147
	Togo	0.611	3.930	0.167	7.019	0.299	12.008	0.511
	South Africa	0.659	48.221	1.365	55.109	1.559	127.255	3.601
	Sierra Leone	0.675	0.451	0.200	2.608	1.161	6.226	2.770
G4	Guinea-Bissau	0.759	0.773	0.859	1.500	1.789	4.011	4.786
	Gambia	0.980	1.958	0.121	5.706	0.342	12.888	0.773
	Swaziland	1.005	8.661	0.556	27.634	1.775	69.736	4.480
	Nigeria	1.065	2.719	0.433	5.250	0.837	9.656	1.539
	Ethiopia	1.128	4.477	0.111	14.724	0.367	29.081	0.724
	Uganda	1.181	0.186	0.195	0.396	0.420	0.682	0.723
	Kenya	1.190	8.731	0.255	24.529	0.710	49.595	1.436
	Malawi	1.463	9.053	0.209	19.400	0.446	35.836	0.823
	Burundi	4.189	2.445	0.532	2.268	0.494	5.275	1.148
	Rwanda	5.571	0.502	0.593	0.337	0.392	0.843	0.980

Source: Elaborated by authors.

Notes: *CPA* is potential land suitable for crop production. A_r is arable land. $A_{r\,adj}$ is A_r adjusted for quality: equivalent hectares of land well suited for rainfed crops. Capital is that used for crop production.

Table 4.4 Population density and inputs per hectare of different measures of agricultural area by quantile of population density (average values for 1995–2000)

Variable	Population density	Fertilizer/ CPA	Capital/ CPA	Fertilizer/ A_r	Capital/ A_r	Fertilizer/ $A_{r\,adj}$	Capital/ $A_{r\,adj}$
Quantile							
G1	0.12	0.292	0.052	4.5	0.626	9.093	1.265
G2	0.30	2.262	0.207	10.4	0.946	19.938	1.773
G3	0.54	5.990	0.522	9.1	0.853	19.515	2.000
G4	1.85	3.950	0.386	10.2	0.757	21.760	1.741
Correlation between population density and averaged values, 1995–2000	1.000	0.435	0.507	0.522	-0.048	0.628	0.306
p-value		0.565	0.493	0.478	0.952	0.372	0.694
Correlation between population density and pooled country-year values	1.000	0.186	0.235	0.023	-0.119	0.035	-0.063
p-value		0.000	0.000	0.549	0.000	0.360	0.154

Source: Elaborated by authors.
Notes: *CPA* is potential land suitable for crop production. A_r is arable land. $A_{r\,adj}$ is A_r adjusted for quality: equivalent hectares of land well suited for rainfed crops. Capital is that used for crop production.

We now look at the paths the different countries follow to increase intensification. The first part of Table 4.5 presents the decomposition in levels of total output per hectare of potential agricultural land for countries grouped by quantile of population density, while the second part shows total growth for each component for the period 1995–2011. The differences in output per hectare of *TPA* observed in Table 4.5 can be explained, first, by looking at the crop and livestock components. The proportion of land suitable for crop production is similar across density groups, which means that on average there should not be significant differences between groups in the contribution of crop production to total output per hectare of potential land. We focus on crop production as it is the driver of growth and intensification in all groups.

What explains the differences in the observed levels of crop output per hectare of *CPA* between groups? Only a small part of the differences is explained by the level of crop output per hectare of harvested land. For instance, Y_c/A_h for G4 is $631 (dollar amounts in this and the subsequent paragraph are in 2004–2006 US$) while productivity of harvested land for G1 is $440, or 70 percent of G4's value. Conversely, crop output per hectare of potential arable land is only $24 for G1, or 7 percent of G4's value ($358). The differences between groups are explained by the proportion of potential arable land that is harvested (A_h/CPA) and by crop intensity measured by the ratio of harvested to arable land. There is a vast potential to expand crop production in G1 and G2 countries, where only 7 and 20 percent of land suited for crop production is utilized. These values increase to about 43 and 54 percent in groups G3 and G4, respectively. Differences in crop intensity (A_h/A_r) between groups are smaller, and they appear to be significant only between G4 and the rest (0.96 compared with 0.69 in G1 and 0.79 and 083 in G2 and G3, respectively).

Intensity in livestock production is mostly driven by the number of animals per hectare of *TPA* as differences in output per head of animal stock are small. Output per animal is $88 in G4 and $81 in G1, and it is highest in G3 at $96. On the other hand, the number of animals per hectare of *TPA* is 0.06 in G1 and increases with population density, reaching 0.51 in G4.

The growth rates of the different components of agricultural intensity are presented in the bottom half of Table 4.5. Countries in G1 and G2 increased production in recent years by incorporating new arable land to crop production and by increasing cropping intensity (the ratio of harvested to arable land). With less land available and A_h/A_r close to 1, G3 and G4 are better suited to increase production using land-saving technologies that result in output growth per hectare of harvested land.

Table 4.5 Decomposition of total output per hectare of potential agricultural land (2008–2011) and growth rates of its different components to growth during 1995–2011, countries grouped per quantile of population density

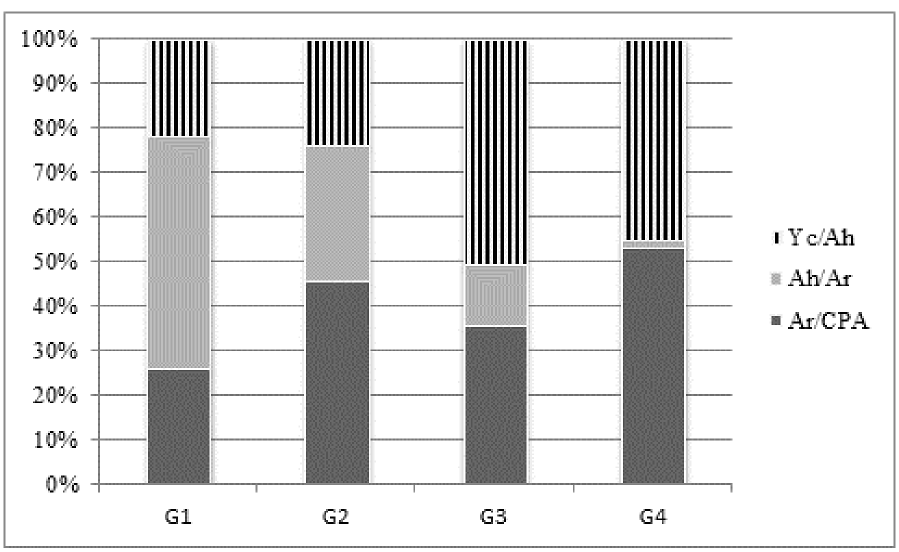
	Total	Crop contribution[a]						Livestock contribution		
Variable	*YT/ TPA*[b]	*Y_c/ TPA*	*CPA/ TPA*	*Y_c/ CPA*	*A_r/ CPA*	*A_h/ A_r*	*Y_c/ A_h*	*YL/ TPA*	*YL/ SK*	*SK/ TPA*
Yield (US$/hectare)										
G1	26	21	0.73	24	0.07	0.71	440	5	88	0.06
G2	80	66	0.70	81	0.20	0.79	475	14	83	0.16
G3	104	81	0.64	123	0.43	0.83	445	23	97	0.26
G4	286	245	0.71	358	0.52	0.96	631	42	81	0.51
Average	124	103	0.70	146	0.31	0.82	498	21	87	0.25
Growth rate (%)										
G1	54	61	-	60	12.67	25.41	11	31	-5	35.70
G2	34	30	-	30	8.35	5.54	4	61	23	21.83
G3	56	55	-	48	15.03	5.81	21	63	23	41.66
G4	68	68	-	74	29.84	0.86	25	70	7	55.11
Average	58	57	-	60	19.47	7.82	16	64	11	43.85

Source: Elaborated by authors.

Note: [a] Note that the product of (1 + growth rate) of A_h/CPA, A_h/A_r, and Y_c/A_h equals (1 + Y_c/CPA growth rate). [b] *YT* = total output in 2004–2006 US$; Y_c = crop output; *YL* = livestock output; *TPA* = total potential agricultural area; *CPA* = potential land suitable for crop production; A_h = harvested area; A_r = area under cultivation including annual and permanent crops and land fallowed for less than five years; *SK* = animal stock in cow-equivalents.

Figure 4.1 uses growth rates of the ratio of arable land used relative to potential arable land, cropping intensity, and output per hectare of harvested land from Table 4.5 to show the contribution of each of these variables to growth of output per hectare of potential cropland. The importance for G3 and G4 of increasing output per hectare (50 percent) and for G1 and G2 of cultivating more land and to increase cropping intensity (70 percent of total growth) is clear from the figure.

Figure 4.1 Contribution of new arable land, cropping intensity, and output per hectare of harvested area to growth of crop output per hectare of potential cropland by quantile of population density, 1995–2011



Source: Elaborated by authors.

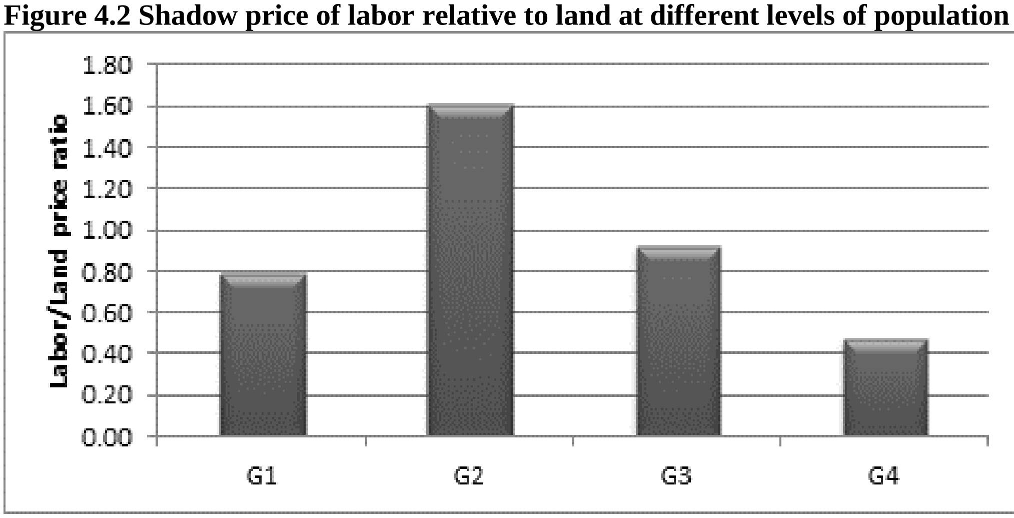
Notes: Y_c is crop output in 2004–2006 US$; *CPA* = potential land suitable for crop production; A_h = harvested area; A_r = area under cultivation, including annual and permanent crops and land fallowed for less than five years.

Based on Figure 4.1, we can determine the apparent intensification paths of SSA countries. At very low levels of population density, the main contribution to intensification comes from increasing cropping intensity, which is still low compared with other groups. Incorporation of new land to production and increasing yields show similar contributions (around 20 percent of total growth).

Several factors could explain differences in the rate at which new land is brought into production between G1 and G2. For example, very low densities and remoteness could play a role in countries in forest-based production systems and in some of the large semiarid countries in G1. Using available land next to roads and population centers more intensively could be the strategy when infrastructure is poor and returns to public investments are low. With higher population pressure, the contribution of new land to production increases as is the case in G2, reducing the contribution of increased cropping intensity but keeping the contribution of yields at a similar level as in G1. When population density reaches 0.5 persons per hectare as in G3, the contribution of yields suddenly jumps from 20 to 50 percent and the importance of cropping intensity reduces substantially. At the highest levels of population density, the contribution of cropping intensity becomes insignificant but the contribution of yields remains at about 50 percent. Incorporation of new arable land still plays a significant role, increasing production even at high levels of population density.

These patterns of intensification should be reflected in the relative prices of land and labor at different levels of population density. To check this we use shadow prices from the solution of linear programming problems used to calculate technical efficiency as in Charnes, Cooper, and Rhodes (1978) (Figure 4.2). Shadow prices clearly reflect the relative abundance of land and labor in G2, G3, and G4. The price of labor in G2 is four times greater than in G4, 80 percent greater than in G3, and two times greater than in G1. Notice that the high relative price of labor in G2 corresponds to the highest contribution among all groups of incorporation of new land as the main driver of intensification. Relatively low shadow prices in G1 are more difficult to interpret but correspond to a lesser importance of the incorporation of new land to production, as shown in Figure 4.1. Very low population densities, remoteness, and low land productivity associated with poor infrastructure could play a role as mentioned before. This could suggest the existence of a population density threshold for the incorporation of new land to production as a significant driver of intensification as happens in G2.

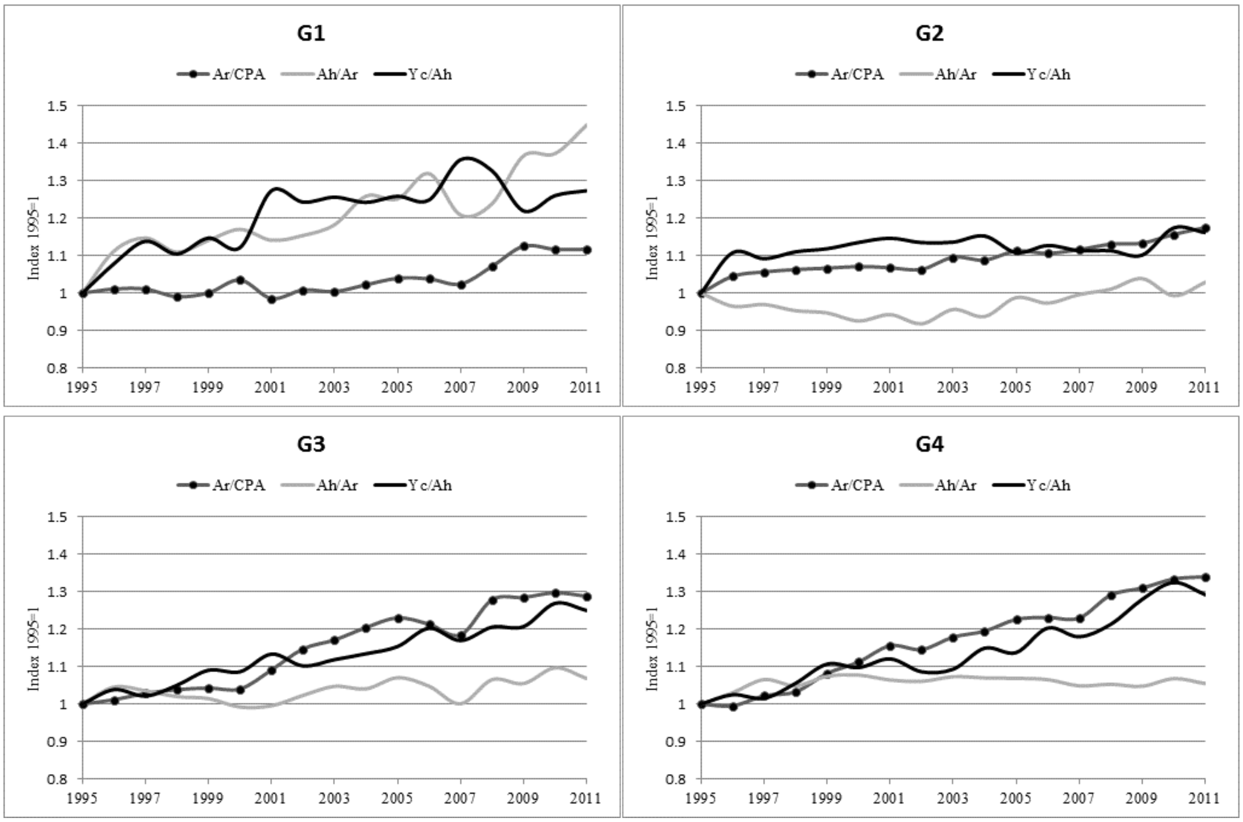
Figure 4.2 Shadow price of labor relative to land at different levels of population density



Source: Elaborated by authors.
Note: Shadow prices are obtained from linear programming problems used to calculate technical efficiency (see Charnes, Cooper, and Rhodes 1978).

Figure 4.3 complements Figure 4.1 as it shows the evolution of the contribution of different factors to output per hectare of *CPA* in crop production. The contrast between G1 and the other three groups is clear. Cropping intensity and yields are the main drivers of intensification in G1. In all other groups, the curve for cropping intensity shows little growth and is replaced by the incorporation of new arable land to production (A_r/CPA), including G4.

Figure 4.3 Patterns of the contribution of different components to growth of total crop output per hectare of potential cropland by quantile of population density



Source: Elaborated by authors.
Notes: Y_c is crop output in 2004–2006 US$; *CPA* = potential land suitable for crop production; A_h = harvested area; A_r = area under cultivation, including annual and permanent crops and land fallowed for less than five years.

According to these results, between 1995 and 2011, countries in G1 and G2 increased output following a "land-abundant" path that includes (a) more land incorporated to crop production and (b) increased cropping intensity through reducing fallow periods or double cropping, or both. Beyond densities of 0.5 people per hectare of potential agricultural land, the contribution of yields substantially increases. What is still puzzling is the persistence of the contribution of new land to production even at the highest levels of population density. We provide more information on these issues by looking at the intensification paths followed by individual countries.

Table 4.6 shows the structure of intensity of all countries, while Figure 4.4 decomposes the contribution of increased arable land, cropping intensity, and yields to growth in crop intensity, as in Figure 4.1, but in this case at the country level. The importance of incorporating new land to production even at high levels of population density is clear in Q4. Six countries show a contribution of about 40 percent or more to crop production coming from incorporating arable land, including Rwanda, the country with the highest population density. The exceptions are Burundi with less than 10 percent contribution of new land and Swaziland with no arable land incorporated to production. Kenya is an intermediate case with a contribution of about 20 percent of new land to growth.

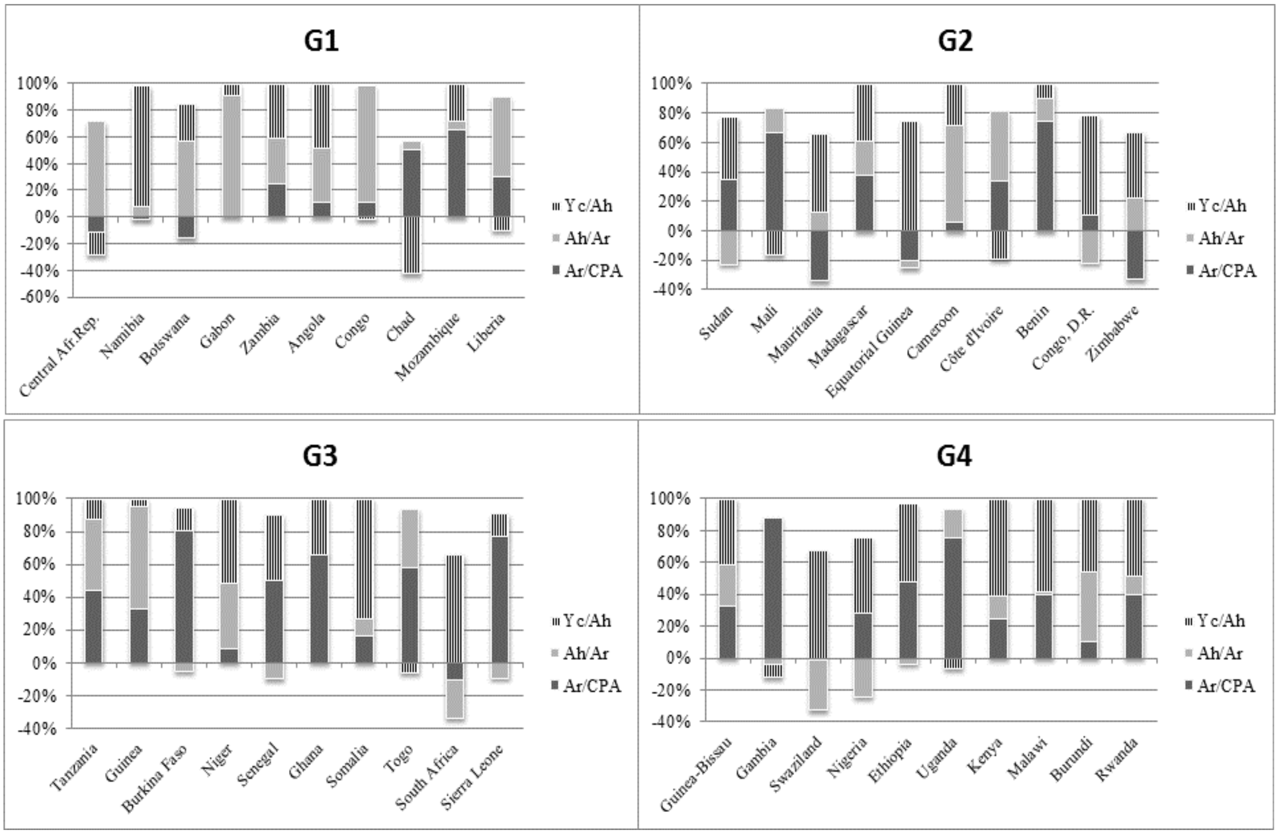
Table 4.6 Decomposition of total output per hectare of potential agricultural land (2008–2011) and contribution of its different components to growth during 1995–2011, by country

			Crop contribution[a]						Livestock contribution		
	Country	***YT/ TPA***[b]	***CPA/ TPA***	***Y_c/ TPA***	***Y_c/ CPA***	***A_r/ CPA***	***A_h/ A_r***	***Y_c/ A_h***	***YL/ TPA***	***YL/ SK***	***SK/ TPA***
G1	Central African Republic	16	0.98	9	9	0.04	0.49	488	7	69	0.10
	Namibia	4	0.20	1	3	0.06	0.46	100	4	82	0.05
	Botswana	4	0.17	0	1	0.03	0.71	60	4	62	0.06
	Gabon	67	0.94	62	66	0.15	0.51	854	5	92	0.05
	Zambia	23	0.93	17	18	0.06	0.58	498	6	94	0.07
	Angola	38	0.86	32	37	0.06	1.00	615	6	85	0.07
	Congo	26	0.99	23	23	0.05	0.61	749	3	75	0.04
	Chad	14	0.43	9	20	0.12	0.79	213	6	47	0.12
	Mozambique	30	0.91	25	27	0.08	1.04	313	5	124	0.04
	Liberia	35	0.91	31	33	0.07	0.90	514	4	148	0.03
G2	Sudan	56	0.55	16	29	0.18	0.66	241	39	119	0.32
	Mali	40	0.36	24	66	0.21	0.87	359	16	95	0.17
	Mauritania	12	0.04	2	38	0.28	0.82	169	10	72	0.14
	Madagascar	59	0.75	45	61	0.10	0.88	697	14	72	0.20
	Equatorial Guinea	31	0.79	29	37	0.20	0.46	405	1	80	0.01
	Cameroon	151	0.87	130	150	0.29	0.77	671	21	86	0.24
	Côte d'Ivoire	182	0.99	175	175	0.25	1.02	676	7	79	0.09
	Benin	195	0.99	182	184	0.27	0.92	735	14	54	0.25
	Congo, D.R.	31	0.93	30	32	0.08	0.84	485	1	72	0.02
	Zimbabwe	44	0.76	27	35	0.16	0.70	312	17	99	0.17
G3	Tanzania	91	0.93	69	73	0.20	0.96	388	22	69	0.32
	Guinea	64	0.59	52	88	0.25	0.96	367	11	48	0.23
	Burkina Faso	97	0.96	68	71	0.25	1.04	271	29	57	0.51
	Niger	39	0.20	19	94	1.16	1.06	76	20	80	0.24
	Senegal	82	0.74	62	81	0.31	0.71	365	21	65	0.32
	Ghana	299	0.97	285	294	0.37	0.89	898	14	84	0.16
	Somalia	27	0.04	2	66	0.50	0.72	181	24	90	0.27
	Togo	157	0.96	134	140	0.54	0.63	409	23	91	0.25
	South Africa	109	0.21	51	239	0.53	0.41	1100	58	318	0.18
	Sierra Leone	77	0.80	68	86	0.23	0.96	395	8	68	0.12
G4	Guinea-Bissau	130	0.79	104	130	0.32	0.91	446	26	59	0.44
	Gambia	134	0.92	113	120	0.49	0.97	254	21	41	0.52
	Swaziland	169	0.63	127	203	0.19	0.80	1331	42	95	0.44
	Nigeria	344	0.89	306	341	0.52	1.04	634	39	91	0.42
	Ethiopia	43	0.39	30	77	0.34	0.95	240	12	23	0.53
	Uganda	304	0.93	245	262	0.52	0.87	579	59	105	0.57
	Kenya	120	0.38	62	164	0.31	0.84	628	57	130	0.44
	Malawi	358	0.88	323	366	0.54	1.02	662	35	113	0.31
	Burundi	353	0.77	326	427	0.73	0.93	629	27	56	0.47
	Rwanda	906	0.54	810	1488	1.29	1.27	902	96	100	0.96

Source: Elaborated by authors.

Notes: [a] Note that the product of (1 + growth rate) of A_h/CPA, A_h/A_r, and Y_c/A_h equals (1 + Y_c/CPA growth rate). [b] YT = total output in 2004–2006 US$; Y_c = crop output; YL = livestock output; TPA = total potential agricultural area; CPA = potential land suitable for crop production; A_h = harvested area; A_r = area under cultivation including annual and permanent crops and land fallowed for less than five years; SK = animal stock in cow-equivalents.

Figure 4.4 Contribution of new arable land, cropping intensity, and output per hectare of harvested area to growth of crop output per hectare of potential cropland by country and quantile of population density, 1995–2011



Source: Elaborated by authors.
Notes: *YC* is crop output in 2004–2006 US$; *CPA* = potential land suitable for crop production; A_h = harvested area; A_r = area under cultivation including annual and permanent crops and land fallowed for less than five years.

We observe a similar pattern in G3 in terms of the importance of the incorporation of new land to crop production. Note that the contribution of new land is particularly high in West African countries (Burkina Faso, Ghana, Togo, and Senegal). There is more variability than in G4 in the contribution of yields, and there is still a significant contribution of cropping intensity, especially in the countries with the lowest population density levels within the group.

Expected patterns are observed in G1 and G2 countries. Large low-density countries with forest-based production systems like Central African Republic, Congo, and Gabon and arid low-density Botswana and Namibia increase crop intensity (A_h/A_r) instead of bringing new land to production. The contribution of new arable land increases in countries with the highest population density in G1 (Chad, Mozambique, and Liberia), and it extends to countries in G2 with exceptions such as Mauritania, a country with very limited possibilities to expand cropped area, an outlier in agricultural production like Equatorial Guinea, and the cases of Congo, D.R. and Zimbabwe (probably related to political conflict in those countries).

5. INTENSIFICATION AND FERTILIZER USE

Analysis in previous sections shows that the framework developed by Boserup, Ruthenberg, and others with a focus on population density is a powerful tool to explain agricultural growth and intensification in Africa. Although the overall results obtained can be explained by the conceptual framework used in this study, some puzzling issues with policy implications remain. The most important of these is fertilizer use and its low correlation with population density in the Africa context. Table 4.4 shows no correlation between fertilizer use per hectare of arable land and population density. On the other hand, it does report a significant but low correlation between population density and fertilizer per hectare of potential cropland. A possible interpretation of this relation is that population pressure on natural resources increases fertilizer use but not necessarily the amount used per hectare of arable land. In other words, and as it happens with other inputs, incorporating more land to production could increase overall fertilizer use but at the same rates of application per hectare of arable land.

Table 5.1 depicts the correlation between two measures of fertilizer use per hectare and the different factors contributing to intensification in crop production. A comparison of the overall correlation of the two fertilizer measures with the different variables shows that fertilizer per hectare of *CPA* is correlated with population density, with crop output per hectare of *CPA,* with arable land use per hectare of *CPA*, and with output per hectare of harvested area. We see a similar correlation pattern in the case of fertilizer per hectare of arable land except that no correlation exists with the proportion of arable land used.

Table 5.1 Correlation coefficients of different components of intensification and fertilizer use

	Fertilizer/*CPA*					Fertilizer/A_r				
Variable	**G1**	**G2**	**G3**	**G4**	**All**	**G1**	**G2**	**G3**	**G4**	**All**
Population density	-0.05	0.25	0.45	0.01	0.18	-0.18	0.27	0.40	-0.33	0.02
p-value	0.49	0.00	0.00	0.92	0.00	0.02	0.00	0.00	0.00	0.55
Y_c/CPA	0.22	0.31	0.69	0.08	0.30	-0.24	0.11	0.67	-0.27	0.12
p-value	0.00	0.00	0.00	0.29	0.00	0.00	0.14	0.00	0.00	0.00
A_r/CPA	0.30	0.26	0.19	-0.01	0.29	-0.19	0.02	0.12	-0.46	0.05
p-value	0.00	0.00	0.01	0.94	0.00	0.01	0.83	0.11	0.00	0.22
A_h/A_r	-0.15	0.31	-0.71	0.13	-0.04	-0.15	0.23	-0.66	-0.26	-0.09
p-value	0.04	0.00	0.00	0.09	0.24	0.05	0.00	0.00	0.00	0.02
Y_c/A_h	0.11	0.08	0.71	0.18	0.37	-0.22	0.01	0.72	0.45	0.37
p-value	0.15	0.27	0.00	0.02	0.00	0.00	0.91	0.00	0.00	0.00

Source: Elaborated by authors.

Notes: Y_c is crop output in 2004–2006 US\$; *CPA* = potential land suitable for crop production; A_h = harvested area; A_r = area under cultivation, including annual and permanent crops and land fallowed for less than five years.

Focusing on the values of fertilizer/*CPA* in Table 5.1, we observe that correlations within groups show some contrasting patterns. First, no correlation exists between population density and fertilizer per hectare within the two extreme groups (G1 and G4). Within G1, high levels of fertilizer use are related to the proportion of arable land use relative to *CPA* but not to yields. In the case of G4 the opposite is observed: the proportion of arable land used is not correlated with fertilizer use, but higher yields are expected in countries with high levels of fertilizer use. There are also some interesting contrasts between G2 and G3. As in G1, fertilizer use in both groups is correlated to the proportion of potential arable land being used, but yields relate to fertilizer use only in G3. The role of cropping intensity is also different in G2 and G3 as it is positively correlated with fertilizer use in G2 and high and negatively correlated with fertilizer use in G3.

The analysis so far has shown that we expect to observe higher yields in high-density countries in SSA (those in G3 and G4) and that yields should be correlated with relatively high levels of fertilizer use per hectare. So what explains the observed variability between population density, output per hectare, and fertilizer use among these countries? Table 5.2 shows population densities, output per hectare of harvested land, and fertilizer per hectare of arable land sorted by output per hectare. On average, Rwanda, Burundi, Uganda, and Nigeria employ less than 4 kilograms of fertilizer per hectare with a population density of 3 people per hectare compared with 22 kilograms in Malawi, Kenya, and Ethiopia. Why do countries with the highest levels of population density like Rwanda, Burundi, Uganda, and Nigeria use low levels of fertilizer compared with other countries in the same range of population density? Why do some countries in G1 and G2 use relatively high levels of fertilizer producing more output per hectare of potential agricultural land (Zambia, Botswana, Mali, Côte d'Ivoire, and Zimbabwe)? Why do Burkina Faso and Senegal use twice as much fertilizer as other countries in G3?

Table 5.2 Population densities, output per hectare of harvested land, and fertilizer per hectare of arable land (1995–2011)

Quantile	Country	Population	Output per	Fertilizer per
G1	Central African Republic	0.047	483	0.3
	Namibia	0.068	91	1.1
	Botswana	0.078	68	17.5
	Gabon	0.104	807	5.4
	Zambia	0.115	451	14.7
	Angola	0.117	443	4.1
	Congo	0.127	754	4.7
	Chad	0.139	248	4.0
	Mozambique	0.183	307	2.8
	Liberia	0.198	569	0.5
G2	Sudan	0.202	237	3.6
	Mali	0.239	376	10.9
	Mauritania	0.257	148	6.5
	Madagascar	0.263	631	2.9
	Equatorial Guinea	0.294	335	0.0
	Cameroon	0.297	610	5.7
	Côte d'Ivoire	0.329	735	11.1
	Benin	0.360	730	7.7
	Congo, D.R.	0.364	497	0.6
	Zimbabwe	0.373	394	26.0
G3	Tanzania	0.412	365	3.1
	Guinea	0.448	372	1.0
	Burkina Faso	0.448	274	9.4
	Niger	0.503	67	0.4
	Senegal	0.515	325	7.6
	Ghana	0.516	772	4.5
	Somalia	0.606	162	0.5
	Togo	0.611	420	6.0
	South Africa	0.659	919	55.4
	Sierra Leone	0.675	329	1.1
G4	Guinea-Bissau	0.759	379	3.6
	Gambia	0.980	274	5.9
	Swaziland	1.005	1237	33.7
	Nigeria	1.065	547	7.7
	Ethiopia	1.128	195	14.3
	Uganda	1.181	588	1.2
	Kenya	1.190	543	25.4
	Malawi	1.463	508	25.3
	Burundi	4.189	605	1.7
	Rwanda	5.571	671	4.6

Source: Elaborated by authors.

As developing a model explaining fertilizer use in SSA is beyond the scope of this study, we compare the mean values of several variables that are expected to be related to fertilizer use (and in general to intensification). These are variables representing the importance of the market faced by the country (domestic and international), infrastructure, and quality of natural resources. A "tropicality" index (TI) that intends to capture agroecological conditions for production in different countries is calculated as output of root crops and fruits divided by cereal output. A high TI is an indicator of relative advantage of the country to produce root crops, fruits, and other tropical tree crops typical of tree-crop, forest-based, and cereal-root-crop-mixed production systems (as defined by Dixon, Gulliver, and Gibbon 2001). As root and tree crops in Africa respond less to fertilizer and are expected to benefit less than cereals from research and development (R&D) spillovers, we expect a high TI to be associated with low levels of fertilizer use.

We look first at the differences in fertilizer use among countries in G4, the group of high-population-density countries. Table 5.3 shows the variables expected to affect fertilizer use for the four countries using the lowest levels of fertilizer in the group: Burundi, Rwanda, Uganda, and Nigeria. The values of the different variables for these three countries are compared with the average values of the rest of the group. A two-sample *t*-test is included to check for statistically significant differences between the means of the two groups. With better infrastructure (positive and significant difference in road density and negative and significant difference in travel time), better quality of natural resources (larger proportion of high-quality land for crop production in total agricultural area), a larger domestic market, and a higher population density than the rest of the group, we expect Burundi, Rwanda, Uganda, and Nigeria to be using more fertilizer than what they are actually using. No significant differences between groups were found in income per capita, urbanization, and R&D investment. On the other hand, countries using low fertilizer levels export less than other countries (not surprising as three of the four countries in the group are landlocked), and according to the TI index, those countries are also producers of root crops, fruits, and tree crops rather than cereals. It is possible then that differences in agroecology could be part of the explanation of the differences in fertilizer use between groups.

Table 5.3 Variables expected to affect fertilizer use showing countries with high population density and low fertilizer use (all countries in G4)

Variable	Burundi	Rwanda	Uganda	Nigeria	Average	Rest of G4
Fertilizer/hectare	1.5	11.9	2.1	12.0	6.9	19.6
Population density	4.2	5.6	1.2	1.1	3.0	1.1
Tropicality index[a]	12.1	14.4	5.8	3.6	9.0	1.5
Income per capita	392	940	1064	1775	1043	1308
Market size[b]	266	2500	283	2084	1283	786
% of urban population	10.5	18.5	13.1	48.7	22.7	27.6
Exports/output	0.1	0.1	0.1	0.0	0.1	0.4
Road density	6.2	7.3	5.1	2.2	5.2	2.6
Travel time[c]	4.7	4.7	4.5	3.5	4.4	6.2
R&D intensity[d]	2.6	0.8	1.8	2.5	1.9	1.9
Potential arable land [e]	0.8	0.5	0.9	0.9	0.8	0.7

Table 5.3 Continued

Ratios Average/Rest of G4						Two-sample *t*-test	
	Burundi	Rwanda	Uganda	Nigeria	Average	*t*-value[f]	*p*-value
Fertilizer/hectare	0.08	0.61	0.11	0.61	0.35	-5.1382	0.000
Population density	3.85	5.12	1.09	0.98	2.76	6.2399	0.000
Tropicality index	7.95	9.45	3.81	2.36	5.89	9.993	0.000
Income per capita	0.30	0.72	0.81	1.36	0.80	-1.2168	0.229
Market size	0.34	3.18	0.36	2.65	1.63	2.2223	0.030
% of urban population	0.38	0.67	0.47	1.76	0.82	-1.3998	0.166
Exports/output	0.18	0.15	0.26	0.05	0.16	-4.8893	0.000
Road density	2.36	2.75	1.94	0.85	1.97	6.7229	0.000
Travel time	0.77	0.75	0.73	0.57	0.70	-3.8666	0.000
R&D intensity	1.39	0.45	0.96	1.33	1.03	-0.0142	0.989
Potential arable land	1.15	0.82	1.40	1.34	1.18	3.2045	0.002

Source: Elaborated by authors.
Notes: [a] Measured as the ratio of outputs of different crops: TI = (cassava + other roots + fruits)/(maize + millet + rice + sorghum). [b] (Urban population×GDP per capita/cropland equivalent. [c] Travel time to towns of 50,000 people. [d] Public expenditure in agricultural R&D per hectare of quality-adjusted cropland. [e] Ratio of potential land suitable for crop production to total potential agricultural area: *CPA*/*TPA*. [f] *t*-statistics for a *t*-test of the differences between means: * difference is significant at the 1% level; ** significant at the 0.1% level.

Table 5.4 shows the case of higher fertilizer use by Burkina Faso and Senegal in G3. These countries employ on average 8 kilograms of fertilizer nutrients per hectare compared with only 2 kilograms in other countries in the group.

Table 5.4 Variables expected to affect fertilizer use showing countries with intermediate levels of population density and high fertilizer use (all countries in G3)

Variable	Burkina Faso	Senegal	Average	Rest of G3	
Fertilizer/hectare	10.78	5.51	8.14	2.31	
Population density	0.45	0.52	0.48	0.54	
Tropicality index[a]	0.05	0.56	0.30	2.22	
Income per capita	900	1444	1172	901	
Market size[b]	167	769	468	549	
% of urban population	24	42	33	35	
Exports/output	0.12	0.16	0.14	0.10	
Road density	1.62	1.56	1.59	1.89	
Travel time[c]	4.07	3.64	3.86	6.67	
R&D intensity[d]	0.37	1.10	0.73	0.55	
Potential arable land[e]	0.56	0.32	0.44	0.34	
Ratios Average/Rest of G3				**Two-sample *t*-test**	
	Burkina Faso	**Senegal**	**Average**	***t*-test[f]**	***p*-value**
Fertilizer/hectare	4.67	2.39	3.53	11.78	0.0000
Population density	0.83	0.96	0.89	-3.66	0.0003
Tropicality index	0.02	0.25	0.14	-3.58	0.0005
Income per capita	1.00	1.60	1.30	3.60	0.0004
Market size	0.30	1.40	0.85	-0.93	0.3524
% of urban population	0.70	1.20	0.95	-1.04	0.3020
Exports/output	1.20	1.58	1.39	2.99	0.0033
Road density	0.86	0.83	0.84	-1.59	0.1148
Travel time	0.61	0.55	0.58	-4.44	0.0000
R&D intensity	0.68	2.00	1.34	4.68	0.0000
Potential arable land	1.64	0.93	1.28	2.06	0.0410

Source: Elaborated by authors.
Notes: [a] Measured as the ratio of outputs of different crops: TI = (cassava + other roots + fruits)/(maize + millet + rice + sorghum). [b] (Urban population×GDP per capita)/cropland equivalent. [c] Travel time to towns of 50,000 people. [d] Public expenditure in agricultural R&D per hectare of quality-adjusted cropland. [e] Ratio of potential land suitable for crop production to total potential agricultural area: *CPA*/*TPA*. [f] *t*-statistics for a *t*-test of the differences between means: * difference is significant at the 1% level; ** significant at the 0.1% level.

Income per capita, exports, R&D investment, and travel time to towns of 50,000 or more are significantly different from those in other countries in G3 and contribute to explain differences in fertilizer use between groups. On the other hand, Burkina Faso and Senegal have poorer infrastructure and a lower population density than other countries in the group, factors expected to have a negative effect on the use of fertilizer. No significant differences were found in urbanization and in the size of the domestic market. As in the previous case, the TI is significantly lower for these two countries—probably related to the fact that the savannah agroecology, more favorable to produce cereals and cash crops, will demand higher levels of fertilizer for production.

The last case is the one of relatively high levels of fertilizer use among low-density countries and is presented in Table 5.5. The table shows that Botswana, Côte d'Ivoire, Mali, Zambia, and Zimbabwe use on average 15 kilograms of fertilizer compared with only 4 among other countries in groups 1 and 2. Even without including Botswana, which could be seen as an outlier in this group of countries, average fertilizer use is 12 kilograms, significantly higher than in the rest of the group. Both groups show similar population densities, income per capita, market size, urbanization, and infrastructure. Conversely, high fertilizer users have less potential for agricultural production as the potential area suitable for crop production is smaller than in the group of low fertilizer users (the difference is not highly significant). Factors that appear to favor fertilizer use are a low TI index and a higher share of exports in total production.

Table 5.5 Variables expected to affect fertilizer use showing countries with low population density and high fertilizer use (all countries in G1 and G2)

Variable	Botswana	Côte d'Ivoire	Mali	Zambia	Zimbabwe	Average	Rest of G1 and G2	
Fertilizer/hectare	18.98	9.60	8.04	13.00	8.02	11.53	3.68	
Population density	0.08	0.33	0.24	0.12	0.37	0.23	0.19	
Tropicality index[a]	0.02	7.44	0.20	0.52	0.62	1.76	9.24	
Income per capita	10022	1284	951	1377	310	2789	2459	
Market size[b]	2292	459	196	127	72	629	869	
% of urban population	60.00	49.43	34.69	35.48	37.52	43.43	45.27	
Exports/output	0.92	0.58	0.07	0.00	0.34	0.38	0.15	
Road density	0.58	2.57	0.36	2.42	3.39	1.86	2.08	
Travel time[c]	14.23	4.32	13.97	10.68	4.99	9.64	9.85	
R&D intensity[d]	2.16	0.91	0.48	0.09	1.34	1.00	0.66	
Potential arable land [e]	0.03	0.68	0.17	0.53	0.33	0.35	0.44	
Ratios Average/Rest of G1 and G2							**Two-sample *t*-test**	
	Botswana	**Côte d'Ivoire**	**Mali**	**Zambia**	**Zimbabwe**	**Average**	***t*-value[f]**	***p*-value**
Fertilizer/hectare	5.162	2.610	2.186	3.535	2.182	3.135	9.835	0.0000
Population density	0.401	1.690	1.225	0.592	1.918	1.165	1.737	0.0847
Tropicality index	0.002	0.805	0.021	0.056	0.067	0.190	-2.989	0.0033
Income per capita	4.076	0.522	0.387	0.560	0.126	1.134	0.533	0.5951
Market size	2.636	0.528	0.225	0.146	0.083	0.723	-0.903	0.3684
% of urban population	1.325	1.092	0.766	0.784	0.829	0.959	-0.686	0.4937
Exports/output	6.098	3.865	0.478	0.000	2.234	2.535	5.912	0.0000
Road density	0.280	1.236	0.176	1.164	1.629	0.897	-0.645	0.5199
Travel time	1.445	0.439	1.418	1.085	0.507	0.979	-0.287	0.7747
R&D intensity	3.254	1.373	0.731	0.143	2.030	1.506	1.238	0.2197
Potential arable land	0.075	1.547	0.394	1.202	0.759	0.795	-1.988	0.0489

Source: Elaborated by authors.

Notes: [a] Measured as the ratio of outputs of different crops: TI = (cassava + other roots + fruits)/(maize + millet + rice + sorghum). [b] (Urban population×GDP per capita)/cropland equivalent. [c] Travel time to towns of 50,000 people. [d] Public expenditure in agricultural R&D per hectare of quality-adjusted cropland. [e] Ratio of potential land suitable for crop production to total potential agricultural area: *CPA*/*TPA*. [f] *t*-statistics for a *t*-test of the differences between means: * difference is significant at the 1% level; ** significant at the 0.1% level.

The recurrence of significant differences in the tropicality index between high and low fertilizer users suggests that production systems and the agroecology play an important role in the low fertilizer use in Africa, ceteris paribus. We expect lower levels of fertilizer use in root- and tree-crop-based systems relative to cereal-based systems. Table 5.6 shows a comparison of the means of fertilizer per hectare in countries grouped by farming system as defined by Dixon, Gulliver, and Gibbon (2001) showing that this is a plausible hypothesis. The biggest difference in the use of fertilizer between maize-mixed systems and others occurs with root and tree crop systems.[6]

Table 5.6 Comparison of average values of fertilizer use per hectare between the maize-mixed system and other production systems (2005–2011)

Variable	Coefficient	Standard error	*t*-statistics	*P > t*
Cereal-root crops[a]	-16.9	4.94	-3.42	0.002
Tree crops[b]	-16.9	6.51	-2.60	0.014
Forest based	-16.8	7.17	-2.34	0.026
Highland[c]	-12.7	7.17	-1.77	0.086
Pastoral[d]	-14.3	5.12	-2.79	0.009
Constant term	21.7	3.93	5.52	0.000

Number of observations	= 39
F(5, 33)	= 2.75
Prob > F	= 0.03
R-squared	= 0.29
Adj. *R*-squared	= 0.19
Root MSE	= 10.39

Source: Elaborated by authors.

Note: Farming systems defined in Dixon, Gulliver, and Gibbon (2001). Results are differences with respect to mean fertilizer per hectare in the maize-mixed system. [a] Root crops and cereal-root-crops-mixed. [b] Rice-tree crops and root-crops-tree-crops. [c] Highland temperate mixed and highland perennial. [d] Pastoral and agro-pastoral millet/sorghum.

Where in SSA can we expect good agroecological conditions for a cereal Green Revolution? Table 5.7 shows the distribution of total land in SSA suited to crop production by country and two groups of farming systems. We assume that maize-mixed systems and those of temperate highlands are the ones with a comparative advantage for cereal production. Of the total land suited for crop production in SSA (under cultivation or not), 18 percent is advantageous for cereal production. About 70 percent of that land is located in five countries—Tanzania, Ethiopia, Zambia, Zimbabwe, and Mozambique; 95 percent is located in 10 countries (including Kenya, Uganda, Sudan, Congo, D.R., and Malawi).

We conclude that the agroecological conditions for the expansion of a package of high-yielding cereal varieties and fertilizer are limited, and even when those conditions are met, differences in relative prices and in economic and institutional constraints will require different technological packages adapted to the needs of the different countries. At low levels of population density, agricultural output and labor productivity result from increased cropping intensity and incorporation of new land to production, with relatively low contribution of increased land productivity. With high population density, the contribution of land productivity increases, but that is not necessarily related to fertilizer technologies but to production systems based on crops (tree and root crops) that use land more intensively and are less responsive than cereals to fertilizer.

[6] Gibson, Gulliver and Gibbon (2001) defined 15 broad farming systems: Irrigated; Tree crop; Forest based; Rice-Tree Crop; Highland perennial; Highland temperate mixed; Root crop; Cereal-root crop mixed; Maize mixed; Large commercial and smallholder; Agropastoral millet/sorghum; Pastoral; Sparse (arid); Coastal artisanal fishing; and Urban based.

Table 5.7 Total land suitable for crop production under maize-mixed and temperate highland systems compared with other systems by country

Country	Maize-mixed (MM) and temperate highlands (TH) Crop area	Maize-mixed (MM) and temperate highlands (TH) Population density	Other systems Crop area	Other systems Population density	Total crop area	% MM-TH
Tanzania	42,800	0.34	24,200	0.51	67,000	63.9
Ethiopia	28,000	0.95	18,500	0.38	46,500	60.2
Zambia	28,000	0.15	28,500	0.09	56,500	49.6
Zimbabwe	21,100	0.32	5,557	0.12	26,657	79.2
Mozambique	15,600	0.15	48,600	0.24	64,200	24.3
Kenya	13,100	1.12	6,692	0.21	19,792	66.2
Uganda	10,900	1.09	6,267	2.03	17,167	63.5
Sudan	10,100	0.07	95,200	0.13	105,300	9.6
Congo, D.R.	8,080	0.24	87,200	0.26	95,280	8.5
Malawi	5,666	1.35	1,156	2.30	6,822	83.1
South Africa	4,908	0.72	19,200	0.15	24,108	20.4
Angola	1,477	0.45	70,300	0.06	71,777	2.1
Central African Republic	983	0.00	48,100	0.05	49,083	2.0
Swaziland	975	0.66	23	0.45	998	97.7
Namibia	605	0.10	13,900	0.02	14,505	4.2
Cameroon	247	0.36	25,600	0.25	25,847	1.0
Nigeria	213	0.43	74,000	0.96	74,213	0.3
Lesotho	142	0.66	23	1.04	165	86.4
Botswana	16	0.03	8,105	0.02	8,122	0.2
Other	-	-	277,700	0.57	277,700	0.0
Total	192,913	0.48	858,823	0.53	1,051,736	18.3

Source: Elaborated by authors.

6. SUMMARY AND CONCLUSIONS

This study proposes a set of indicators that uses information on available agricultural land and land suitability to measure intensity of land use in agricultural production. The indicators are used to assess the patterns of agricultural intensification in 40 countries in SSA, their evolution in recent years, and the changes in output composition and input use associated with different intensification patterns. In particular, we look at the use of fertilizer and the role it played in the different intensification paths followed by SSA countries. No definitive conclusions can be reached with the simple cross-country comparisons in this study, but our results suggest some hypotheses that could be tested with more detailed information at the country level by future studies. Our findings show that half of the countries in our sample, those with low population densities, followed a clear land-abundant intensification path, with output growth driven by new land incorporated to crop production and increased cropping intensity resulting from the reduction of fallow periods and increased double cropping. High-population-density countries, on the other hand, show a substantial contribution of land productivity to output growth.

Although these results confirm that the framework developed by Boserup, Ruthenberg, and others is a powerful tool to explain patterns of agricultural intensification in Africa, some of our findings are still a puzzle. The most important of those is the low observed correlation between intensity of input use, in particular of fertilizer, and population density. Our findings show clear patterns in the use of fertilizer per hectare between population density groups and large variability in the use of fertilizer within population density groups. At low population densities, population pressure on natural resources increases fertilizer use but not necessarily fertilizer intensity per hectare of arable land, with no correlation between fertilizer use and output per hectare at these density levels. In other words, in low-population-density countries fertilizer seems to be an instrument for land expansion and not for yield increases. On the other hand, at high levels of population density, the correlation between land productivity and fertilizer use is positive but low, with high variability in fertilizer use between countries. A possible explanation for this variability is that incorporating new land into production is still a significant driver of output growth among high-density countries. A second possible explanation seems to be related to production systems and agroecology as root and tree crop systems demand lower levels of fertilizer than cereal-based systems. The importance of root and tree crop production systems in Rwanda, Burundi, Uganda, and Nigeria, the countries with the highest levels of population density in SSA, could explain the relatively low level of fertilizer use in these countries compared with its use in Malawi, Kenya, and Ethiopia. According to our results, of the total land suited for crop production in SSA (under cultivation or not), only 18 percent is better suited for cereals than for root and tree crops, with 70 percent of that land located in five countries: Tanzania, Ethiopia, Zambia, Zimbabwe, and Mozambique.

The policy implications of these results are significant. First, the agroecological possibilities for an Asian-style Green Revolution are limited, and low population densities in regions with advantages for cereal production do not make the Green Revolution technology attractive unless it is complemented by capital investments that increase labor productivity. The best possibilities of success for the fertilizer technology package are in Ethiopia, Kenya, Uganda, and Malawi, countries with more than 60 percent of potential agricultural land in favorable agroecologies and high population densities in those areas. For other cereal-producing countries, the best strategy seems to be the promotion of labor-saving technologies that accelerate the incorporation of new land to production and create incentives for increased fertilizer use in the future as the countries approach their land frontier. Finally, for the 60 percent of land under root crop, tree crop, perennial highlands, and forest-based systems, Africa will need to develop its own Green Revolution, one that increases output of root crops and tree crops in the most productive agroecologies. This strategy will require more investment in agricultural R&D as international spillovers for such crops and ecologies are expected to be smaller than those for cereals. It will also require opening new markets, especially for staple crops like cassava that are nontradable and constrained to small domestic markets.

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