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Transforming African Agriculture by Promoting Improved Technology and Management Practices

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Fundamental source of agricultural transformation is technological change or innovation, which accompanies the introduction of modern agricultural technology and improved cultivation practices in the context of developing countries, such as sub-Saharan Africa (SSA). Markets fail to generate and disseminate modern agricultural technology in a socially optimum manner because technological knowledge is often public goods. Thus, appropriate government intervention is necessary to achieve desirable technological change in agriculture. The critical questions are what kinds of crops are promising in SSA, what kind of agricultural technology is needed, and what kind of government intervention is desired. Based on the literature review and new statistical evidence, this study attempts to identify the promising crops, required technologies to realize major productivity gains, and desirable government policies. In short, the purpose of this study is to design a strategy to transform agriculture in SSA by means of generation and diffusion of modern agricultural technology and management practices for selected key crops. The expectation is that the agricultural revolutions thus initiated in these crops will diffuse to other sub-sectors and ultimately transform the whole of agriculture.

1. Introduction

Deep concerns with the persistent and widespread food insecurity and rural poverty in sub-Saharan Africa (SSA) are expressed by policy-makers, practitioners, and researchers interested in poverty reduction and rural development in this region. Alarmingly, grain production per hectare has largely been stagnant in SSA except in the early 2010s (Otsuka 2013), which is in sharp contrast to tropical Asia where the Green Revolution has significantly contributed to the improvement of grain yields since the late 1960s (Otsuka and Larson 2013). As a result, grain production per capita has been declining in the region, in distinct contrast to Asia where the Green Revolution has significantly contributed to the improvement of the food-population balance. As a result, SSA is a net importer of grains, particularly rice and wheat. Therefore, the increasing grain prices, which took place in 2008 and may be repeated in the near future, can have devastating impact on food security and poverty in SSA, unless dramatic improvement in grain yields are achieved.[1]

Considering the increasing population pressure on limited land resources in SSA (Holden and Otsuka 2014; Otsuka and Place 2015), one possible solution is to realize a Green Revolution (Otsuka and Larson 2013, 2016), which is characterized by the development and diffusion of high-yielding, fertilizer-responsive, semi-dwarf crop varieties and the use of fertilizer (David and Otsuka 1994). Many specialists in African agriculture, however, question whether a Green Revolution, similar to the one achieved in Asia in the 1960s to the 1980s, is possible in SSA. For example, World Bank (2007) does not support the effort to realize a Green Revolution in SSA in its analysis of agricultural development in SSA. Selected papers on success stories in African agriculture by Haggblade and Hazell (2010) rarely mention the possibility of a Green Revolution. While it is true that there have been a relatively small number of published studies which report successful cases of Green Revolution even in limited areas in SSA,[2] does this mean that it is really an impossible dream to realize a Green Revolution in SSA? What are the major constraints on the Green Revolution and the

1 Otsuka, Liu, and Yamauchi (2016a, 2016b) point out that Asia is likely to lose comparative advantage in agriculture because of the dominance of labor-using small-scale farming in this continent in the face of increasing cost of labor due to rapid growth of nonfarm sectors.

2 Recently, however, the author of this background paper and his colleagues published a number of journal articles on rice Green Revolution in SSA (deGraft-Johnson et al. 2014; Kijima et al, 2011, 2012; Nakano and Otsuka 2011; Njagi et al. 2016). Balasubramanian et al. (2007) point out that rice is promising in SSA from the viewpoint of agronomy and other agricultural sciences. In addition, Gyimah-Brempong et al. (2016) provide detailed report on the prospect of rice production in Nigeria.

right policies to realize a Green Revolution in SSA? These are the first main issues that this study attempts to address.

We argue, based on the recent case studies and yield data to be examined later, that rice is the most promising crop in SSA, because of the high transferability of Green Revolution technology from Asia to SSA (Otsuka and Larson 2013). Thus, we recommend the investment in the capacity building to disseminate the improved rice technology in SSA. We also argue that maize Green Revolution might be possible if sufficient resources are allocated to adaptive research to establish profitable farming systems. Therefore, we recommend investment in maize research before undertaking extension. We further contend that the failure to realize a Green Revolution in the past can be attributed to the failure to recognize that Green Revolution is not only "seed-fertilizer intensive" but also "management intensive" (Otsuka and Larson 2016).[3]

Another possibility to transform African agriculture is to facilitate the production of high-value products, such as fresh fruits and vegetables and dairy products (Otsuka, Nakano, and Takahashi 2016). Unlike grains, whose quality variations are relatively small, high value products are characterized by large variations of the quality and safety of products, which gives rise to information asymmetry between producers and consumers. In other words, market is more likely to fail due to the imperfect information in the case of high-value products. Considering the increasing demand for such products in export markets as well as urban markets in SSA, it is worth speculating the strategy to develop agricultural sectors producing high-value products, even though the literature in this area is scant.

At this point, I would like to make it clear that I support the thesis of Theodore W. Schultz (1964) that "farmers are efficient but poor," because of the lack of technological change or innovation to use our preferred term. I would also like to argue that while Schultz' thesis is valid in SSA, we must recognize that "appropriate innovations" are different for different crops and, hence, we have to identify them before designing effective strategy to transform African agriculture.

Organization of this paper is as follows. Section 2 provides a unified conceptual framework for the transformation of agriculture in SSA. Section 3 compares yield growth of major grains in SSA with that in India to identify the promising crops. While Section 4 reviews the case studies of rice production, Section 5 highlights the promising maize farming system found in highlands in Kenya. Section 6 discusses a possibility of high-value product revolution in SSA. Finally, Section 7 concludes the paper by proposing promising strategy to transform African agriculture.

2. A Unified Conceptual Framework

To begin with, it will be instructive to consider appropriate technology policies in a hypothetical situation in a poor farming community, in which a few farmers adopt improved varieties and apply only a little bit of chemical fertilizer, whereas the majority of them rely on traditional variety without using any fertilizer (Otsuka and Kijima 2010). Crop yield as well as profit per hectare

3 Green Revolution in Asia is alternatively called "seed-fertilizer" revolution (Johnston and Cownie 1969). While their argument may be valid for Asia, where agricultural intensification has been taking place under strong population pressure on limited land for a long period, it may not be relevant for SSA where extensive farming practices have been adopted. Following the Johnston-Cownie tradition, Sheahan and Barrett (2014) carefully examine the adoption of modern inputs without analyzing management issues.

remains low and is not significantly different between traditional and improved varieties. Such situation is depicted by point A for production with traditional variety and point B for production with an improved variety in Figure 1, where chemical fertilizer, pesticide, and herbicide are called modern inputs. Actually this situation is very common in SSA (e.g., Otsuka and Kalirajan 2005). The question is what the appropriate development strategy is in such a situation. Needless to say, we have to diagnose the whole value chain "comprehensively" to identify why a Green Revolution has not been realized. Once a major constraint is identified, however, we should focus on the strategy to remove it.

While there can be many possible explanations for the failure to realize a Green Revolution in SSA, I believe that the following three are potentially most important:

1. Lack of superior variety: Available improved variety is not sufficiently fertilizer-responsive and high-yielding, so that most farmers are largely indifferent between improved and traditional varieties. Furthermore, the demand for fertilizer is nil or small, as the marginal product of fertilizer is low.
2. Ignorance about improved management practices: While improved rice production requires not only improved high-yielding varieties and ample application of chemical fertilizer but also the adoption of improved agronomic practices, such as bunding, leveling, and straight-row planting (Otsuka and Larson 2016), improved maize and other upland crop production requires rotation of crops including leguminous crops with capacity to fix nitrogen and application of manure, compost, and crop residues as well as improved variety and modern inputs (Kajisa and Palanichamy 2013; Otsuka and Muraoka 2015). The yield function shifts upward with the introduction of the improved management practices, as is illustrated by the upper curve in Figure 1. Since marginal product of modern input is high, its application will also increase, e.g., from point A or B to point C.
3. Exorbitant prices of fertilizer and other modern inputs and low product prices: Prices of chemical fertilizer and other chemical inputs are much higher than the value of marginal product of fertilizer, particularly when traditional variety is adopted, so that it is perfectly rational for farmers not to apply any fertilizer, as is indicated by point A in Figure 1. Even if farmers know that crop production can be increased by increased fertilizer application, they do not want to do so because the product market is so underdeveloped that the product price is low and increased outputs cannot be easily sold (Matsumoto and Yamano 2011).

Needless to say, there can be other factors that prevent significant increase in crop yield, including weak property rights on land, the lack of access to credit markets, and high production risk due to the vagaries of weather.[4] We would like to focus on the three possible constraints enumerated above, as we believe that the innovation in a broad sense is always an engine of agricultural development (Schultz 1964).[5] An important point is that appropriate policies are different depending on the critical constraints on the Green Revolution. If the lack of superior variety or the lack of knowledge about appropriate management practices is a major constraint, it is necessary to invest in agricultural research to generate truly productive crop varieties and identify appropriate management practices. If profitable technologies are potentially available but farmers do not know

4 Weak property rights on land are not a major constraint on growth in agricultural productivity in SSA, according to Otsuka and Place (2001) Holden et al. (2009), and Holden et al. (2013). In Asian Green Revolution, farm size which would affect the access to credit does not matter in technology adoption and crop yield (David and Otsuka 1994).

5 According to Schumpeter (1934), not only new technology but also improvements of management and marketing are important components of innovations.

them, the priority should be placed on strengthening extension systems and training of farmers. On the other hand, if inefficient marketing is a constraining factor, we have to invest in transportation and communication infrastructure to reduce marketing cost, to subsidize the fertilizer use, or to nurture entrepreneurship for farmers, so as to increase input application, e.g., up to point D in Figure 1.

First of all, let us assume that neither policy-makers nor economists know anything about the major constraints on the Green Revolution. Then they would have no choice but to adopt "bag-bang" approach and to invest in research, extension systems, farmer training, marketing infrastructure, and fertilizer subsidy simultaneously, as advocated by Sachs (2005). Given the limited budget and human resources, however, such approach is bound to be ineffective, particularly if there is a range of investment areas which are subject to increasing returns.

Now suppose that it is found that the superior variety is unavailable, improved management practices are not known, extension system is not working, and markets are inefficient. What should the government do using limited resources? While some people may advocate the comprehensive approach, our recommendation is to invest in research first to generate useful varieties and management knowledge. Without new profitable technology including improved management, what information shall we disseminate to farmers? Without sufficient demand for fertilizer and other chemical inputs and increased supply of products to the market, what roles do we expect markets to play? In our observation, markets do respond to profitable opportunities created by new technology in SSA as well as elsewhere, but if there is no such opportunity, markets will continue to be inactive (Yamano et al. 2011). In other words, investing in extension systems and marketing infrastructure does not make sense in the absence of new profitable technology.

A special case is the production of high-quality vegetables. Since the quality as well as the safety of products cannot be easily identified by consumers, product market does not work well due to information asymmetry. In order to produce high-quality products, improved seeds, safe pesticides, and desirable fertilizer must be applied but markets for such high-quality inputs are often missing in developing countries. Furthermore, farmers may not know appropriate management practices. This is where contract farming may be applied, in which the contractor provides inputs on credit, technological advice, and marketing services in return for delivery of required high-quality products at predetermined prices (Otsuka, Nakano, and Takahashi 2016). Assumptions here are that the improved seeds and other modern inputs are available, so that the upper curve in Figure 1 is potentially attainable, and that contractor has access to such markets, knows appropriate management practices, and has expertise on marketing of final products, so that point like D can be attained. Note that since the quality of products is a major concern, the value of product per hectare rather than the physical yield per hectare is measured on the vertical axis in Figure 1. In other words, contract farming may work, if the improved technologies are established and contractor has assurance that farmers will deliver required product to him, so that he can receive profit in excess of costs incurred. Such assurance is hardly guaranteed in the case of grains, because there are many competing buyers of the product, so that "side-selling" can be rampant. We will further consider the case of contract farming, which may lead to "high-value revolution," in Section 6.

Let us now assume that new superior grain production technology is developed or available from other countries, but extension system is inefficient and markets are not working, so that new technology is not widely diffused. Where should we invest limited resources? Our recommended policy is to invest in capacity building of extension workers and training of farmers. More often than not, the relevant knowledge on appropriate farming practices is not patentable and improved seeds can be reproduced by farmers, unless they are hybrid seeds. This means that new seeds and new knowledge are often public goods. Thus, public support for extension activities and farmer training is indispensable.

We do not argue that investment in infrastructure is unnecessary. On the contrary, the government should invest in transportation and communication infrastructures to enhance marketing efficiency. Our contention is that such investments tend to be induced, when the expected returns to investment become sufficiently high due to the dissemination of fertilizer-responsive and yield-enhancing varieties and appropriate management knowledge. It is also worth emphasizing that investment in marketing infrastructures before developing and disseminating new profitable technology is not recommendable, because it is in general difficult to predict in advance what technology will be developed and where it will be diffused. Considering the location-specific nature of agricultural technologies, investment in infrastructure should be made only after the prospect of new technological possibilities becomes apparent.

Economists ought to play a key role in designing effective development strategies (Ruttan and Hayami 2011). First of all, they should examine whether productive agricultural technologies are already available. If not, they should recommend investment in research about promising crops. This can be justified, because returns to investment in public-sector agricultural research are known to be high in SSA (Evenson and Gollin 2003). If improved varieties and desirable management practices are known, economists should recommend investments in the capacity building. Economists can also assess the efficiency of marketing systems. Furthermore, economists should consider how to support the development of contract farming, particularly for smallholders, who may be excluded from modern market chains due to the high transaction costs of dealing with a large number of small-scale farmers.

3. Yield Growth of Major Grains[6]

In order to identify which crops are promising to realize a Green Revolution in SSA, it will be instructive to (1) confirm the extent to which the Green Revolution took place in the production of various grains in tropical Asia, (2) measure the yield gap per hectare between tropical Asia and SSA, and (3) inquire if the Green Revolution has already taken place in the advanced regions in SSA, including South Africa. If Green Revolution did not take place in the production of certain crops in Asia, which is endowed with much better infrastructure and research and extension systems and more favorable policy environments than in SSA, it is probably difficult to realize a Green Revolution in such crops. Furthermore, if we do not observe significant yield gap between the two continents, the opportunity for technology transfer from Asia to SSA will be limited. If Green Revolution already took place in some crops in some advanced regions in SSA, such crops are likely to be promising. In this case, there is a possibility of scaling up Green Revolution by inter-regional technology transfer within SSA. Similarly, to the extent that South Africa is technologically advanced, we should consider technology transfer from this country to the rest of countries in SSA. Empirical evidence on this possibility, however, is scant.

6 This section partly draws on Otsuka and Muraoka (2015).

In what follows, we examine yields of five major grains; paddy, maize, wheat, millet, and sorghum. Except for wheat, these crops are grown mainly by smallholders, in which the inverse relationship between crop yield and farm size is observed, indicating that smallholders are not inefficient producers (Larson et al. 2014; Njagi et al. 2016; Sheahan and Barrett 2014). To represent tropical Asia, we choose India, as its climate is not far different from SSA (Tsusaka and Otsuka 2013). In fact, millet and sorghum, which are widely grown in SSA, are grown primarily in India in tropical Asia. To represent advanced regions in SSA, we choose top 10 countries in terms of average yield from 1961 to 2012, as well as South Africa.[7]

Figure 2 shows changes in the average paddy yield in SSA, top 10 countries, South Africa, and India.[8] It is remarkable to observe that yield in the top 10 countries increased significantly since around 1980 and became 70% higher by the early 2010s. Furthermore, the yield of 3 tons per hectare at present is not far below yield in India. According to Balasubramanian et al. (2007), the irrigation ratio of these top 10 countries is nearly 50%, so that production environment is favorable. These observations strongly indicate that rice Green Revolution has taken place in irrigated areas in SSA. Indeed, Otsuka and Larson (2013) argue that rice Green Revolution technology is highly transferable from Asia to SSA, particularly if irrigation is available. As far as rice is concerned, yield is not particularly high in South Africa. Average yield in SSA is much lower than the yield of top 10 countries importantly because nearly a half of the rice producing area in SSA is upland, where average yield is only around 1 ton per hectare.[9] It is also interesting to find that average yields in SSA and India were similar in the 1960s before the Asian Green Revolution began, which indicates that SSA is not inherently or climatically less favorable for rice production than in India. Although the average yield is much lower in SSA since the 1970s, it has increased roughly by 50% since the early 2000s. This may be partly due to the effects of food crisis and concomitant hike of rice prices around 2008 but it cannot be the whole story as yield growth began much earlier. It seems fair to conclude that rice is a promising crop for a Green Revolution in SSA.

Figure 3 examines the case of maize. Like the case of rice, yields were similar between SSA and India in the 1960s. However, yield gap appeared in the 1980s and widened thereafter. Unlike the case of rice, the yield of top 10 countries did not increase appreciably compared with India, and remained close with the average yield in SSA.[10] The similarity of average yield and that of top 10 countries indicates that the yield variations are small with no outstanding leading areas in maize production in SSA. Although maize yield has been increasing gradually in SSA, we can hardly say that a maize Green Revolution has taken place even in advanced regions in SSA. Smale et al. (2013) point out that due to the high location specificity, the inter-regional transferability of improved hybrid seeds is severely limited. It is interesting to observe that maize yield is exceedingly high in South Africa. It seems that there is room for other countries in SSA to learn from this country. Since maize is by far the most important staple crop in SSA, it is socially advisable to intensify effort to improve maize yield.

Judging from the relatively stagnant yield, realizing a maize Green Revolution in SSA may look

7 Top 10 countries are different for different crops. Also not that South Africa is not included in top 10 countries.

8 Top 10 countries in paddy yield are Kenya, Mauritania, Somalia, Rwanda, Burundi, Niger, Cameroon, Ethiopia, Madagascar, and Senegal.

9 Yield of upland rice increased in a few countries in SSA due to the adoption of improved varieties, called NERICA (Kijima et al. 2011; Diagne et al. 2013).

10 Top 10 countries in maize yield are Réunion, Tanzania, Côte d'Ivoire, Nigeria, Guinea, Liberia, Zimbabwe, Comoros, Zambia, and Ethiopia.

a daunting task, even though transfer of technology from South Africa is an option. Sheahan and Barrett (2014), however, point out that observing relatively high adoption rate of improved maize seeds (from one-third to one-half) and inorganic fertilizer use (about 35 percent) compared with other crops, "maize may be on 'on the move' in Africa."

It is encouraging to find that the average wheat yield more than doubled in SSA for the last several decades and that yield of top 10 countries had been higher than in India until the mid-1980s and only modestly lower since then.[11] Moreover, wheat yield is highest in South Africa. According to Negassa et al. (2013, p. 17), nearly 100% of wheat area was irrigated and fertilized in Ethiopia, Kenya, South Africa, Tanzania, Zambia, and Zimbabwe, and semi-dwarf improved varieties, which were similar to those disseminated in the Asian Green Revolution, were almost fully adopted by settler populations (Kenya and Zimbabwe), commercial farmers (Zambia) and government farms (Tanzania). Thus, unlike rice and maize, cultivators of wheat are not smallholders but large-scale farmers. Yet, there is no question that wheat Green Revolution has taken place in many parts of SSA, if we follow the definition of Green Revolution as the adoption of semi-dwarf varieties coupled with the increased application of chemical fertilizer. Limitation of wheat in SSA is that it is primarily grown in highlands endowed with cool climate, which are not abundant.

It is important to learn from Figures 5 and 6 that Green Revolution in millet and sorghum did not take place in India, as evidenced by slow yield growth and low yield level as of now. It seems that it is scientifically difficult to develop high-yielding varieties of these crops even in India. Another important observation is that the average yield of these crops in SSA is comparable to, and the average of top 10 countries is even higher than the yield in India, which indicates that there is not much room for transfer of technology from India to SSA.[12] Yet, as far as sorghum is concerned, the yield in South Africa is distinctively high, so that some of its technology may be transferred to other countries in SSA. Our tentative conclusion is that major research efforts are required to develop yield-enhancing technologies for these crops particularly suitable for agro-climate in many regions in SSA.

As can be seen from Figure 7, maize harvested area in SSA is largest in recent years among the five crops under study and it has been increasing. Thus, Green Revolution cannot have significant impacts on food security and poverty in SSA, unless maize Green Revolution is pursued. Rice harvested area is smaller but it has been steadily increasing. According to Balasubramanian et al. (2007), vast unused marshy land exists in SSA, which can be converted to lowland paddy fields. Moreover, about one-third of rice consumption in SSA is imported due to increasing demand for rice. Considering the increasing yield trend and high yields achieved in advanced regions in SSA, there is no doubt that rice Green Revolution should be pursued. While harvested areas of millet and sorghum are much larger than that of rice, they began declining due partly to the substitution by maize. Coupled with their low and stagnant yields, it does not seem particularly promising to realize millet and sorghum Green Revolutions in SSA. We will examine the possibility of rice and maize Green Revolutions in Sections 4 and 5 below.

11 Top 10 countries in wheat yield are Zambia, Zimbabwe, Namibia, Madagascar, Uganda, Kenya, Mali, Chad, Nigeria, and Sudan.

12 While top 10 countries in millet yield are Uganda, Guinea, Sierra Leone, Burundi, Nigeria, Gambia, Kenya, Cameroon, Ethiopia, and Central African Republic, top 10 countries in sorghum yields are Uganda, Guinea, Ethiopia, Sierra Leone, Rwanda, Burundi, Nigeria, Cameroon, Gambia, and Kenya.

4. Possibility of a Rice Green Revolution

Using country-level yield data, previous section indicated that rice is a promising crop for the Green revolution in sub-Saharan Africa. It is desirable to supplement such analysis by an analysis using household-level data in selected countries. This section draws on Otsuka and Larson (2016), which compares the performance of lowland rice production in Mozambique, Tanzania, Uganda, Ghana, and Senegal based on intensive household survey.[13] Note that out of 7.2 million hectares of rice land for 1995-2004 in SSA, 20% are irrigated lowland, 34% rainfed lowland, and 38% are upland, of which the potential for area expansion is enormously high for lowland (Balasubramanian et al. 2007).[14]

Table 1 demonstrates that the yield per hectare of lowland rice cultivation is much higher under irrigated than under rainfed conditions. Since the average paddy yield in tropical Asia is about 4 tons per hectare at present, yields of 3.7 tons per hectare in Tanzania and 4.5 tons per hectare in Senegal are reasonably high. Indeed Asian-type semi-dwarf modern rice varieties are grown in these irrigated areas, attesting that rice Green Revolution took place in these sites. Yield is relatively low even in irrigated areas in Mozambique, however, because irrigation facilities are not well maintained in the irrigation scheme.

That rice Green Revolution in fact took place in SSA is strongly indicated by Figure 8, upper panel of which shows the relationship between yield and fertilizer use per hectare in selected irrigation schemes in Asia in the late 1980s and SSA in recent years (Njagi et al. 2016). Roughly speaking, observed points seem to be located along the same "production function." In other words, the yield appears to be similar between Asia and SSA, if the amount of fertilizer applied is similar. This obviously cannot be understood, unless the Green Revolution has taken place in both Asia and SSA. As is suggested by lower panel in Figure 8, fertilizer application per hectare tends to be lower in SSA importantly because price of fertilizer relative to price of paddy tends to be higher in SSA than in Asia.

Experience in Tanzania demonstrates that it is possible to realize rice Green Revolution in irrigated areas by providing rice production training program (Nakano et al. 2015, 2016). In the study sites, "key farmers," who are considered as relatively competent producers, were trained intensively about the adoption of modern varieties, seed selection, bunding, leveling, timing of transplanting and fertilizer application, and post-harvest operations. Each key farmer is requested to choose five intermediary farmers to teach newly acquired rice production technology and management knowledge. Remaining farmers or ordinary farmers are expected to learn from key and intermediary farmers. According to Table 2, the key farmers obtained 3.1 tons in 2008 before they took the training program but after taking it, their average yield jumped to 4.4 tons per hectare in 2009 and reached more than 5 tons per hectare in 2011. The yield of key farmers was higher than other farmers already in 2008, as they were selected to introduce new technology and management practices. Yet, the yield of intermediary farmers gradually increased from 2.5 tons per hectare in 2008 to 4 tons per hectare or so in 2011-12 periods. Finally yield of ordinary farmers also increased to nearly 4 tons per hectare in the same periods. These data indicate that paddy yield increased

13 The volume edited by Otsuka and Larson is a result of a research project being conducted at the Japan International Cooperation Agency (JICA) Research Institute to empirically analyze how best the Coalition for African Rice Development (CARD) initiative can serve to increase rice productivity and reduce poverty in SSA.

14 The remaining 8% is deepwater and mangrove areas. Note that upland rice area is always unirrigated.

by 60% or so by learning rice production management directly by training program or indirectly through farmer-to-farmer network.

Returning to Table 1, we find that rice yield in rainfed areas in Mozambique is particularly low where traditional varieties are adopted, no chemical fertilizer is applied, no improved management practices are applied, and neither animal-drawn nor mechanized ploughing is carried out. Yields under rainfed conditions in Tanzania, Uganda, and Ghana are substantially higher than in Mozambique, because modern varieties are partially adopted, some fertilizer is applied, and improved management is partly adopted even in rainfed areas in these countries. Since less than 20% of lowland paddy fields are irrigated in SSA (Balasubramanian et al. 2007), whether rice Green Revolution is feasible under rainfed conditions is a major question in SSA.

Data shown in Table 3 support the view that rice Green Revolution is possible under rainfed conditions if rice production training is offered. In Uganda, paddy yield became as high as 3.7 tons per hectare in two training villages, if all four improved management practices (i.e., bunding, leveling, proper timing of transplanting which is about three weeks after germination, and transplanting in rows) are adopted.[15] Yield tends to be lower if improved management practices are less completely adopted and reaches 0.8 ton per hectare if no improved practices are adopted in training villages. Such data strongly suggest that the adoption of improved management practices is critically important for increasing yield under rainfed conditions. It is also interesting to find that in non-training villages or two villages where no training was offered, the average yield is not only much lower but also does not change with the extent of the adoption of improved technologies. This is most likely because farmers in these villages do not know the improved management practices.[16]

The evidence consistent with the findings in Uganda is also observed in rainfed areas in Northern Ghana, where we collected the data from 20 training villages, 20 nearby villages which may have favorable access to new information about improved production practices, and 20 remote villages. Clear positive association is observed between the extent of the adoption of improved technology and management practices and paddy yield (see Table 3). Note that the yield of 2.6 tons per hectare among full adopters of improved technology and management practices is almost identical to average yield under rainfed conditions in several Asian countries in the late 1980s (David and Otsuka 1994). Thus, it seems reasonable to conclude that rice Green Revolution is also possible under rainfed conditions, if Asian-type rice production technology and management practices are transmitted by the training program.

Although it is desirable to show profitability of adopting improved production practices over the existing ones, it is difficult to do so in SSA importantly because of the difficulty in imputing the cost of family labor. This is primarily because agricultural labor markets are so underdeveloped in SSA that only peak season wage rates, which are relatively high, are available and so their use for imputation of family labor cost leads to relatively large estimate of family labor cost and small or even negative profits. While keeping this caveat in mind, let us take a look at Table 4, which compares income, labor cost, and profit per hectare between irrigated and rainfed areas in Tanzania, between training participants and non-participants in Uganda, and full adopters and

15 Note that improved varieties are also adopted.

16 Note that the adoption of management practices is reported by interviewed farmers, who may not understand what are being asked, particularly in non-training villages.

non-adopters in Ghana.[17] According to this table, income per hectare is higher in irrigated areas than in rainfed areas and higher among training participants and full technology adopters than others, as would be expected. Although the labor cost is higher in irrigated areas than in rainfed areas in Tanzania, profit is far higher in the former and the latter. In Ghana, labor cost is lower for full technology adopters than non-adopters and so profit is also higher for the former than the latter. These observations indicate that the profitability and yield per hectare are positively correlated.

5. Possibility of a Maize Green Revolution[18]

While lowland rice cultivation is extremely sustainable because micro organs under the submerged soil fix nitrogen from atmosphere, which maintains soil quality, how to maintain soil quality is a major issue in upland farming (e.g., Place et al. 2003). Needless to say, maize is no exception.

According to the review of empirical literature on maize production in SSA (Otsuka and Muraoka 2015), adoption rate of hybrid seeds is pretty high in many countries in SSA (e.g., 50%) and its impact on maize yield is reasonably high (e.g., 50% growth), which is inconsistent with the data of low maize yield shown in Figure 3. Fertilizer application is generally low in SSA but it tends to increase with the adoption of improved maize seeds (Sheahan and Barrett 2014). One possible hypothesis is that maize yield increases with the adoption of improved seeds in the short run, but its impact on yield is not sustainable due to the mining of soil quality. Several researchers (Place et al. 2003; Morris et al. 2007; Jayne and Rashid 2013; Sheahan et al. 2013) argue that in order to achieve sustainably high maize yield, an integrated farming system is necessary, which applies crop rotation, such organic inputs as manure, compost, and crop residue, and intercropping with leguminous crops which have capacity to fix nitrogen, in addition to improved hybrid seeds and inorganic fertilizer. These studies, however, are “theoretical” and none of them provide a concrete example of such integrated farming system.

Otsuka and Muraoka (2015) report the emergence of new maize-based farming system in the highlands of Kenya. There are several important features of the new system. Frist, cows, which used to be grazed, are stall-fed, in order to collect dung and urine thoroughly. For stall feeing, feed crop needs to be grown on crop fields. Then manure or compost is applied to maize field. This is reminiscent of the Agricultural Revolution in the United Kingdom, which replaced grazing by stall-feeding to increase manure application (Timmer 1969). Second, dairy cows, which are cross-breeds between European cows and indigenous cows, are adopted. According to our own estimate, milk production per dairy cow is roughly 4 times as much as indigenous cow. It is conceivable that manure production per cow is significantly larger with dairy cows than with indigenous cows. This is similar to the White Revolution in India in the 1970s, which introduced the dairy cows (Kajisa and Palanichamy 2013). Third, most maize fields are planted to high-yielding hybrid seeds and inorganic fertilizer is usually applied. Undoubtedly, this is similar to the essence of the Asian Green Revolution in rice and wheat. Furthermore, more often than not, maize is intercropped with leguminous crops. This emerging maize-based farming system is obviously promising but highly complicated.

17 Income is defined as the value of production minus paid-out costs, whereas profit is defined as income minus imputed costs of family-owned non-land resources, notably family labor.

18 This section draws on Otsuka and Muraoka (2015).

According to Table 5, which uses panel data of nearly 800 households in highlands in Kenya in 2004 and 2012, maize yield slightly increased from 1.8 tons per hectare in 2004 to 2.1 tons per hectare in 2012, which are slightly higher than the average maize yield of top 10 countries in SSA shown in Figure 3. Although real crop income per hectare, manure use per hectare, and the adoption of hybrid seeds significantly increased from 2004 to 2012, chemical fertilizer use per hectare and the share of intercropped fields slightly declined.

An interesting finding from the regression analysis, which is not reported in this article, is that dummy variable for intercropping is insignificant in the yield and income functions per hectare. This may be taken to imply that reduction in maize yield due to allocation of a part of the field to leguminous crops is offset by the positive effect of growing leguminous crop on soil fertility. Thus, the "effective" maize yield per unit of land purely planted to maize should be higher, even though such high yield may not be sustainable without intercropping. Compared with Uganda, where intensified maize-based integrated farming system is seldom adopted (Table 5), maize yield is significantly higher in Kenya.

Nevertheless, we wonder if it is still possible to further increase maize yield in Kenya, because the emerging farming system is highly complicated but not supported by scientific research. What is the optimum number of dairy cows and the optimum amount of manure application per hectare? What is the best combination of manure, inorganic fertilizer, and intercropping with leguminous crops, including the quantities and the timing of applications? What is the best rotation of maize, feeds, and other crops? How location specific is this farming system and what kind of adaptations are needed for wider dissemination? What is the best substitute for dairy cows and manure application in areas where cows cannot be raised? These are critical questions but not explored in depth by research.

Considering that this integrated maize-based farming system is highly management-intensive, there seems to be room for further improvement of the efficiency of the system by means of scientific research. Also needed will be an extension system capable of disseminating the new farming systems, once the profitable systems are firmly established.

6. Possibility of a High-Value Revolution[19]

As was mentioned earlier, unlike grains, whose quality variations are relatively small, high-value products are characterized by high quality variations and consequently information asymmetry about the quality and safety of products. In other words, their markets are more likely to fail than markets of grains due to the imperfect information about the quality and safety. Furthermore, in order to produce high-value products, which are often new, high-quality seeds and new purchased inputs are needed and new production technologies and management practices are required, but their markets may not exist or do not function effectively in developing countries. Thus, input market inefficiencies and absence of technology information channels are another problem. In addition, the lack of credit to purchase inputs could be another constraint. In consequence, while the main issues of developing grain sector are to establish and disseminate new profitable production technologies and management practices, the main issues of developing high-value

19 This section draws on a recent and comprehensive review of the literature on contract farming, particularly case studies, by Otsuka, Nakano, and Takahashi (2016).

product sectors are how to overcome a variety of the market failures, assuming that improved technologies and management practices are established and potentially available.

There are a large number of case studies on contract farming, particularly in SSA. They do not show, however, how geographically widespread contract farming is. Nor are there official statistics to show the extent of adoption of contract farming. As a result, it is difficult to tell at this moment how prevalent contract farming is and how promising it will be in SSA. Considering the increasing demand for high-value products associated with increasing income and the increasing opportunities to export to high-income countries, it will be reasonable to assume that the agricultural sectors to produce high-value products have high potential to grow (World Bank 2007).

Contract farming is a response to the increasing demand for high-quality products closely associated with the "supermarket revolutions" (e.g., Reardon et al. 2009). Since input requirements are stringent and the provision of advice and close supervision of farmers by the agents of supermarkets are necessary, the transaction costs are high. Therefore, it was widely believed that contract farming confers advantages primarily to large farmers, because making contracts with a large number of smallholders is more costly than contracting with a small number of large farmers. On the other hand, since contract farming brings about new improved technology and new marketing practices, there is no question that production and marketing efficiencies improve. In other words, there is likely to be a tradeoff between efficiency and equity associated with the adoption of contract farming.

Although it appears that large farmers were selected to be involved in the contract farming a few decades ago, small farmers were also involved in contract farming in more recent years, according to an almost exhaustive review of the empirical literature by Otsuka, Nakano, and Takahashi (2016). More specifically, even if large farmers are more actively involved in contract farming, the difference in farm size between large and small farms are small in a large number of case studies. To my knowledge, there have been at least two developments, which support the increasing participation of small farmers in contract farming.

Strictly speaking, there are two types of contract farming: (1) production contract in which the contractor provides modern inputs on credit as well as technical services and (2) marketing contract in which the contractor designate particular inputs that the contracted farmers must use. Production contract is common for export, whereas marketing contract is dominant for delivery to domestic supermarkets. This is reasonable, as the quality and safety requirements are more stringent in the case of export. Consequently, transaction costs are much lower in market contract than production contract. Furthermore, markets of modern inputs have gradually developed and farmers have also learned technology and market practices over time. Thus, as the importance of market contracts has increased, as in the case of Kenya, smallholders can also participate in contract farming more actively.

One way to reduce transaction cost for the contractor is to form a producer group or a cooperative consisting of smallholders. The producer group makes contracts with the contractors on behalf of its members, controls the use of modern inputs, and guarantees the quality and safety of the products delivered to the contractor. Although clear-cut evidence is not available, it is possible that in order for smallholders to participate in contract farming, they might have voluntarily formed the producer groups based on the strong social capital accumulated among community members. There have been an increasing number of empirical studies reporting the successful cases of contract farming under the leadership of producer groups. However, there is no study that identifies the conditions under which the producer groups effectively promote contract farming.

Is there room for the government to facilitate contract farming, particularly for smallholders? This is an area where we do not have much evidence to make clear recommendations. Yet, it may be useful to recognize that rice or maize markets as well as input markets are largely competitive, whereas markets of high-value products are far from competitive due to imperfect information. Thus, rice and maize farmers are basically "producers," who purchase inputs at the given market prices and sell the products at the prevailing market prices, whereas farmers of high-value products are "entrepreneurs," who look for appropriate high-quality inputs, produce high-quality products by applying the appropriate production methods, and sell such products at the highest possible prices. Like entrepreneurs in other businesses, farmers have to find out the contractor who offers the most favorable terms and conditions. It is difficult to assume that farmers, particularly small farmers, possess the required entrepreneurship. If so, it may make sense to offer training program on management and marketing, as has been done for entrepreneurs of micro and small manufacturing enterprises in SSA (Sonobe and Otsuka 2011, 2014). Such intervention by the government is justified by the spillovers of useful knowledge from training participants to non-participants.

7. Strategy for Agricultural Transformation in SSA

We argued in the introduction that appropriate innovations hold keys to transforming African agriculture and they are different for different crops. Hence, we have to identify them before designing effective strategy to transform African agriculture. For this purpose, it is useful to distinguish among new technology (e.g., new high-yielding varieties), improved management practices, and improved marketing (e.g., branding, establishment of reputation of high-quality producers, and direct sales from farmers or farmers' groups to retailers and consumers). In identifying the critically important innovation, it is important to recognize that the three types of innovations are complementary: the productivity impact of new variety is limited without proper management as is illustrated by Figure 1, whereas marketing becomes more important when both the demand for modern inputs and supply of outputs increase owing to the improvements in technology and management practices. This implies that productive technology and improved management practices must be developed first, which should be followed by extension activities and improvements in marketing.

In our view, the failure in the rice Green Revolution in the past in SSA stems from the lack of extension, particularly the extension of the agronomic management practices in rice production. The findings that productivity in rice farming was significantly improved after management training is prima facie evidence that productivity in rice production can be improved by extension of available technologies and management knowledge even without improvement of marketing, credit availability, and so on. In order to activate extension systems, investments must be made in the capacity of extension workers and dissemination of useful information on improved technologies and management practices to rice farmers to arouse their interests in extension services.

It is likely that the failure in the maize Green Revolution results from the lack of research to establish truly profitable integrated maize-based farming system, which combines the use of dairy cows, allocation of land to the production of feed crops, the application of manure and compost, crop rotation and intercropping, application of inorganic fertilizer, and adoption of high-yielding seeds. Jayne and Rashid (2013), Morris et al. (2007), and Sheahan et al. (2013) also support the importance of integrated maize-based farming system in SSA. It is amazing and admirable that small-scale farmers in Kenya voluntarily adopt such complicated farming system, which is consistent with the Asian Green Revolution, British Agricultural Revolution, and Indian White Revolution. In order to establish such new farming systems, interdisciplinary research among breeding, agronomy, and livestock science must be carried out. Also important would be further socioeconomic research on successful maize-based farming systems in countries other than Kenya.[20]

Regarding the high-value product revolution, the real issue is neither technological nor managerial, as the contractor seems to know improved technology, management practices, and useful inputs. In order to expand contract farming, it seems best to reduce transaction cost in contracting between contractors and farmers. For this purpose, it is likely that improvement of entrepreneurial human capital of farmers is critically important. As Schultz (1975) suggests, poor small farmers cannot move out of poverty, unless they acquire the ability to deal with disequilibria or to make appropriate production, marketing, and technology decisions in dynamic setting. Promoting the acquisition of such ability by farmers ought to be the fundamental strategy to expand the production of high-value products by smallholders in SSA. Given that contract farming is entrepreneurial activity, it is possible that it could attract young educated people and other business entrepreneurs who are not farmers now. Once we allow for this possibility, expanded access to land or efficient functioning of land markets will become the key issue.[21]

To sum up, I recommend investment in capacity building for the extension of modern rice technology and management practices to realize the rice Green Revolution. This is because the Asian-type superior technology and management practices are available and found to be effective in SSA. We do believe that the success in the rice Green Revolution can be a model for the Green Revolution in other crops, such as maize, by showing that establishing profitable technology and management practices is a prerequisite for successful innovations. For maize we strongly recommend the establishment of productive and sustainable farming systems as a first step toward the Green Revolution. Despite the maize farmers' spontaneous efforts to improve farming systems in highlands of Kenya, research systems fail to seize the opportunity to improve the maize-based integrated farming systems. It is urgent to establish what combination of organic and inorganic fertilizers, hybrid seeds, and crop rotations and intercropping is the optimum and to what extent the optimum system is location-specific. It is also important to explore what the desirable farming system is in areas where dairy cows are unavailable. Once the improved farming systems are established, it is advisable to follow the development strategy of rice farming, i.e., the investment in the capacity building for the dissemination of new profitable farming systems.

20 According to the discussions with staff at the Alliance for Green Revolution in Africa, similar farming systems are widely adopted in Rwanda. Also in our exploratory field survey in February 2016 in Eastern Uganda, we found that adoption rate of hybrid maize, the use of fertilizer, and intercropping between maize and legumes have significantly increased in the last several years. Also badly needed is the careful empirical studies on the Green Revolution in maize in Asian countries.

21 According to Holden, Otsuka, and Place (2009) and Holden, Otsuka, and Deininger (2013), land rental markets have been gradually developing in SSA.

Although evidence is much weaker, the key to the development of high-value crops seems to hinge on the creation of a system to reduce the transaction costs of contract farming so as to induce the active participation of smallholders. More specifically, it is advisable to assist producer groups and associations and to train promising farmers to acquire entrepreneurship for efficient management of farms and active participation in market transactions, as in the case of management training of entrepreneurs of marginal, small, and medium scale manufacturing firms in SSA (Sonobe and Otsuka 2011, 2014). This is, however, the area for further studies.

So far, we did not mention roles of investments in infrastructure including irrigation, transportation, and communication facilities, the provision of cheap credit, and the facilitation of mechanization. It is not because they are unimportant but it is because the promotion of infrastructure, credit provision, and mechanization become profitable, only if innovations are about to take place on crop fields of farmers. In all likelihood, if innovations in technology, management, and marketing are supported by appropriate policies and if supporting investments are made subsequently, African agriculture can be substantially and sustainably transformed.

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Table 1. Comparison of paddy yield per hectare (tons/ha) between irrigated and rainfed areas across study sites

Country	Irrigated area	Rainfed area
Mozambique	2.0	1.0
	(2007)	(2008)
	1.6	0.8
	(2011)	(2011)
Tanzania	3.7	1.8
	(2009)	(2009)
Uganda	n.a.[b]	2.5
		(2009)
		2.3
		(2011)
Ghana	n.a.[b]	2.0
Senegal	4.5	n.a.[b]
	(2011)	

Source: Otsuka and Larson (2016).
[a] Numbers in parentheses are production year.
[b] "n.a." means not available.

Table 2. Changes and differences in paddy yield (tons/ha) over time, by training status, in irrigated areas in Tanzania: key farmers, intermediary farmers, and ordinary farmers

	2008	2009	2010	2011	2012
Key farmers	3.1	4.4	4.8	5.3	4.7
Intermediary farmers	2.5	2.6	2.8	4.6	3.9
Ordinary farmers	2.6	2.7	2.5	3.6	3.7

Source: Nakano et al. (2016).

Table 3. Paddy yield (tons/ha) and adoption of improved technology and management practices in rainfed areas in Uganda and Ghana

	Uganda		Ghana
	Training villages	Non-training villages	
All improved practices[a]	3.7	0.8	2.6
Almost all improved practices[b]	3.0	1.5	2.3
One improved practice only	2.1	1.6	1.7
No improved practices	0.8	1.0	1.5

Source: Otsuka and Larson (2016).
[a] Four management practices considered in Uganda: bunding, leveling, proper timing of transplanting, and transplanting in rows; and five production practices considered in Ghana:adoption of modern varieties, chemical fertilizer, bunding, leveling ,and dibbling.
[b] "Almost all practices" refers to three practices in Uganda and to four practices in Ghana.

Table 4. Income and profit per hectare of rice cultivation (USD/ha), by status of irrigation, management training participation, and technology adoption

	Income per ha[a]	Labor cost per ha	Profit per ha[b]
Tanzania			
Irrigated area	1,011	421	590
Rainfed area	453	300	153
Uganda (rainfed)			
Training participants	1,327	n.a.[c]	n.a.[c]
Non-participants	905	n.a.[c]	n.a.[c]
Ghana (rainfed)			
Full adopters	374	114	260
Non-adopters	228	169	59

Sources: Kijima (2016), deGraft-Johnson et al. (2016), Nakano et al. (2016), and Otsuka and Larson (2016).
[a] Income is defined as the value of production minus paid-out costs.
[b] Profit is defined as income minus imputed costs of owned resources. including family labor.
[c] "n.a." means not available.

Table 5. Comparison of maize yield, crop income, and technology adoption between Kenya and Uganda

	Kenya		Uganda
	2004	2012	2009/2010
Maize yield (tons/ha)	1.8	2.1	1.2
Crop income (KSh/ha)[a]	37,869	46,786	na[b]
Chemical fertilizer use (kg/ha)	49	47	0.3
Manure use (kg/ha)	971	1,578	22
Share of intercropped fields (%)	76	72	45
Adoption of hybrid maize (%)	50	78	30

Source: Larson et al. (2016), Muraoka et al. (2016).

[a] Crop income is defined as crop production minus all paid costs associated with crop production

[b] "n.a." means not available.

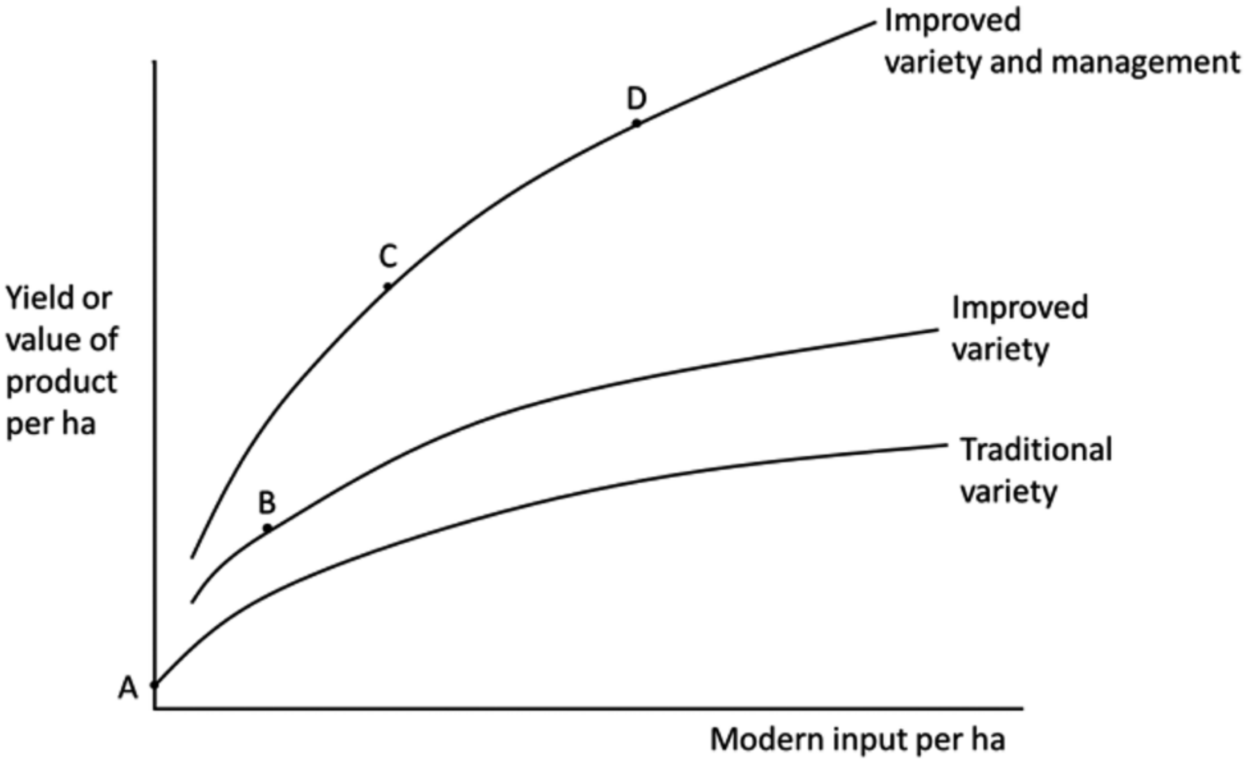
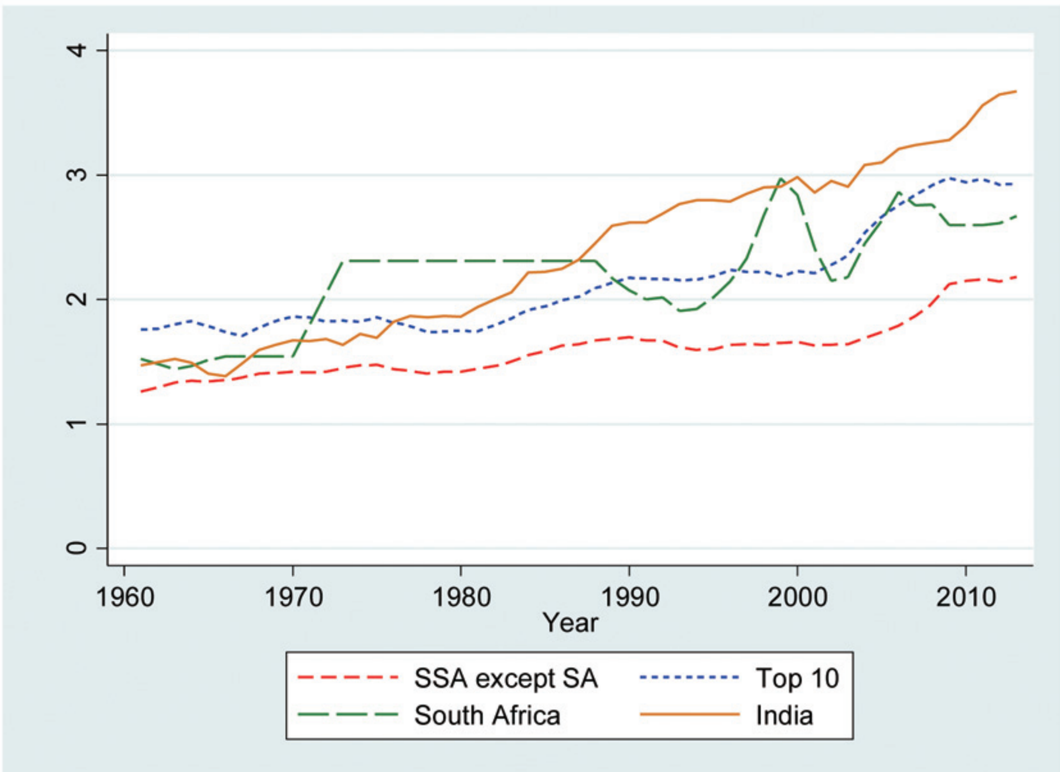
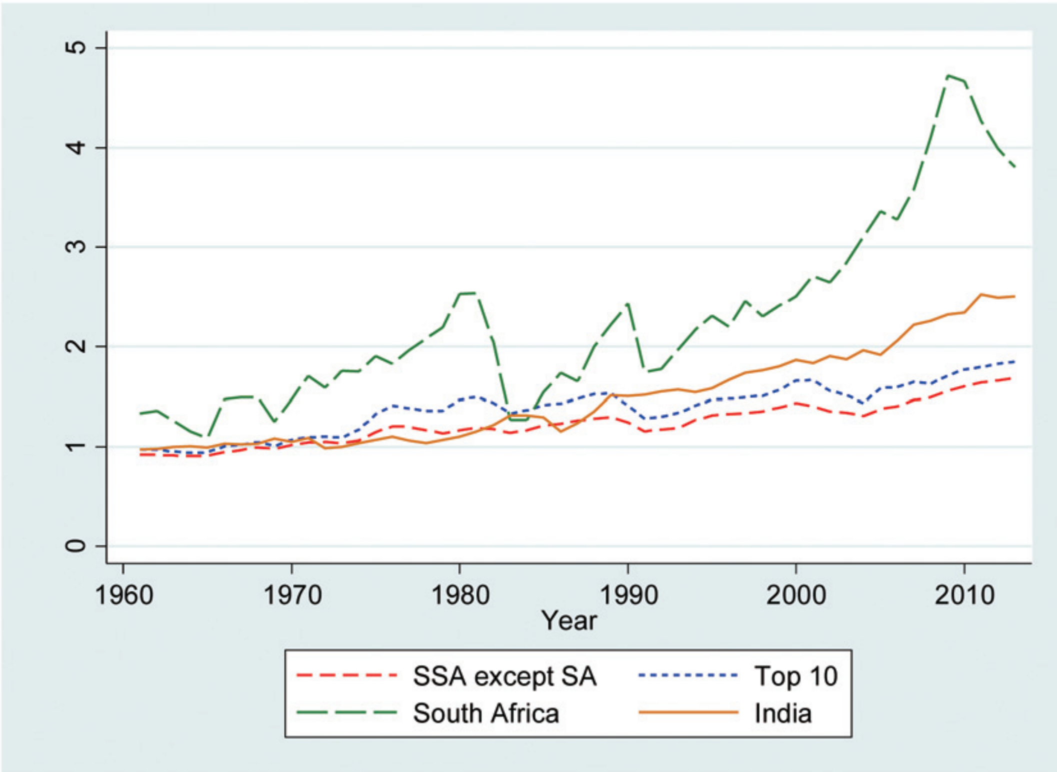


Figure 1. Illustrated relationship between the application of modern input and yield or value of product per hectare



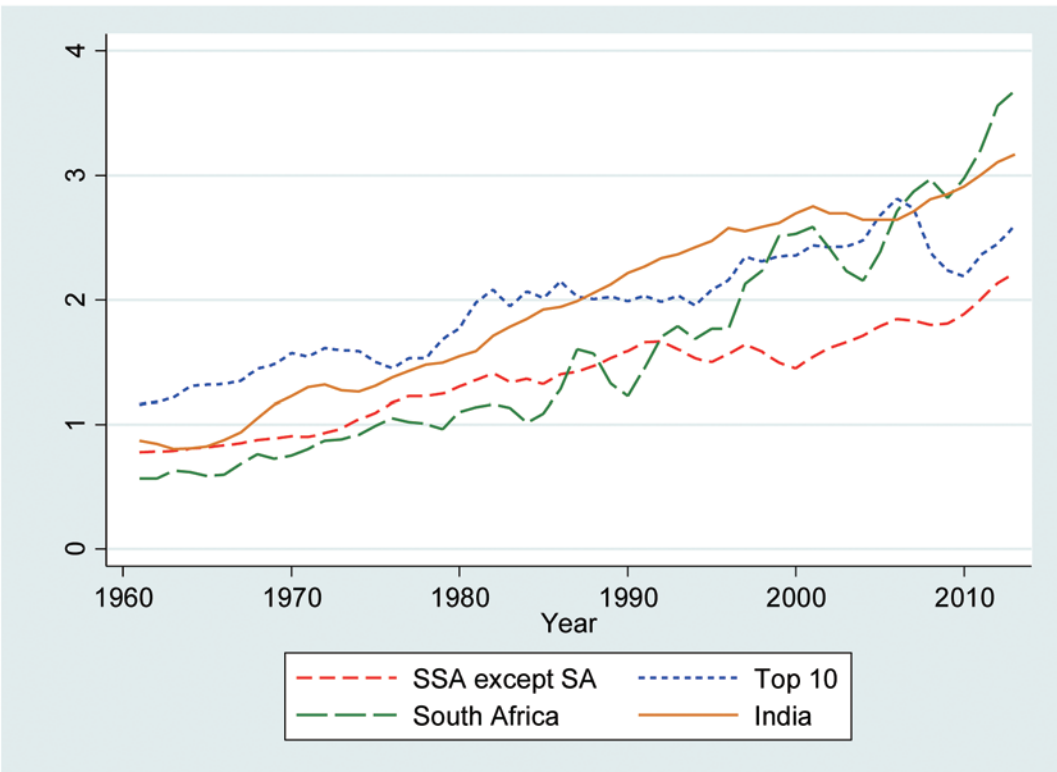
Source: FAOSTAT (2015).

Figure 2. Changes in average paddy yields in SSA, top 10 countries, South Africa, and India



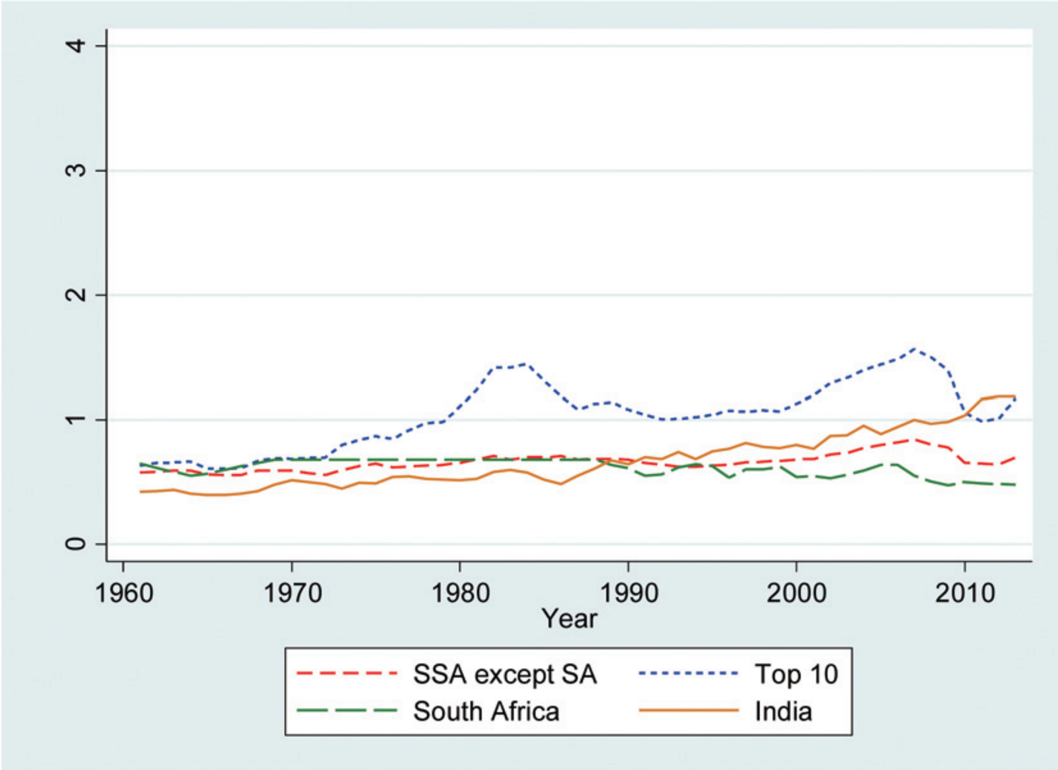
Source: FAOSTAT (2015).

Figure 3. Changes in average maize yields in SSA, top 10 countries, South Africa, and India.



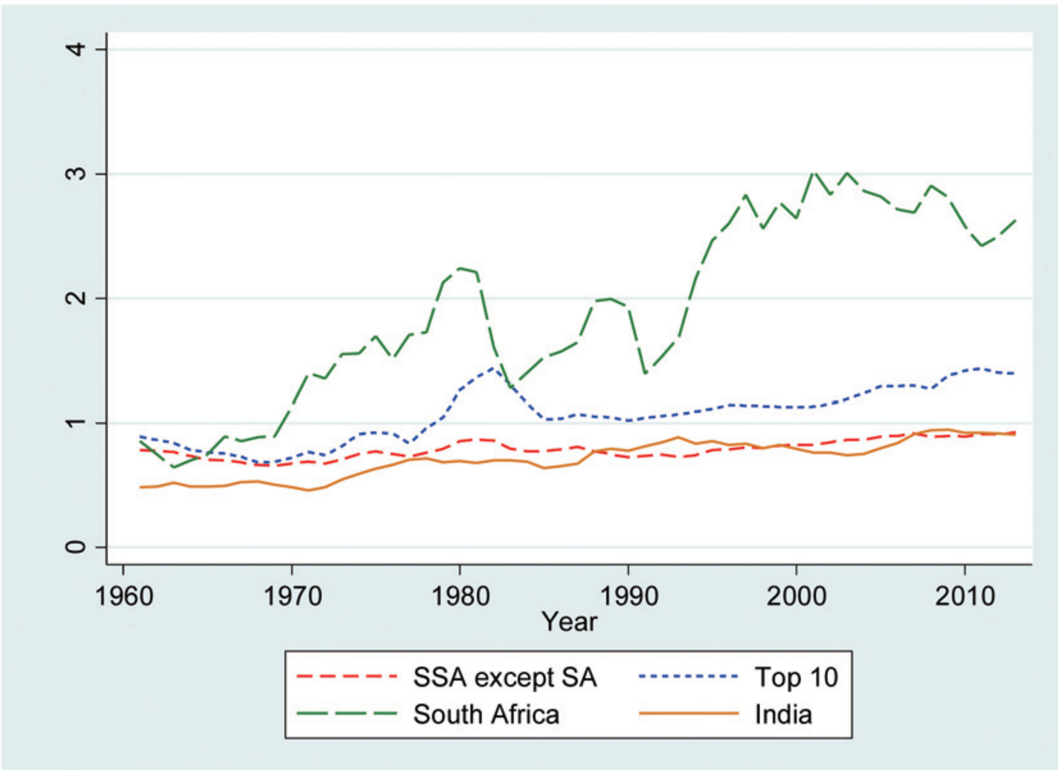
Source: FAOSTAT (2015).

Figure 4. Changes in average wheat yields in SSA, top 10 countries, South Africa, and India



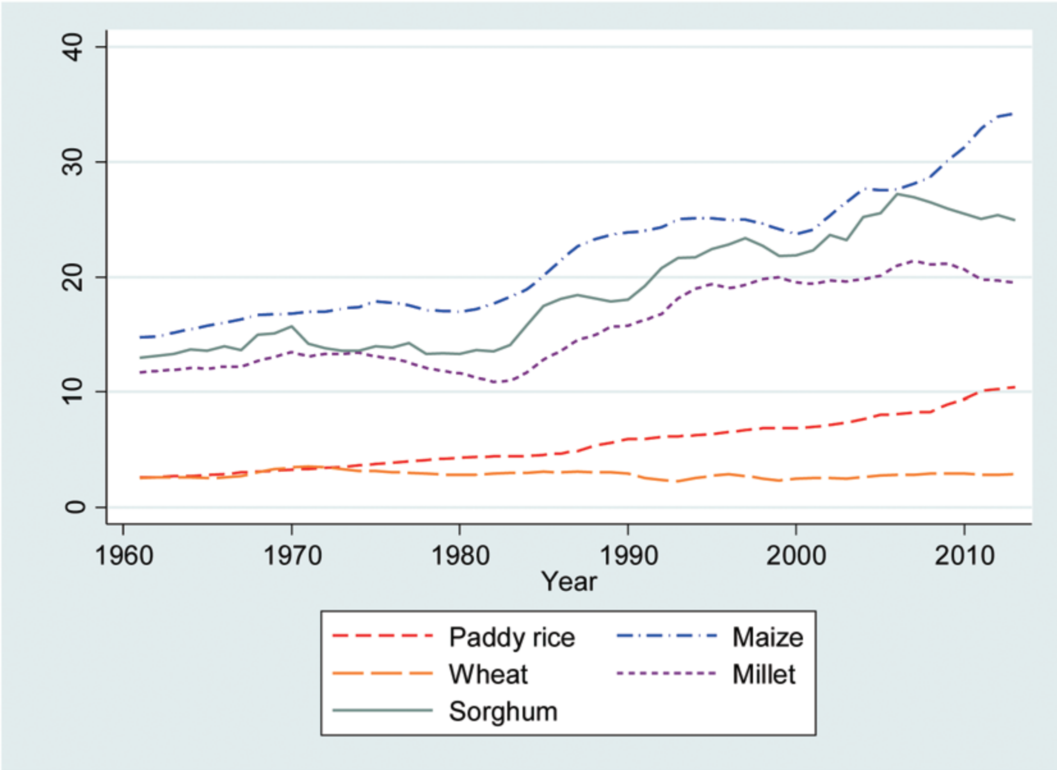
Source: FAOSTAT (2015).

Figure 5. Changes in average millet yields in SSA, top 10 countries, South Africa, and India



Source: FAOSTAT (2015).

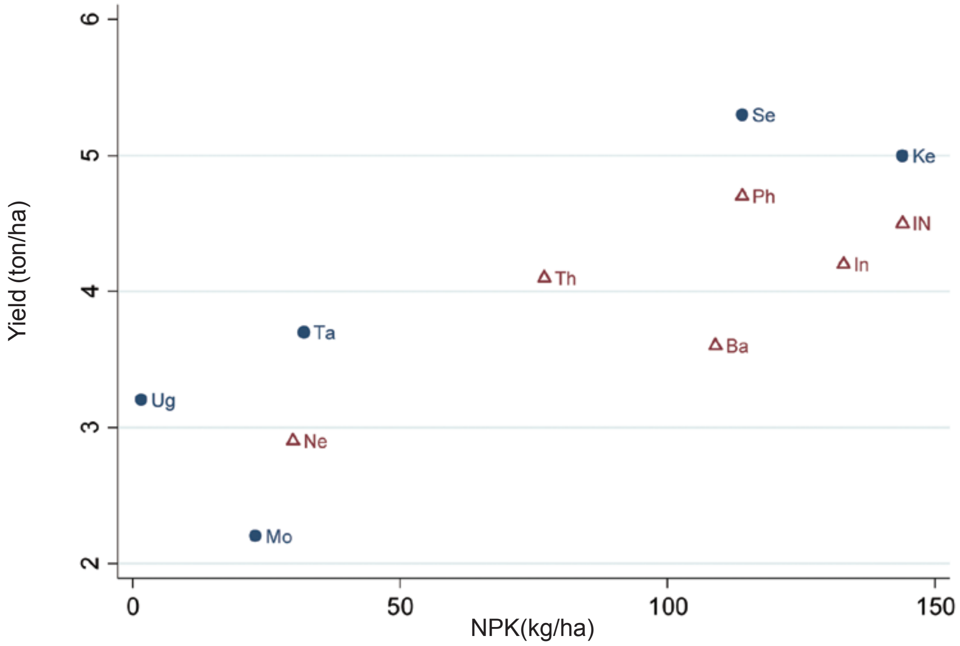
Figure 6. Changes in average sorghum yields in SSA, top 10 countries, South Africa, and India



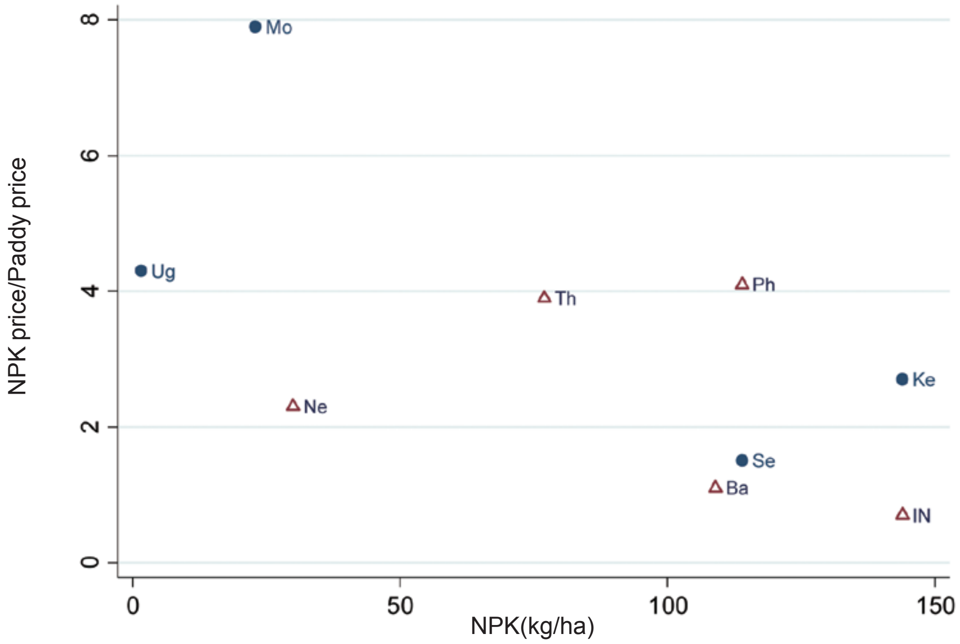
Source: FAOSTAT (2015)

Figure 7. Changes in harvested areas of major grains in SSA

A. Relationship between yield and fertilizer use per hectare



B. Relationship between relative price of fertilizer and fertilizer use per hectare



Legend			
Ba - Bangladesh	In-India	Ne - Nepal	Ta- Thailand
Mo - Mozambique	IN - Indonesia	Ph - Philippines	Tz- Tanzania
	Ke - Kenya	Se - Senegal	Ug - Uganda

Figure 8. Yields, Fertilizer Use and Fertilizer Price relative to Paddy Price

Source: Survey data for Mwea were collected in 2011; Data for Uganda (Doho), Mozambique (Chokwe), Senegal (Senegal River Valley) are from Nakano et al., (2013). Data for Tanzania are from Nakano and Kajisa (2013). Data for Philippines (Central Luzon), Indonesia (Lampung), Thailand (Suphan Buri), Bangladesh, Nepal (Chitwan & Sarlahi Districts), and India (Tamil Nadu) are from David and Otsuka (1994).