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Can Africa Replicate Asia's Green Revolution in Rice?

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Abstract

Asia's green revolution in rice was transformational and improved the lives of millions of poor households. Rice has become an increasingly important part of African diets and imports of rice have grown. Agronomists point out that large areas in Africa are well suited for rice and are encouraged by the field tests of new rice varieties. So is Africa poised for its own green revolution in rice? This study reviews the recent literature on rice technologies and their impact on productivity, incomes, and poverty, and compares current conditions in Africa with the conditions that prevailed in Asia as its rice revolution got under way. An important conclusion is that, to a degree, a rice revolution has already begun in Africa. Moreover, many of the same practices that have proved successful in Asia and in Africa can be applied where yields are currently low. At the same time, for many reasons, Africa's rice revolution has been, and will continue to be, characterized by a mosaic of successes, situated where the conditions are right for new technologies to take hold. This can have profound effects in some places. But because diets, markets, and geography are heterogeneous in Africa, the successful transformation of the Africa's rice sector must be matched by productivity gains in other crops to fully launch Africa's Green Revolution.

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Can Africa Replicate Asia's Green Revolution in Rice?

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Introduction

Advances in agricultural productivity have been central to economic growth and the structural transformation of most countries, so it is sensible to look for evidence that this process has begun in Africa. Moreover, there is good reason to believe that agriculture-led growth can be especially effective in reducing poverty in Africa. This is partly because the poor are disproportionately rural and dependent on agriculture for their livelihood.[4] But it is also the case that poor households, whether urban or rural, spend a large portion of their income on food. As a result, productivity gains in staple crops like rice and an associated decline in the price of staple foods can bring about spectacular reductions in poverty. The consequence of Asia's Green Revolution is a recent and dramatic example.[5] What's more, the genesis of Asia's success occurred under conditions similar to those found in Africa today and was closely linked to the successful adoption of a handful of innovative technologies, the most important of which centered on rice. Therefore, there are compelling reasons to look at the role rice might play in an African Green Revolution and to draw comparisons with experiences in Asia.

During the course of Asia's Green Revolution, policy makers vigorously promoted new high-input technologies aimed at wheat, rice and other crops grown on smallholder farms. To date, a focus on smallholders and more intensive staple crop technologies – mostly for maize and rice -- has been a pillar of most African agricultural policies as well. Still, the sweeping gains in agricultural productivity and the virtuous structural transformation of national economies that characterized Asia's Green Revolution have yet to reach Africa. Instead, average cultivated land per worker has declined in Sub-Saharan Africa by about 40% since the 1960s and valued added per worker now averages around 12% below 1980 levels (World Development Report 2008).

In this essay, we look closely at the specific case of rice, which was so important to Asia's Green Revolution and where already available technologies are promising for Africa. We look backward at the role rice has played in African diets and African agriculture during the last 50 years and forward to the potential role rice can play in bringing a Green Revolution to Africa. We draw on lessons from Asia and from Africa, and, in particular, from on-going efforts by IRRI and AfricaRice (formerly WARDA) to promote the use of new rice varieties. Taken together, what we find suggests that the successful development and dissemination of rice technologies has an important role to play in bringing productivity gains to Africa and that there are already signs of success. At the same time, because rice plays a less central role in African diets and livelihoods and because of the geography of Africa, the consequences of success for incomes and poverty are likely to be less sweeping than in Asia. Even so, for some places and for many households in Africa, especially in West Africa,

[4] According to the World Bank, more than 70 per cent of the continent's poor people live in rural areas and depend on agriculture for their livelihood (World Development Report 2008).

[5] See Larson and Mundlak (1997); Mundlak, Larson and Butzer (1999), and Otsuka, Estudillo and Sawada (2009).

the gains from adopting more productive rice technologies will be substantive, and it is difficult to envision a successful path to an African Green Revolution that does not include rice.[6]

The early debate on Asia's Green Revolution

Before looking at the potential role for rice in an African Green Revolution, it is useful to revisit early discussions about the anticipated consequences of Asia's new agricultural technologies shortly after their introduction, since concerns discussed then touch on topics still relevant for Africa. Though strong links between the introduction of modern varieties of wheat and rice with poverty reduction would be later documented, there were early questions about whether the new production methods would benefit large and wealthy farmers rather than poorer smallholders, and whether they would promote mechanization as a substitute for agricultural labor. At the time, some economists predicted the new varieties would lead to increased landlessness and falling rural wages, exacerbating rural poverty rather than reducing it.[7]

The new varieties that led Asia's Green Revolution were bred to work better with greater applications of fertilizer than traditional varieties and to work best on irrigated land (David and Otsuka, 1994). This entailed greater costs at planting time and greater capital outlays. Uncertainty over the local performance of the new varieties added to the financial risk of up-front investments, especially in the face of weak input and insurance markets. All of this seemed to favor larger farmers with better access to capital and rich enough to take on additional risk. Still, early evidence suggested that the scale of production and the wealth of the household mattered less than was supposed. For example, Hazell and Ramasamy (1991) report on an early study by Barker and Herdt (1978) on the effects of the adoption of the new semi-dwarf rices and associated technology on income and employment, based on surveys conducted in 36 villages in India, Indonesia, Malaysia, Pakistan, Philippines and Thailand. The authors found that while smallholders faced considerable hurdles in acquiring inputs and credit, rates of adoption for the new varieties were similar, even in villages where there were large inequalities in the distribution of land. Bell, Hazell and Slade (1982) studied the introduction of irrigation and high-yielding varieties of rice in Malaysia's Mudha River region from 1967 to1974 and found both an increase in mechanization and a large increase in the incomes of landless paddy workers. Blyn (1983), using data from Punjab and Haryana reported that, in practice, yields declined with farm size and that mechanization did not hamper rural wage income. Around the same time, a number of studies suggested that the indirect local effects of the Green Revolution on incomes and employment opportunities were large (Bell and Hazell, 1980; Estudilo and Otsuka, 1999) and an important element of overall economic growth (Johnston and Kilby, 1975; Mellor, 1976; Timmer, 2000).

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[6] This is not to minimize the importance of rice for food security for some regions and urban centers. See for example discussion in Wodon et al. (2008).

[7] Chapter 1 in Hazell and Ramasamy (1991) provides a useful perspective. See in particular, Frankel (1971), Cleaver (1972) and Griffin (1974).

One of the lasting effects of gains in agricultural productivity in Asia and elsewhere has been a relatively steady decline in the price of food staples from the 1970s until recent times. Because of the inelastic demand for rice and wheat as well as the competitive nature of agricultural markets, there were concerns that the benefits of technology gains in agriculture would flow exclusively to consumers, adding further to the gap between agricultural and non-agricultural incomes (Quizón and Binswanger, 1986). Nevertheless, early studies suggested that this was not the case and that significant income gains accrued to rural villages following the adoption of the new varieties (Blyn, 1983; Ahluwalia, 1978; Pinstrup-Andersen and Hazell, 1985; David and Otsuka, 1994). Much of the early evidence was selective and not broadly representative of national economies, but with time, and especially after the launch of representative living standards surveys by the World Bank in the 1980s, better measures of the broad and cumulative effects on poverty of improving agricultural productivity emerged. And, on balance, there is now strong evidence that gains in agricultural productivity, especially in combination with investments in education and infrastructure, are transformational elements of poverty reduction and economic growth and that advances in agricultural techniques have contributed significantly to rising farm incomes and reductions in rural and urban poverty.[8]

Eventually, Asia's Green Revolution came to encompasses technological innovations in a number of crops, but breakthroughs in wheat and rice served as catalysts and conduits for most of the benefits associated with Asia's Green Revolution.[9] And with the Asian experience in mind, a number of authors have called for a similarly styled African Green Revolution based smallholder agriculture, staple crops and high-input technologies designed to substantively improve agricultural productivity.[10]

Even when successful, the approach of expanding agricultural productivity by relying on input-intensive methods is not without problems. Many relate to the poor management of natural resources, especially water and soils, and to the human and environmental costs of mismanaged chemical inputs[11]. Nevertheless, there is evidence that input intensive techniques can be effective in Africa, particularly in the case of rice, which we discuss below. More importantly, current less input-intensive practices appear unsustainable in Africa. This is

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[8] The literature is large, but for a sampling of the contributions of agricultural productivity on growth and poverty reductions see: Thorbecke and Jung (1996); Datt and Ravallion (1998); Foster and Rosenzwieg (2004); Mundlak, Larson and Butzer (2004); Chen and Ravallion (2004); Christiansen and Demery (2007); Gulati and Fan (2008); Bezemer and Headey (2008), Otsuka, Estudillo and Sawada (2009), and Suryahadi, Suryadarma and Sumarto (2009). There is also a large literature about the consequences of the Green Revolution for caste, gender and culture. See Samaddar and Das (2008) and references therein.

[9] The start of the green revolution is often set at 1966 when the first modern or high-yielding varieties of rice and wheat were introduced in developing countries, although a case could be made for an earlier start with the development of new wheat varieties in Mexico. For an early discussion of the Green Revolution see Hayami (1971). Evenson and Gollin (1997) and Evenson (2004) provide later perspectives.

[10] See, for example, Mosley (2002), Evenson (2003), Evenson and Gollin (2003), Djurfeldt et al. (2005), and Annan (2007).

[11] See Pimentel and Pimentel (1990), Byerlee and Siddiq (1994) Huang, Hu, Rozelle and Pray (2008) and Klemick and Lichtenberg (2008), and references therein.

because organic input use and low-input soil management practices are not widely practiced in Africa with the consequence that nutrients are continually extracted from African soils to feed current crops.[12] In the specific case of upland rice, growing population pressure has also reduced the length of traditional fallowing periods, putting more pressure on soils and exacerbating competition from weeds (Johnson et al., 1998).

Still, while chemical fertilizer will be needed to intensify agriculture in Africa, a combination of organic and inorganic inputs works best under a variety of circumstances since they fulfill different roles.[13] While fertilizers directly supply plant nutrients, organic inputs may especially contribute to build the soil organic matter pool and improve soil structure, often resulting in reduced losses and improved capture of fertilizer nutrients by the crop. In addition, the restoration of degraded lands often results in a buildup of sequestered soil carbon, providing in the aggregate an important mechanism for mitigating climate change (Larson and Dinar, 2010).

Developments in Africa's rice economy

In Asia, the important role of rice in the diet and livelihoods of the poor provided a leverage that translated significant production gains into reductions in poverty. As shown in Table 1, rice, on average, accounted for more than a third of caloric intake in Asia during the early stages of Asia's Green Revolution, so that incomes were sensitive to improved supplies and declining real prices. In Africa, the story is different and rice is less central to diets and income. Consequently, a set of coordinated gains across rice, maize and cassava is needed to generate the same welfare effects. Even so, rice is different from other African staples because of its growing importance. As can be seen in the table, the share of calories from rice in the African diet is growing, while the share of maize and tubers has been relatively constant. Figure 1 illustrates both points and also highlights regional differences within Africa. As can be seen in the figure, rice consumption is becoming increasingly important in West Africa, thought the gap between the region and Asia is still large.

Another significant feature of the African rice market is the growing importance of imported rice. As Figure 2 illustrates, rice imports have grown along with consumption and have accelerated during the last two decades. Contributing factors are urbanization and also likely the steady decline in the international price of rice, which has fallen in real terms from the mid-1970s until recent times (Figure 3).[14]

A broad shift in commodity policies is another factor that has influenced rice markets in Africa. By the late 1970s, many governments, including those in Africa, intervened significantly in food and other commodity

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[12] Henao and Baanate (2006), reported in Morris et al. (2007), estimate that 85 percent of African farmland suffer soil nutrient loses at a rate of 30 kg per year or greater.

[13] See for example discussions in Vanlauwe et al. (2002).

[14] The welfare gains from declining prices over time are mirrored by the costs of the recent spike in food prices. For example, Ivanic and Martin (2008) estimate that the most recent surge in food prices increased global poverty by105 million people.

markets. In the case of rice, state monopolies on trade, processing and regulated prices were commonplace in Africa (Pearson et al., 1981). For example, in Mali a parastatal (Office des Produits Agricoles du Mali) held a legal monopoly on cereal marketing and processing for rice (McIntire, 1981); in Senegal, the government limited trade, subsidized inputs and set producer prices (Craven and Tuluy, 1981) Beginning in the late 1980s and early 1990s, African governments began to dismantle internal marketing restrictions and lower trade barriers, a process driven by a desire to boost stagnating production, by fiscal necessity and often supported by structural adjustment lending (Meerman, 1997; Akiyama et al., 2003).[15] As a consequence, world market conditions became increasingly important for African rice producers by the early 21st century.

The effects of the policies and the move to market-driven approaches are captured by Figure 4, which reports nominal assistance rates for eight African countries. The rates provide measures, in the case of a positive value, of the relative protection provided domestic farmers or, in the case of a negative value, the implicit tax trade policies impose on producers, which largely benefits domestic consumers. The figure shows that the net effects of rice policies in Africa have been inconsistent in the past decades, sometimes benefiting consumers, sometimes producers. However, in recent years, there has been a trend toward more neutral policies where neither consumers nor farmers benefit at the expense of the other.

Despite policies that sometimes worked against farmers, rice production has grown steadily in Africa. However, the increase has come through expanded area. This differs from the experience in Asia and there is concern that further production increases in Africa will be eventually constrained by land availability, or that additional gains in rice will crowd out other crops. Figure 5 shows how the components of production have grown in Africa and in Asia during recent decades. In Africa, the area planted to rice has grown steadily, while there has been little land added to rice production in Asia during the last two decades. In contrast, rice yields have grown dramatically in Asia. In Africa, rice yields are much lower on an aggregate basis, but this is partly explained by the fact that rice in Africa is still overwhelmingly grown under rainfed conditions. Moreover, the large differences in average yields between Africa and Asia belie the steady gains that have occurred in Africa.

Table 2 shows how production, area and yields have changed for Sub-Saharan Africa's largest producers between the 1980s and the first decade of the 21st century. In most cases, both area and yields have grown, although there are differences in the mix of area and yield growth. For example, while a significant portion of the growth in production in Nigeria is due to expanded area, cultivated land expanded little in Madagascar and most production gains came via better yields. Average yields improved significantly in Mali and Senegal as well.

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[15] To continue the examples, Mali began restructuring its rice markets in the late 1980s and Senegal in 1995. Both received structural adjustment loans from the World Bank (Meerman, 1997).

On the whole, very little of Africa's rice comes from irrigated plots – on average less than 20 percent in 2004 (Balsubramanian et al. (2007). Table 3 reports the percentage of rice area partially or fully irrigated for Sub-Saharan Africa's largest producers. With the exception of Senegal and Madagascar, the rice economies of most of the top rice production economies in Sub-Saharan Africa are not centered on irrigation technologies. Nevertheless, as will be discussed in the next section, for large areas in Africa, water and land resources are available for expanding lowland production.

Natural resources and the potential for rice in Africa

In a recent article, Balasubramanian et al. (2007) discuss the opportunities and constraints presented by Sub-Saharan Africa's natural resource base. They argue convincingly that land and water resources suitable for rice are abundant in Africa. Any estimate depends greatly on the definition of suitable, but the authors calculate that upwards of 240 million hectares of agroclimatically suitable wetlands is available in Africa. They argue as well that the expansion of rice production need not compete with other food crops, since much of the low-lying wetlands suitable for rice during rainy seasons is inhospitable for other crops. Even so, only an estimated 3.5 million ha of wetlands are planted to rice in Africa.

Agroclimatic potential and economic viability differ, and the constraints on expanding rice production and productivity in Africa are numerous. Some have to do with abiotic risks, such as weather variability leading to droughts, flooding and extreme temperatures, soil conditions related to erosion, salinity, low carbon content and phosphorus fixation, which limits the efficacy of fertilizers. Other constraints relate to pests and disease for the crop (weeds, blast, the rice yellow mottle virus and the gall midge) and risks to draft animals and farming households, especially from water-borne diseases such as malaria and bilharzia. Additional constraints are economic, especially those related to poor transportation systems that adversely affect the relative farm-gate prices for inputs and marketed rice surpluses. The fundamental economic constraints are exacerbated by limited credit and insurance markets and by low-levels of education, which hamper information dissemination and extension efforts. In some cases, insecurity, the risk of predation and weaknesses in the institutions charged with managing property rights and water resources also work against the up-take of more profitable and productive farming techniques. Moreover, because rice production can also take place in areas sensitive to the adverse effects of poorly managed production, the expansion of rice into wetlands can extract high environmental costs when the institutions that manage natural resources are weak.

Still, not all obstacles are equally present in all of the areas potentially suitable for rice production. In addition, advances in breeding and the dissemination of recently developed varieties can help with some of the biotic and abiotic challenges to rice in Africa and, by allowing rice plants to use nutrient and water resources more efficiently, address some of the economic hurdles as well.

In Africa, rice is grown in four ecosystems: upland (38% of planted area), rainfed wetland (33%), deepwater and mangrove swamps (9%) and irrigated wetland (20%) (Balasubramanian et al. 2007). Wetlands can be sub-divided into four categories: inland basins and low-lying drainage areas, river flood plains, inland valleys and coastal wetlands. Among these, inland basins and inland valleys account for most of the area-- about 193 million hectares; the Congo basins are examples. Often, though well suited for rice, these areas can be remote from markets. River floodplains such as those adjacent to the Niger and the Zambezi, and coastal wetlands, including large rive deltas and estuaries of the Gambia and Zaire are part of this group and offer similar opportunities for rice cultivation. Total areas in these latter two subcategories amount to nearly 47 million hectares and, as a group, are more accessible. Upland rice, also known as dryland rice, is dependent on rainfall and is grown on level or mildly slopping lands. Traditionally, upland rice is produced for home consumption in Africa and an examination of the area suitable for upland rice has not garnered the same attention as areas where water is more abundant. Still, Balasubramanian et al. report that more than 2.7 million hectares of land in Africa was planted to upland rice. Low productivity and profitability appear to be limiting factors, since upland rice requires moderate rainfall (annual totals of 0.9 to 2.0 m) and the shifting cultivation practices common in many of the areas where upland rice is currently grown suggest abundant land resources presently.

The relationships among modern rice varieties, ecosystems and land scarcity are important for understanding the past evolution of Africa's rice sector and its future prospects. As Hossain (2006, 2007) points out, growing population pressure on food resources in Asia spurred the development of land-saving (higher yielding) rice varieties and also led to the establishment of research institutions aimed at fostering further progress. One outcome was a set of technologies that disproportionately benefited water-and-fertilizer intensive rice. Looking at global growth rates across ecosystems, the author finds that yields for partially-irrigated and irrigated rice grew 2.8 and 2.4 percent annually for 20 years between 1970 and 1990, while yields for rainfed upland rice increased at 0.9 percent annually for the same period. On balance, the new technologies for rice were less relevant for Africa, where investments in irrigation were lower and where high transport costs kept fertilizer prices high relative to the farmgate price for rice. Importantly, the lack of substantive progress for non-irrigated rice left most African rice farmers without a strong alternative to traditional upland seeds and farming methods.

Still, as discussed, the use of Africa's abundant land resources is limited by a host of abiotic and biotic constraints and isolated by poor infrastructure. In addition, deteriorating water quality and declining soil fertility threaten some areas currently farmed. Moreover, in some cases it will be important to preserve land otherwise suitable for rice, especially around estuaries, since these lands already provide valuable environmental services, for example, serving, as buffers against storm surges and providing unique habitats for rare plants and animals.

For these reasons, the amount of new land available for expanding rice production is already limited in some countries and, with time, land frontiers in Africa will eventually close. It is perhaps telling that, while the average amount of arable and permanent cropland per capita of agricultural population is significantly larger than in South Asia today, the amount is not so different from the late 1960s, when Asia's Green Revolution was getting underway (Figure 6). Moreover, events in global markets may hasten this process, since there is evidence that gains from low-land innovations of the type that fueled Asia's Green Revolution are slowing. For example, Hossain (2007) finds that, world-wide, annual yield gains for irrigated and partially irrigated rice from 1990 to 2005 slowed to 0.7 and 1.7 percent, while the growth in rainfed yields was largely unchanged. With new land suitable for rice limited elsewhere, the deceleration of yield growth among the world's largest rice producers and the growing demand for rice in and out of Africa will create new incentives for farmers in Africa to adopt the land-conserving farming practices common in Asia.

A New Rice for Africa

The previous sections highlighted the current importance of lowland rice and the slow pace of improvement in rainfed yields worldwide. Overall, yield improvements can come about by improving the way current crop technologies are applied and through the innovations in the form of new varieties. In the next section, we explore this first avenue for improving yields, looking especially at crop husbandry and water management practices commonly used in Asia that can be adapted for use in Africa. But in this section we turn our attention to a new family of rice varieties, initially developed for rain-fed conditions.

This family of varieties is based on the successful crossing of an African (Oryza glaberrima) and Asian (Oryza Sativa) rice and the term, NERICA (New Rice for Africa) applies to the rice varieties that come out this interspecific crossing of the two distinct rice species. [16] Field tests suggest the new varieties hold great promise with higher yield potential under a variety of soil and weather conditions, more protein, a shorter growing period, and a greater resistance to African pests and diseases.

NERICA varieties were developed at the main M'bé research center of the Africa Rice Center (AfricaRice), through conventional crossbreeding. AfricaRice estimates that the initial research, which focused on upland rice, generated more than 3,000 interspecific siblings, encompassing a wide variety of attributes. By the close of 2005, 18 upland varieties (NERICA1-NERICA18) has been selected through Participatory Varietal Selection (PVS) and on farm trials by African NARS for release in their countries. On-farm tests report paddy yields in excess of 1 ton per hectare (Table 4) without fertilizer in rainfed areas and up to 5.7 tons per hectare when fertilizers are applied (Table 5). AfricaRice has also examined ratooning yields – that is, a secondary production obtained by leaving the lower part of the rice plant during harvesting. Based on field studies from Dévé, a savannah zone of Benin, Sanni et al., (2009) report that ratooning yields ranged from 39

[16] This section draws on an informative NERICA compendium edited by Somado, Guei and Keya (2008).

to 13 percent, potentially pushing the combined yields in excess of six tons per hectare. Kouko et al. (2006), reported in Somado, Guei and Keya (2008), find similar results from field tests in Kenya.

The scope of the interspecific breeding program has grown substantially since 2000. Of particular interest is the creation of a set of NERICA lines suitable for irrigated areas and rainfed low-lands. While the upland NERICAs are based on the upland strain of Asian rice (*japonica*), the so-called NERICA-Ls are based on the lowland strain (*indica*). The breeding efforts date from 2000, and research has focused on 60 progenies. By 2006, eight NERICA-Ls had been released for testing in farmers' fields in Burkina Faso, Cameroon, Kenya, Mali, Niger Togo, and Sierra Leone (Somado, Guei and Keya, 2008). The lowland NERICA varieties are expected to make a bigger impact than the upland NERICA with paddy rice yield potential of 6-7 tons per hectare. The results from a study conducted in 2004 wet season in 8 countries on 19 sites gave lowland NERICA yield ranging from 5-7 tons per hectare. NERICA L-9 and NERICA L-33 obtained the higher yield between the 37 selected varieties with 7.2 tons per hectare and 7.1 tons per hectare respectively (Sie et al., 2008).

As discussed, in many places, upland rice is a crop grown to meet food needs and little is marketed. Consequently, markets for inputs and outputs are not necessarily well established and the full benefits of the new lines may go unrealized. An immediate problem is the supply of rice seeds. Private seed companies sell to a limited market in Africa. Further, in some cases, import policies aimed at safeguarding agriculture can also create hurdles to adequate seed supplies. As a result, farmers acquire most seed from informal sellers or produce the seed themselves. In the case of NERICA varieties, farmers who have been trained properly can maintain the quality of their seed for extended periods, since NERICAs, like other rice varieties, is self-fertilizing. To fill the gap, AfricaRice has promoted community-based seed production systems in Benin, Gambia, Ghana, Guinea, Cote d'Ivoire, Mali, Nigeria and Sierra Leone.

Early evidence from the first round of NERICAs suggests obstacles to the diffusion and adoption of the new technology among farmers and, consequently, adoption rates in terms of proportions of farmers and area planted.[17] For example, Diagne et al. (2009) report adoption rates of 4 percent for Côte d'Ivoire in 2000, 20 percent for Guinea in 2001, 18 percent in Benin in 2004 and 40 percent in Gambia in 2006. In Nigeria, Spencer et al. (2006) estimated that up to 30 percent of farmers in the state of Ekiti, Nigeria cultivated NERICA varieties in 2005 and that 42 percent of farmers in PVS villages in Kaduna Nigeria grew NERICAs. Diagne suggests a range of social, economic and institutional hurdles. Markets played a role; both land availability and participation in land markets boosted adoption. Programs that increased farmers' awareness about characteristics of particular NERICA varieties proved key as well.

[17] By diffusion, we refer to the degree to which farmers have knowledge of NERICA technology and access to seed. These are the preconditions for adoption – that is, the farmer's choice to plant NERICA.

Still, even in places where NERICAs have been introduced, overwhelming evidence from the field of substantial yield benefits are slim. This point is emphasized by Orr et al. (2008), who discuss the gap between the potential of NERICA varieties and evidence of its success. For example, the studies by Diagne cited earlier show mixed outcomes. On one hand, an impact evaluation suggests that NERICA varieties generated significantly higher yields in Benin, but similarly structured evaluations provide no strong evidence of broad yield improvements in Côte d'Ivoire, or Guinea. In Uganda, where rice is a relatively new crop, Kijima et al. (2008, 2010) report favorable yield outcomes for some NERICA varieties. Moreover, consistent with evidence on yields, studies suggest consumption benefits in Benin (Adekambi et al., 2007) and Uganda (Bergman-Lodin 2005; Kijima et al. 2006). At the same time, a recent study by Kijima et al. (2010), suggests that heterogeneous outcomes should be expected. Based on a panel of rice farmers in Uganda, their study suggests that differences related to climate and alternative income sources, as well as differences among farmers in their capacity to replicate seeds of NERICA varieties, can lead to different adoption outcomes.

While there is an urgent need to increase the number of evaluations of the impact of NERICA varieties on yield, there are suggestions that evaluations should be broadened beyond measures of land productivity. Wopereis et al. (2008) emphasize this point in their discussion of the role farmer preferences should play in the evaluation of new varieties. For example, Diagne suggests the reason farmers might prefer NERICA varieties to traditional varieties with similar yields has to do with the shorter growing season for NERICAs. This characteristic reduces the risks associated with terminal droughts, saves on labor and sometimes allows for a second rice crop. Because evaluations tend to focus on yield (land productivity) rather than labor or total factor productivity, the benefits of NERICAs go unmeasured under normal weather conditions. There is support for the later view in a study by Dalton (2004), which suggests that the shorter growing cycle, rather than potential yield benefits are NERICA's most attractive feature.

Lessons from Asia

In this section, we turn to the prospects of expanding low-land rice in Africa, based on lessons from Asia's experiences. This is not to diminish the ample opportunities for learning from Africa's own experiences. As will be discussed later, there are several examples of significant productivity gains in Sub-Saharan Africa and yields in Egypt are among the highest in the world. Still, Asia's successful Green Revolution is well established and well studied and this is helpful when considering Africa's future. It is also worth pointing out that the lessons from Asia mostly concern breakthroughs in irrigated and semi-irrigated lowland rice, so the lessons drawn here pertain to the particular places with conditions that are conducive to these rice production systems. Consequently, the degree to which Asia's technologies are directly transferable to Africa will be place-specific, although as we argue below the scope for transfer is large. Moreover, the scope for adaption – that is the scope for modifying Asian practices to suit African conditions is larger still.[18]

The Green Revolution for rice in Asia started in 1966 when the International Rice Research Institute released IR8, the first modern variety of rice. Rice is the essential Green Revolution crop in southern Asia, and while the Green Revolution in Africa may include more than one crop as none dominates, rice will be important for several reasons.[19] First, Asia has already accumulated a huge stock of scientific knowledge and useful production methods that could well serve Africa if selectively and appropriately adapted to its socio-economic and agro-ecological environments. Second, as shown in Figure 2, there has been an increasing demand for rice but low self-sufficiency ratio of only about 60%. Third, lowland rice varieties, which propelled and sustained the Asian Green Revolution, have exhibited high yield potential in lowland areas in sub-Saharan Africa, e.g. a short-duration IRRI bred variety was selected by AfricaRice breeders in the 1990s and is now widely grown in the Senegal River valley. Fourth, and finally, there is a huge amount of farmlands that are agroclimatically hospitable to rice production. As discussed, Balsaubramanian et al. (2007) estimate that upwards of 240 million ha of wetlands is available, which is 1.7 times more than the 142 million ha of rice area harvested in Asia in 2008 (FAOStat, 2009).

Borlaug (2002) argues that what Africa essentially needs is a simple, effective farming system based on modern technology – chemical fertilizer, improved seeds bred for local conditions, and effective crop management practices. This is perhaps an overly simplistic, since it fails to take into account the complexity of Africa's geography and rice production system. Nevertheless, it does reflect a commonly held view that a "seed-fertilizer" approach is also appropriate for Africa. In turn, this makes Asia's stock of potentially profitable matured technologies especially relevant for Africa.

The Asian Green Revolution in rice did not happen overnight but was a long-term evolutionary process involving long and sustained efforts in rice research spanning more than four decades since 1966. The first-generation of modern rice (e.g., IR5 and IR8) were effective in dramatically increasing yield potential but were susceptible to various forms of pests and disease infestations. The second-generation of modern rice (e.g., IR36) incorporated a wide-spectrum of pests and disease resistant traits and early maturity period (Khush, 1995). Resistant modern varieties (MVs) contributed significantly to the acceleration of yield growth by reducing yield variability thereby increasing the expected yield particularly during the dry season (Otsuka et al., 1994). The shorter growth duration increases cropping intensity per year which results in more harvests from a given plot of land each year (Barker, Herdt and Rose, 1985). The third-generation of modern rice varieties

[18] Often, the difference has to do with water availability and water management practices. See, for example, the discussion in Woperis and Defoer (2007).

[19] Although there have been attempts to disseminate high-yielding varieties of sorghum and millet, which also have relevance for Africa, these efforts were confined largely in some parts of India (Deb and Bantillan, 2003).

(e.g., IR64) successfully combined high yield potential with pests- and disease-resistant traits and grain qualities that are preferred by rice consumers. In more recent years, there have been efforts to use biotechnology in developing rices that are suitable to unfavorable environments (i.e., drought-prone rainfed lowland, upland, flood prone, and tidal wetlands) for which the conventional breeding method has produced only a small number of rices (Khush, 1995).

There are already clear success stories on the use of Asian rice technology that indicate the possibility of inducing a string of local Green Revolutions in Africa. Average paddy yields have improved dramatically in the Office du Niger in Mali and the Senegal River Valley in Senegal since the 1980s and now average 5 to 6 tons per hectare. And *Oryza sativa* lowland rice grown in areas with simple irrigation canal in Côte d'Ivoire yield an average of 3.6 tons per ha while those varieties that were grown in areas without canal have an average yield of 2.5 tons per ha with minimum even when application of chemical fertilizer are negligible (Sakurai, 2006). Kajisa and Payongayong (2008) demonstrate that yields of lowland rice can be potentially high (3.8 tons per ha) in irrigated areas of Mozambique, where irrigation facilities are poorly maintained. Evidence from Uganda suggests that NERICA varieties could potentially increase the yield potential of upland fields from 1 ton to 2-3 tons per hectare (Kijima et al., 2008). And finally, a study in Doho irrigation scheme in Eastern Uganda reveals that paddy yields are as high as 3 tons per ha even without application of chemical fertilizer and despite continuous double cropping of rice for the last few decades (Nakano, 2008).

It is important to note that yields can be raised by introducing simple water controls and crop husbandry in general, moving towards the Asian 'Sawah' model, of bunded, well-leveled and puddled rice fields that reduce risk and facilitate investments in mineral fertilizer. For example, Becker and Johnson (2001) point out that the construction of field bunds has the potential to significantly increase rice production in West Africa, while also possibly reducing labor requirements for hand weeding and allowing for a more efficient use of mineral N fertilizers.

A similar point is illustrated in Table 6, which shows rice yields, land condition, and farming practices of two major rice producing regions in Tanzania in 2009. The importance of irrigation for high productivity is obvious from the table. Under irrigated condition, farmers achieve the yield close to 4 t/ha by applying 37-43 kg of chemical fertilizer per ha on average and the most of the plots are leveled.[20] Moreover, under rainfed condition, moderately high yield around 3 t/ha are observed when plots have bunds. Many of these plots are also leveled with significant amounts of chemical fertilizer applied.

[20] Given the achievement of attractive yields under irrigated condition or under rainfed condition with bund in Mbeya, the adoption rates of modern variety look too low. Note, however, that if we include two major local varieties, India rangi and Faya (or Fayaduma), which have the potential yield of 5 t per ha., Mbeya's adoption rates become 5.7% for rainfed without bund, 29.4 % for rainfed with bund, and 51.5 % for irrigated

It is important to mention that markets for inputs and outputs have started to develop in Africa. Kijima et al. (2008) reported that in Uganda, where NERICA varieties were adopted, access to rice millers was greatly improved owing to the rapid increase in the number of rice millers and rice seeds have been increasingly available from seed suppliers and purchase from neighboring farmers. Tsuboi (2008) reported that the total number of private rice mills in Uganda rose from 183 in 2000 to 591 in 2007. These are good examples to show that markets could respond favorably to the diffusion of new profitable technologies in Africa.

Overall, the Green Revolution in rice in Africa is not an impossible dream at all and in some places, approaches and methods that have proved successful in Asia have worked well in Africa. But Africa is diverse and no single approach will suffice. A blend of African methods and innovations and global lessons from Asia and elsewhere can set the stage for a portfolio of successful approaches.

Expectations for the future

Looking forward, it is important for policy and for research to consider whether rice has a special role in African agriculture. Certainly, if past trends hold, it will play an increasingly important role in the African diet, as urbanization and household time constraints favor further increases in consumption. In recent years, imports, made affordable by low world price, have supported increases in rice consumption in Africa. However, the prospects of higher global commodity prices and the production potential of modern varieties both support the notion that future market conditions will favor African producers as well.

At the start, it is important to recognize that there is great potential for improving productivity outcomes for Africa's rice producers with existing technologies, especially for lowland rice. To a large degree, this potential can be achieved by adopting basic production practices as the construction of bunds, leveling, flooding, and straight row planting -- practices currently used by Asian rice farmers without exception and increasingly by many African farmers as well. As in Asia, most African producers are smallholders, who stand to benefit from increases in local demand and the technological promises of low-land rice. Even so, the consequences of an African Green Revolution in rice will likely differ from Asia's. For one, African diets and African agriculture are more diverse. As a consequence, the gains from increases in rice productivity will not be, by itself, transformational for the continent. Still, there are places, especially in West Africa, where rice production and consumption figure prominently. Consequently, there is great potential for local green revolutions in rice that are suggestive of the broad revolutions that swept through South and Southeast Asia. Moreover, existing trends in urbanization will give rice a greater place in African diets and the potential for productivity-associated welfare gains will grow as well.

In past decades, an important factor that distinguished Africa from Asia is Africa's relative abundance of land. This has not been true of all places; however for the most part, the availability of land and water resources in Africa to date has differed significantly from what prevailed in Asia in the later decades of the 20th century when Asia's Green Revolution began, and this has had implications for technology choice (Spencer and Byerlee, 1976). Consequently, in Asia, finding ways to boost the productivity of limited land resources was a necessary step to improving productivity growth overall. In Africa, the constraints faced by households are more complex and gains in yields alone need not be the chief concern in all places. In consequence, it is important to have a comprehensive view of productivity that incorporates all input factors and also addresses potential losses stemming from biotic and abiotic risks. At the same time, Africa's land and water resources are not unlimited and there are more binding limits on suitable areas for expanding rice production outside of Africa, even as global demand grows. Taken together, this suggests that land-saving technologies will be more relevant in Africa's future.

In Asia, productivity gains from new technologies feed directly into existing markets for rice – in part because of the proximity of production and consumption centers. Often in Africa, rice (especially upland rice) is produced for home consumption, so surpluses generated by higher yields do not necessarily have immediate markets. Markets, supported by local traders and processors, may arise endogenously, but with delay. Looking forward, demographic trends point to greater population densities and the current expansion of transport and communication infrastructure in Africa will work to mitigate these obstacles, but continued support through public investments and supportive policies are key.

For these many reasons, the future role for rice in Africa is more complex and nuanced than it was in Asia, when the Green Revolution in rice began. That does not diminish from the significant role for rice currently in Africa nor should it take away from efforts to develop new technologies that promote productivity gains. Rather, it suggests that the constraints households face in Africa differ from place to place and are less homogeneous than in Asia's past. Consequently, the characteristics of the rice varieties that are key to Africa's success are not necessarily the same as Asia's or even across all of Africa. Certainly yields and land productivity are important, but so are the consequences of new seed varieties for labor, fertilizer demand and weather vulnerability. This should shape future research and also guide investments in infrastructure, irrigation, education and the institutions that back markets. Nonetheless, it must be emphasized that there remains an untapped potential for African rice farmers to become more productive now by taking advantage of farming methods common in Asia and used with success in some places in Africa. This, together with the potential associated with new African innovations suggests that a Green Revolution is possible.

This is encouraging, since the importance of Africa's success holds not only for Africans. As the world's food systems become more closely tied and as the potential for supply gains slow in other places, it is hard to imagine a sustained period of affordable food extending far into the future without Africa's participation.

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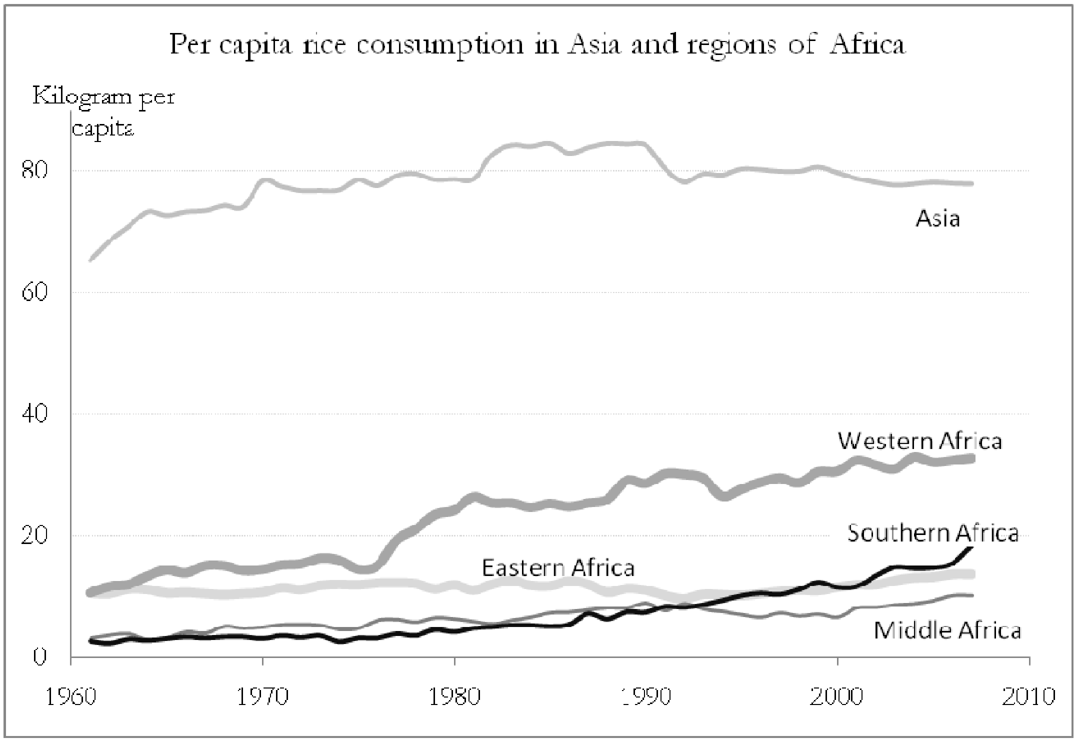
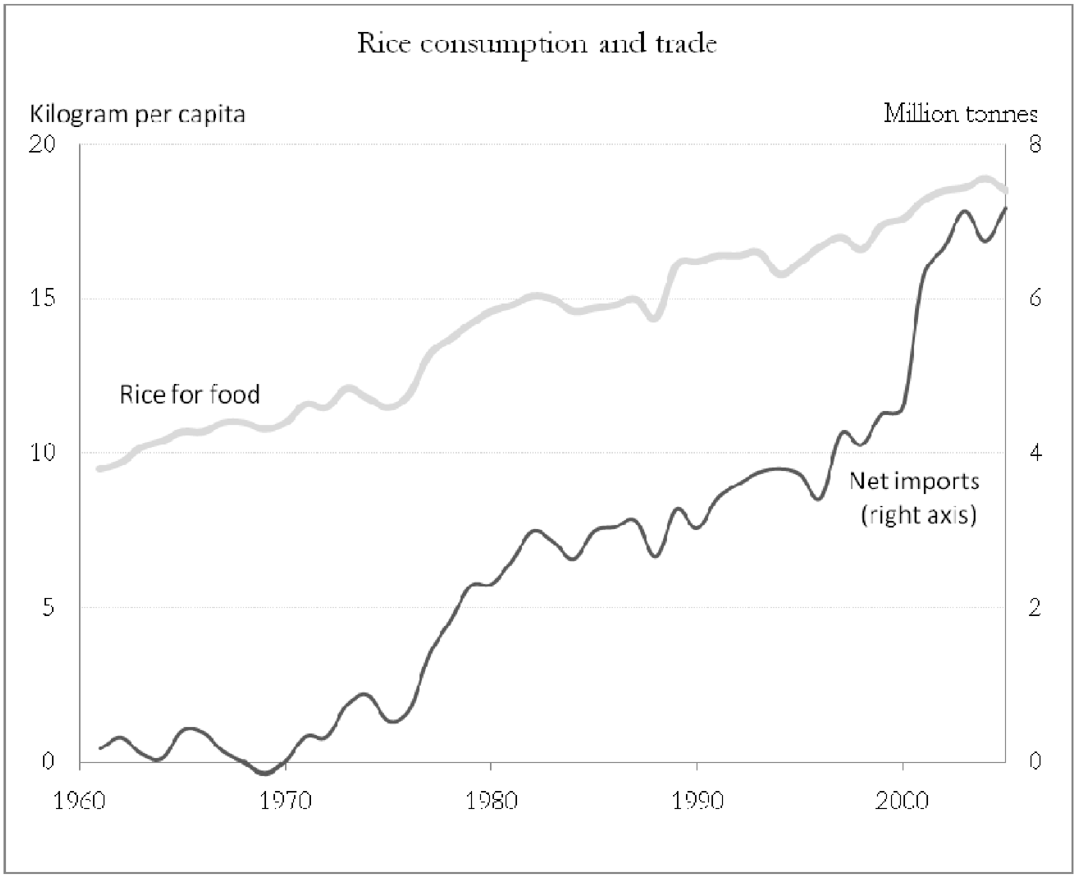
Figures

Figure 1: Rice consumption in Asia and regions of Africa



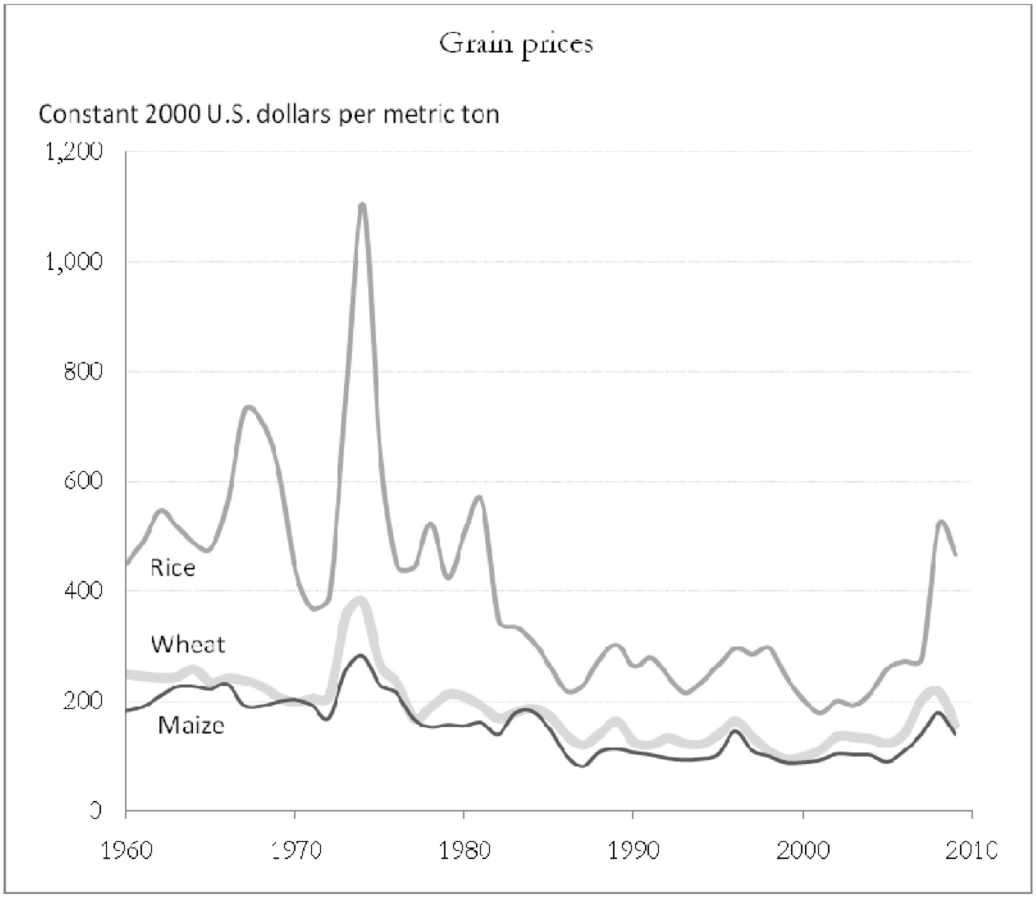
Source: FAO (2010)

Figure 2: Rice consumption and trade in Africa



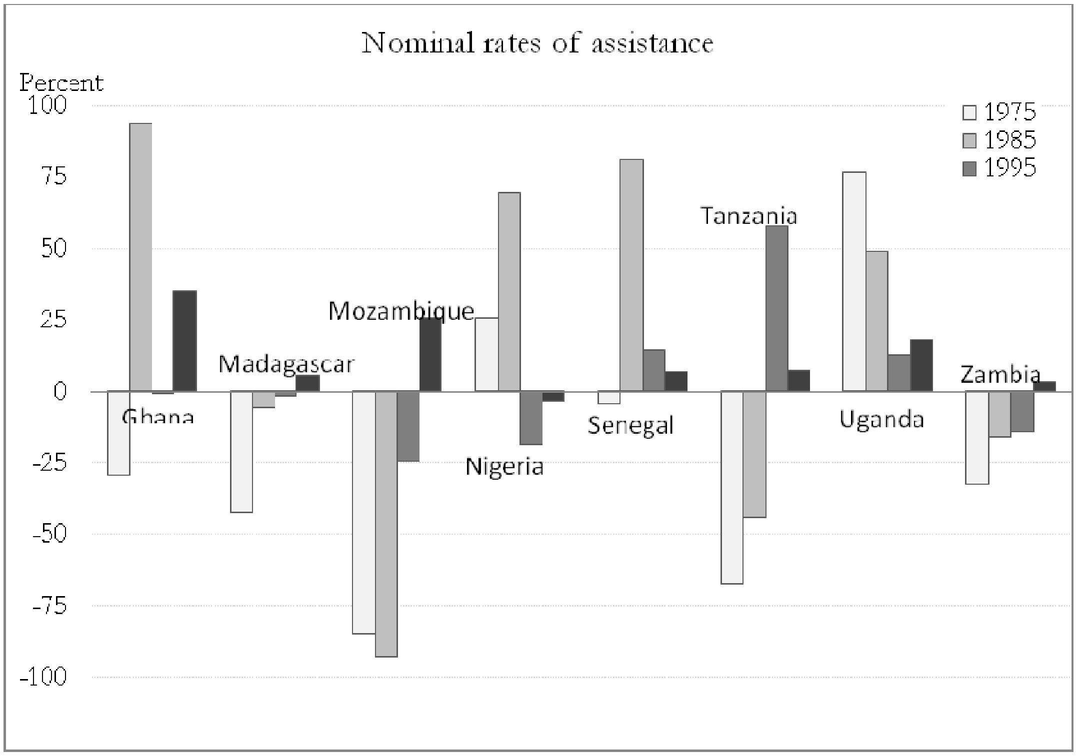
Source: FAO (2010)

Figure 3: Grain prices, 1960-2009



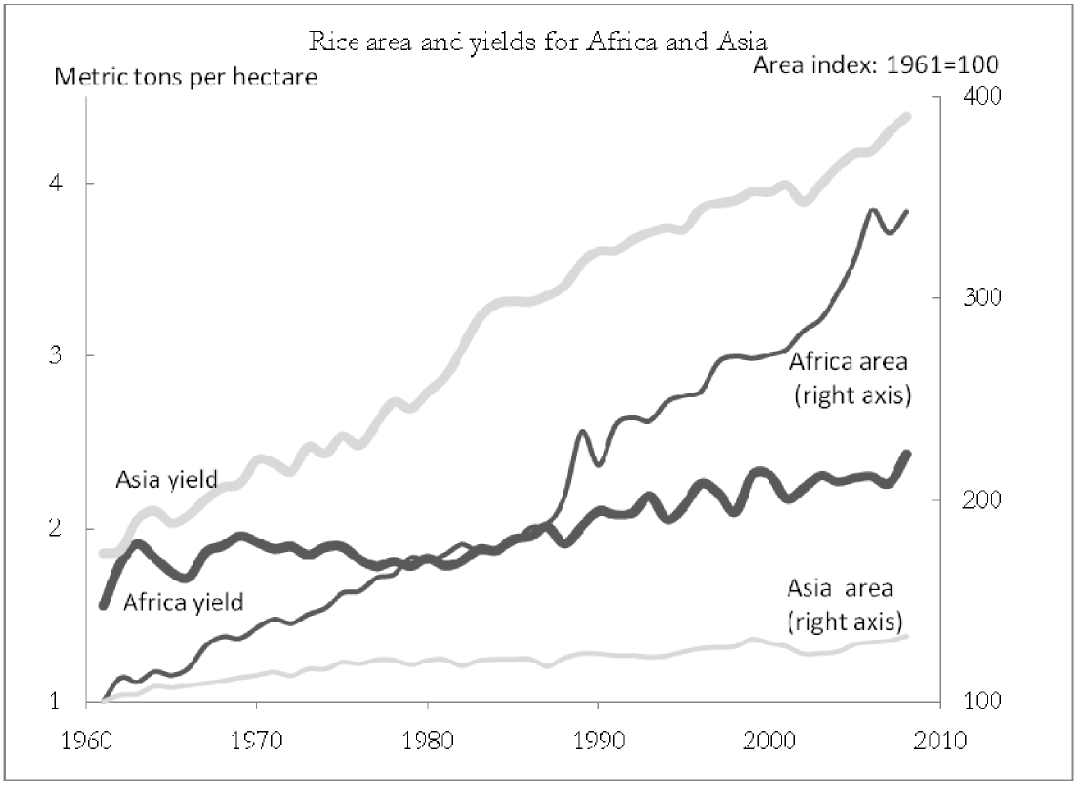
Source: World Bank (2010)

Figure 4: Producer rates of assistance for rice in selected African countries, 1975 to 2004



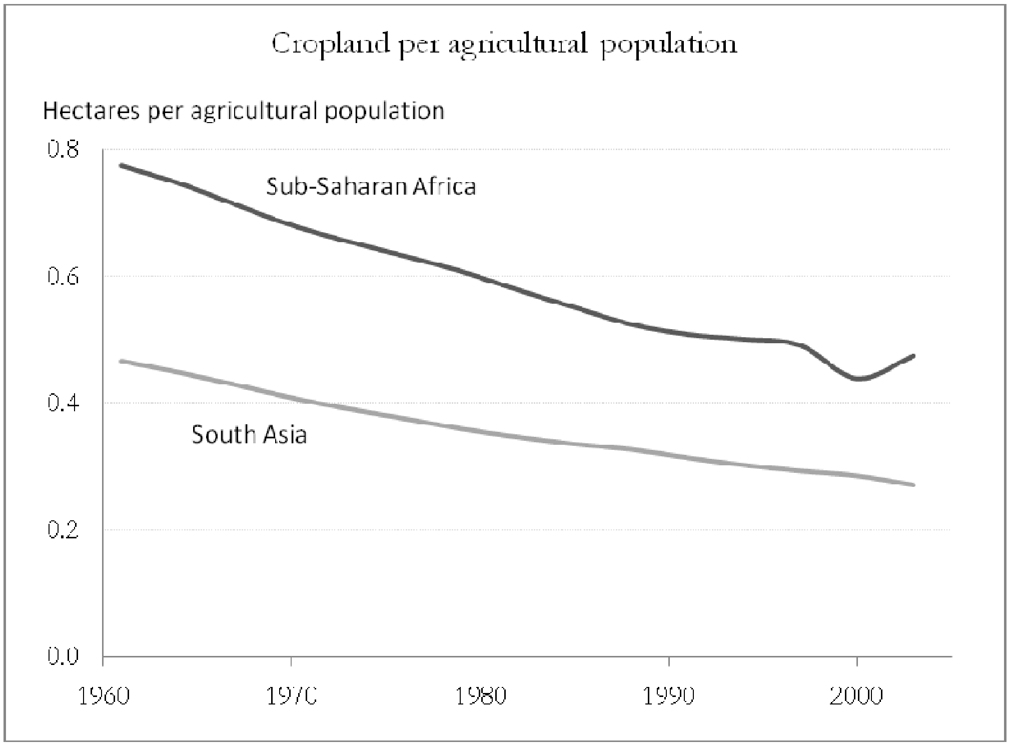
Note: Three-year averages of nominal rates of assistance centered on reporting year. The nominal rate of assistance is the percentage by which the domestic producer price for rice is above or below the border price. Source: Anderson and Valenzuela (2008).

Figure 5: Area and rice yields in Africa and Asia



Source: FAO (2010)

Figure 6: Cropland per agricultural population



Source: 2008 World Development Report

Table 1: The role of rice in Asian and African diets, selected years

	1965	1975	1985	1995	2005
Africa average calories	2,100	2,167	2,238	2,318	2,407
Share of average					
Rice	0.05	0.05	0.07	0.07	0.08
Maize	0.15	0.15	0.15	0.16	0.15
Roots	0.16	0.15	0.13	0.15	0.14
Asia average calories	1,977	2,049	2,360	2,595	2,649
Share of average					
Rice	0.39	0.37	0.36	0.31	0.30
Maize	0.02	0.03	0.02	0.03	0.02
Roots	0.08	0.08	0.04	0.04	0.04

Note: Average calories are calculated on estimates of available food supplies as kilocalories per capita per day (FAO 2010)

Table 2: Production, area and yield for selected African countries

	Production (thousand tons)			Harvested area (thousand hectares)			Yields (tons per hectare)		
Countries	1960s	1980s	2000s	1960s	1980s	2000s	1960s	1980s	2000s
Nigeria	255.33	1,617.13	3,378.00	201.22	783.80	2,345.67	1.25	2.07	1.44
Madagascar	1,640.35	2,148.33	2,939.43	905.28	1,165.76	1,230.71	1.81	1.85	2.38
Guinea	252.38	587.79	1,240.68	148.22	343.94	701.43	1.70	1.71	1.76
Tanzania,	119.34	446.95	1,094.09	104.44	291.21	621.90	1.16	1.51	1.76
Mali	164.37	204.54	937.24	167.02	178.63	415.59	1.00	1.13	2.25
Côte d'Ivoire	265.62	509.10	661.57	265.58	437.60	353.68	0.99	1.16	1.87
Sierra Leone	390.79	493.23	634.35	297.12	372.70	623.69	1.31	1.33	1.02
Congo, DR	95.17	296.50	319.13	123.20	363.60	422.69	0.77	0.82	0.75
Ghana	42.89	71.50	256.10	37.14	72.45	121.72	1.14	1.02	2.11
Senegal	108.38	129.49	227.37	82.00	71.03	88.56	1.30	1.82	2.53
Liberia	135.89	285.05	166.02	190.56	226.94	137.06	0.78	1.26	1.18
Mozambique	88.77	85.60	138.81	67.81	100.00	171.05	1.33	0.86	0.80
Uganda	4.17	22.10	137.33	3.80	17.00	96.56	1.18	1.30	1.43
Chad	31.60	36.63	120.91	27.41	31.58	94.54	1.16	1.11	1.27
Guinea-Bissau	45.28	94.37	104.10	52.33	78.14	69.41	0.94	1.40	1.49
Burkina Faso	34.73	40.02	101.15	41.97	25.52	49.71	0.85	1.62	2.03
Malawi	8.67	34.99	83.94	10.39	24.06	52.10	0.86	1.50	1.59
Mauritania	0.56	30.47	75.40	0.41	6.83	17.61	1.53	4.51	4.30
Togo	20.21	18.79	68.71	25.04	20.72	31.77	0.84	0.94	2.16
Benin	1.34	8.24	67.86	2.21	7.09	27.32	0.59	1.17	2.47
Niger	20.48	52.61	65.41	10.80	21.56	21.34	1.78	2.43	3.07
Burundi	2.77	20.00	64.35	1.31	6.76	19.58	2.26	2.92	3.28
Cameroon	12.97	70.18	52.65	12.56	18.51	35.72	1.00	3.96	1.64
Kenya	16.00	44.79	52.24	4.38	12.51	15.15	4.11	3.63	3.50
Rwanda	0.23	6.44	41.27	-	0.02	0.04		1.88	2.00
Central African Republic	6.59	13.40	37.07	7.22	10.56	18.94	0.91	1.30	1.94
Gambia	32.80	28.79	26.55	25.48	17.86	16.91	1.28	1.68	1.69
Sudan	1.34	3.49	19.75	1.54	4.19	6.43	0.97	0.93	2.99
Comoros	10.78	13.22	17.00	9.57	12.52	14.00	1.13	1.06	1.21
Zambia	0.07	8.12	15.08	0.17	8.53	12.03	0.40	0.92	1.26

Source: FAO

Table 3: Portion of rice land fully or partially irrigated in 2004

Country	Percentage
Benin	2
Burkina Faso	18
Burundi	21
Cameroon	95
Chad	9
Congo, DR	0
Gambia	7
Ghana	4
Guinea	10
Guinea-Bissau	1
Kenya	100
Liberia	2
Madagascar	52
Malawi	28
Mali	22
Mauritania	100
Mozambique	2
Niger	80
Nigeria	15
Rwanda	8
Senegal	50
Sudan	75
Tanzania	27
Togo	1
Uganda	2

Source: Balsubramanian et al. (2007)

Table 4: Grain yields from NERICA grown on-farm without fertilizer application

Country	Sites	Variety	MT/ha.
Cote d'Ivoire	Boundiali	NERICA2	1.37
		NERICA3	1.11
		NERICA4	1.26
	Danane	NERICA2	1.95
		NERICA3	1.87
		NERICA4	1.52
	Gagnoa	NERICA2	2.28
		NERICA3	1.71
		NERICA4	1.83
Mali	Samanko	NERICA2	1.50
		NERICA6	1.00
	Sikasso	NERICA2	1.72
		NERICA6	1.06
Togo	Amlame	NERICA1	2.08
		NERICA4	1.35

Source: Somado et al. (2008)

Table 5: Grain yields from NERICA grown on-farm with fertilizer application

Country	Sites	Variety	MT/ha.
Ghana	Nyankpala	NERICA1	2.58
		NERICA4	2.53
		NERICA6	3.17
	Golinga 1	NERICA1	4.98
		NERICA4	3.65
		NERICA6	4.96
	Golinga 2	NERICA1	3.29
		NERICA4	2.38
		NERICA6	3.59
Guinea	Faranah, Dantilia	NERICA1	3.95
		NERICA3	4.27
Mali	Longorola	NERICA8	1.68
		NERICA9	1.41
	Finkolo	NERICA8	3.40
		NERICA9	4.06
Kenya	Kari Kibos	NERICA1	5.19
		NERICA4	5.77
		NERICA10	4.66
		NERICA11	5.45
Tanzania		NERICA2	4.54
		NERICA3	4.44
		NERICA4	5.10
		NERICA7	4.60
Uganda		NERICA4	4.50 to 5.00
Ethiopia	Oromia	NERICA 1	4.00 to 5.00

Source: Somado et al. (2008)

Table 6: Rice yield, land condition, and farming practice in Morogoro and Mbeya regions, Tanzania in 2009

Region	Morogoro			Mbeya		
	Rainfed		Irrigated	Rainfed		Irrigated
	Without Bund	With Bund		Without Bund	With Bund	
Paddy Yield (t/ha)	2.0	3.1	3.9	1.3	2.8	3.8
Share of leveled plots (%)	20.5	47.1	69.8	33.3	70.6	77.1
Share of area under modern variety (%)	13.5	67.2	90.7	0.0	0.0	1.7
Chemical fertilizer use (kg/ha)	12.0	64.3	43.8	10.1	45.6	37.3
Sample Size	161	17	43	90	17	96

Note: If we include two major local varieties, India rangi and Faya (or Fayaduma), which have the potential yield of 5 t per ha., Mbeya's adoption rates become 5.7% for rainfed without bund, 29.4 % for rainfed with bund, and 51.5 % for irrigated.