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Evidence-Based Strategy for a Rice Green Revolution in Sub-Saharan Africa

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Abstract

It is urgent to increase productivity of staple crops per unit of land in order to improve food security and reduce hunger in sub-Saharan Africa (SSA). It is by now clear that lowland rice is the most promising staple crop in SSA, because of the high transferability of improved technology from Asia. Based on empirical evidence, this short essay argues that SSA has failed to realize rice Green Revolution because basic rice cultivation practices, which have been common all over the Asia, have never been widely adopted in SSA. Therefore, our main conclusion is to invest in the capacity of extension systems to promote widespread adoption of improved rice cultivation practices as well as improved seeds and chemical fertilizer.

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1. Introduction

Considering the rapidly growing population and increasingly limited availability of unused cultivable land in sub-Saharan Africa (SSA), it is urgent to increase the yield of staple crops per unit of land to improve food security and reduce hunger on this continent (Holden and Otsuka 2014). It is by now clear that lowland rice is the most promising staple crop in SSA, because of the high transferability of improved rice production technology from Asia (Otsuka and Larson 2013, 2016). In fact, the yield of lowland rice per unit of land in selected areas in SSA where either Asian rice varieties or their offspring are grown is often higher than or comparable to that in tropical Asia. That is to say, a rice Green Revolution has already begun in limited areas of SSA. Yet, rice consumption has been increasing more rapidly than production, resulting in increasing imports of rice from Asia to SSA.[2] At present, the imported Asian rice is relatively cheap, but this is unlikely to continue because the production cost, particularly the labor cost, of rice production in Asia is likely to increase due to the rapid increase in wages (Otsuka et al. 2016).[3]

The rice Green Revolution in tropical Asia began in 1966 when the International Rice Research Institute, located in the Philippines, released the first high-yielding modern varieties (MVs) of rice, i.e., IR8, which is called miracle rice. Since then a series of improved MVs were developed and disseminated, which more than doubled the rice yield per hectare in tropical Asia (David and Otsuka 1994). Hayami and Ruttan (1985) and Hayami and Godo (2005) argue that the Asian rice Green Revolution is essentially a result of the transfer of intensive rice farming technologies and cultivation practices from Japan—located in a temperate zone—to tropical Asia by means of scientific agricultural research. It is then puzzling why, after 50 years, rice technology developed in the tropical Asia has not been successfully transferred to sub-Saharan Africa (SSA), which is also located in the tropical zone. This short essay explores why SSA has so far failed to realize a full-fledged rice Green Revolution. Our main finding is that although both regions are located in the tropical zone, basic rice cultivation practices, which have been common all over the Asia, have never been widely adopted in SSA. In other words, rice Green Revolution technology consists of not only MVs and fertilizer but also improved cultivation practices. Therefore, our main conclusion is that the major constraint to achieving the rice Green Revolution in SSA is the paucity of investment in the capacity of rice production extension systems, which prevents the widespread adoption of improved rice production technologies.

The organization of this paper is as follows. First, in Section 2 we confirm that improved rice technology is highly transferable from tropical Asia to SSA by examining the high productivity of rice farming achieved in selected areas in SSA where Asian rice technology has been adopted. In Section 3 we examine the sustainability of high-productivity rice farming in areas where rice production training programs were offered as well as spillover effects of

[2] It is worth mentioning that the Coalition for African Rice Development (CARD) organized by the Japan International Cooperation Agency (JICA) and the Alliance for Green Revolution in Africa (AGRA), in which many international organizations and twenty-three African countries participated, has made a significant contribution to increasing rice production in SSA.

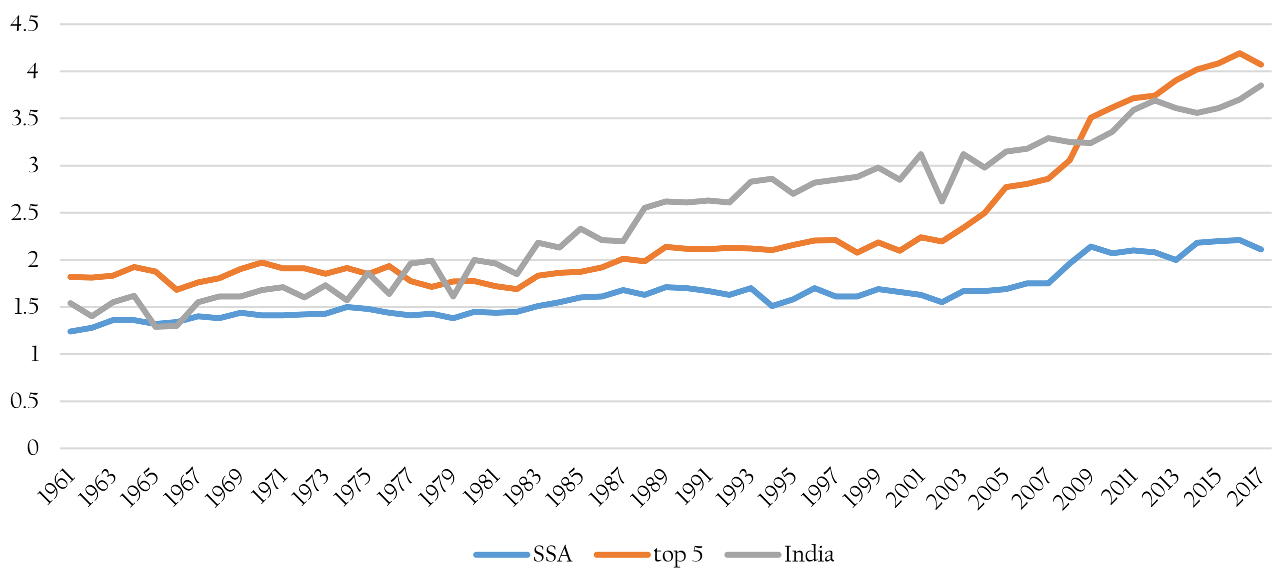
[3] While labor costs can be saved by mechanization, farm sizes in many countries in Asia are too small to introduce large-scale mechanization.

new technology from the training participants to non-participants. Finally, in Section 4 we propose a strategy for the rice Green Revolution in SSA, while considering not only the enhancement of extension capacity but also potential pay-offs of irrigation investments, the introduction of tractors, and improvements in rice milling technology.

2. Transferability of Asian Technology

As is shown in Figure 1, average paddy yield per hectare in SSA began noticeably increasing a few years after the turn of the century. This is likely due to the adoption of Green Revolution technologies in some areas, considering paddy yield had been almost completely stagnant in tropical Asia before the Green Revolution began (Hayami and Otsuka 1994). In fact, paddy yield had been stagnant in India in the early 1960s (see Figure 1), where the agro-climate is relatively similar to that in SSA (Tsusaka and Otsuka 2013a, 2013b). The basic premise of this paper is that the rice Green Revolution has begun in limited areas in SSA. Indeed, paddy yield in the top five most productive countries in SSA began increasing in the early 1980s,[4] and it became almost the same as that in India or even slightly higher in recent years. In these countries, more than half of paddy areas are irrigated, where Asian-type rice production technologies were widely adopted (Balasubramanian et al. 2007).

Figure 1. Changes in average paddy yields in SSA, top 5 countries in SSA, and India



Source: FAO-STAT (2017).

Note: Top five countries are: Kenya, Rwanda, Niger, Burundi, and Madagascar.

[4] After computing the simple average of paddy yield per hectare from 1961 to 2017, 10 countries that recorded the highest yields were initially selected. Then, we deleted Swaziland, Mauritius, Somalia, and Réunion because rice harvested areas and production are tiny in these countries. We took the weighted average yield of five countries, i.e., Kenya, Rwanda, Niger, Burundi, and Madagascar, with the weight being the share of the harvested area among these countries. Although we did not include Mauritania, which is not a member country of CARD, the result remains unchanged quantitatively, even if we include this country among the top countries.

The Green Revolution is alternatively called "the seed-fertilizer revolution" (Johnston and Cownie 1969), which means that its essence is the development and diffusion of fertilizer-responsive improved MVs coupled with the increased application of chemical fertilizer. While this view may be relevant in tropical Asia, it is highly misleading in the context of SSA. This is because beyond MVs and fertilizer, intensive management practices, such as bund construction, leveling of paddy fields, and straight-row transplanting, are critically important to boost paddy yield.[5] In other words, the potential of high-yielding MVs cannot be fully realized without the adoption of proper cultivation practices. An important observation is that such production practices had been largely adopted in tropical Asia even before the Green Revolution, whereas they have seldom been applied in SSA.[6]

According to earlier studies of "An Empirical Analysis of Expanding Rice Production in Sub-Saharan Africa," organized by the JICA Research Institute, MVs and chemical fertilizer along with improved management practices are critically important determinants of rice yield in Mozambique (Kajisa and Payongayong 2011), Tanzania (Nakano et al. 2016), Uganda (Kijima et al. 2012), and Ghana (deGraft-Johnson et al. 2014).[7] It is worth emphasizing that improved management practices were introduced through rice production training programs. It is also clear that paddy yield is significantly higher under irrigated than rainfed conditions. Indeed, paddy yield is as high as five tons per hectare in the Senegal River Valley (Sakurai 2015) and Mwea Irrigation Scheme in Kenya (Njeru et al. 2016), which is much higher than the average paddy yield of nearly four tons per hectare in India at present as well as in tropical Asia as a whole. Such high productivity can be attributed both to the availability of irrigation water and to the adoption of improved technologies and management practices (Nakano et al. 2013).

A spectacular example of high paddy yield is found in the Kilombero Valley in Tanzania (Nakano et al. 2018a). This area is favorable rainfed because additional water flows from nearby mountain ranges and soil is fertile. Rice production management training was offered by the large private rice plantation to farmers nearby in 2012 and 2013. The production management was called a "system of rice intensification (SRI)," but unlike its original definition, the use of MVs and chemical fertilizer were recommended, the use of irrigation was not assumed, and straight-row dibbling was promoted.[8] That is why we call it a "modified system of rice intensification" (MSRI). As can be seen from Table 1, paddy yield was as high as 4.7 tons per hectare on plots where the trainees adopt MSRI technologies. To the best of my knowledge, this is the highest paddy yield under rainfed condition in tropical Asia and SSA. On the other hand, the yield was at most three tons per hectare without the adoption of MSRI even if the plot was cultivated by the same trainees. Almost the same yield was achieved by non-trainees

[5] Aside from studies included in Otsuka and Larson (2013, 2016), Regasa and Chapoto (2017) recently made essentially the same finding.

[6] Although there is no statistical evidence to support this argument, it is based on personal interviews with rice scientists and research assistants who worked in tropical Asia in the 1960s and 1970s.

[7] In each of our empirical studies, rigorous econometric estimations were made. For simplicity, detailed explanations about estimation are dispensed with in this study. It must be understood, however, that my arguments are supported by careful econometric estimations.

8 Dibbling is a method of crop establishment wherein seeds are placed in holes prepared by simple tools, such as sticks. Dibbling is effective in paddy fields that are not completely leveled. Dibbling, however, was not included in the original SRI. Note, however, that wide spacing is a part of the original SRI.

in training villages and farmers in non-training villages. The significant difference in paddy yield can be attributed not only to the difference in the adoption of MVs and use of chemical fertilizer but also to the difference in management practices.

Table 1. Yield and technology adoption by modified system of rice intensification (MSRI) training participation in rainfed areas in Tanzania in 2013

	Training villages					Non-training villages
	Trainees' MSRI plots		Trainees' non-MSRI plots		Non-trainees	
	2012 trainees	2013 trainees	2012 trainees	2013 trainees		
Paddy yield (tons/ha)	4.7	4.7	3.1	2.8	2.6	2.9
Chemical fertilizer use (kg/ha)	57.9	50.8	9.1	5.1	2.5	2.5
Share of MVs (%)	88.0	91.8	10.0	10.2	5.6	2.4
Share of straight-row dibbling (%)	80.0	77.6	0.0	0.0	0.0	0.8
Share of plots adopting recommended spacing (%)	60.0	55.3	0.0	0.0	1.6	2.4

Source: Nakano et al. (2018a).

3. Sustainability of Improved Productivity

While it was found that rice management training is effective in raising the paddy yield of trainees in Uganda (Kijima et al. 2012), Ghana (deGraft-Johnson et al. 2014), and Tanzania (Nakano et al. 2018a), it is not clear how sustainable the impacts of rice management training programs are or how widely knowledge of improved rice production management spreads from trainees to non-trainees. Table 2 shows the performance of trainees in comparison with other farmers in irrigated areas in Tanzania (Nakano et al. 2018b). In the training program implemented by the Japan International Cooperation Agency, competent and motivated farmers, called key farmers, were selected and trained at the nearby training institutes for 12 days before the start of the main crop season in 2009. Each key farmer was supposed to teach five “intermediary” farmers about the improved rice production methods the key farmer has learned. Intermediary farmers were expected to train other farmers.

As would be expected, the performance of key farmers was better than intermediary and other farmers even before the training program in 2008: Their yield was 3.07 tons per hectare, which was the highest among the three groups, and the adoption rates of MVs, improved agronomic practices, and the amount of chemical fertilizer applied per hectare tended to be highest as well. The performance of key farmers improved considerably after they took the training program in 2009; yield increased by 50%, even though rainfall was low in that year. Adoption rates of MVs, leveling, and transplanting in rows, and the use of chemical fertilizer also increased substantially. A critically important observation is that this high performance of key farmers continued for the next couple of years, indicating that the

Table 2. Changes in paddy yield and technology adoption by training status (key, intermediary, and other farmers) in irrigated areas in Tanzania

	2008	2009	2010	2011	2012
	Pre-training	During training		Post-training	
Key farmers					
Paddy yield (tons/ha)	3.07	4.40	4.81	5.34	4.67
Adoption rate of MVs (%)	46.2	69.2	75.0	54.4	66.7
Chemical fertilizer use (kg/ha)	63.4	115.8	137.73	178.3	131.3
Adoption rate of plot leveling (%)	46.1	76.9	81.3	86.7	76.9
Adoption rate of transplanting in rows (%)	23.1	76.9	93.8	93.3	92.3
No. of observations	13	13	16	15	13
Intermediary farmers					
Paddy yield (tons/ha)	2.47	2.57	2.84	4.63	3.93
Adoption rate of MVs (%)	30.4	44.4	54.8	34.4	49.5
Chemical fertilizer use (kg/ha)	22.2	49	79.1	103.9	95.2
Adoption rate of plot leveling (%)	43.5	70.4	74.2	79.2	62.5
Adoption rate of transplanting in rows (%)	13	44.4	64.5	45.8	58.3
No. of observations	23	27	31	24	31
Other farmers					
Paddy yield (tons/ha)	2.57	2.67	2.53	3.58	3.67
Adoption rate of MVs (%)	26.7	26.7	32.3	23.6	32.9
Chemical fertilizer use (kg/ha)	46.5	58.3	69.7	85.8	83.2
Adoption rate of plot leveling (%)	54.8	64.1	69	76.2	66.9
Adoption rate of transplanting in rows (%)	11.1	19	25.8	26.9	36.9
No. of observations	135	142	155	130	130
Annual rainfall (mm)	1027	869	917	1547	651

Source : Nakano et al. (2018b).

impact of rice production training program is sustainable. Also important is the fact that the performance of intermediary farmers improved gradually, followed by the improved performance of other farmers. It is clear there were spillover effects from key farmers to intermediary farmers and further spillover effects to other farmers. Therefore, rice production management training programs have both sustainable direct effects and indirect spillover effects on the performance of rice farmers at large.

Yields of four to five tons per hectare are reasonably high by any standard under tropical conditions during the rainy season. Thus, there is no question that in the study sites in Tanzania, a rice Green Revolution took place after the rice production training program was offered.[9]

Evidence consistent with that found in irrigated areas in Tanzania is also found in rainfed area in Uganda and irrigated areas in Cote d'Ivoire. As is shown in Table 3, in Uganda participants in the training program were not randomly selected and, hence, their average yield was slightly lower than the

[9] Since both "seed-fertilizer" technology and improved agronomic practices were adopted simultaneously, it is not possible to disentangle the effects of the former from the latter. Most likely, they are complementary and it would therefore be misleading to separate their independent effects.

average yield of non-participants during the pre-training period of 2008/09 (Kijima 2018). Owing to the training, the average yield of participants increased by roughly 50% in 2011–12 and it became higher than the yield of non-participants. Critically important findings are that four years later, the high yield of participants was maintained and the yield of non-participants caught up with that of participants, most likely because of the spill-over effects of rice production knowledge from participants to non-participants.

Table 3. Changes in paddy yield and technology adoption by training status in rainfed areas in Uganda

	2008/09 Pre-training	2011/12 During training	2015/16 Post-training
1. Paddy yield (ton/ha):			
Participants	1.24	1.95	2.07
Non-participants	1.35	1.58	2.03
2. Chemical fertilizer use (%)			
Participants	0.0	15.4	22.2
Non-participants	3.1	8.5	28.3
3. Bund construction (%)			
Participants	51.1	89.7	88.9
Non-participants	60.9	67.8	63.3
4. Transplanting (%)			
Participants	66.7	79.5	91.7
Non-participants	63.7	66.1	77.4

The number of participants is 45, 39, and 36 in respective years, whereas the number of non-participants is 64, 59, and 53, respectively.

Source: Kijima (2018)

A similar tendency is observed in Cote d'Ivoire (see Table 4), where training participants were randomly selected in accordance with the design of the randomized controlled trial (RCT) (Takahashi et al. 2018). While participants and non-participants were requested not to communicate with one another during the training year of 2015,[10] unlike in an ordinary RCT, they were advised to communicate in the following year. As a result, the yield of participants increased from 2014 to 2015, even though the rainfall substantially declined in July, which is the main crop planting season. Despite the fact that 2016 was a more severe drought year, the yield of non-participants did not decline and became slightly higher than participants. There are some indications that management of non-participants improved relative to participants from 2015 to 2016, indicating the presence of spill-over effects.

Table 4. Changes in paddy yield and technology adoption by training status in irrigated areas in Cote d'Ivoire

	2014	2015	2016
1. Paddy yield (ton/ha)			
Participants	3.44	4.05	3.42
Non-participants	3.94	3.67	3.72
2. Fertilizer use (kg/ha)			
Participants	215	249	233
Non-participants	254	261	255
3. Leveling (%)			
Participants	77.2	85.7	86.7
Non-participants	79.1	67.7	81.0
4. Transplanting in row (%)			
Participants	5.4	37.8	34.9
Non-participants	1.9	10.8	17.9
Rainfall in July (mm)	29.9	92.5	19.8

Source : Takahashi et al. (2018)

To sum up, the evidence reviewed above indicates that the impact of management training is significant and sustainable and that it has significant spillover effects on non-participants in the training program. It must be pointed out that such an impact was realized without any improvement in irrigation or other infrastructure, marketing, or credit programs.[11] Thus, our findings can be taken to imply that rice management training is an effective entry point to the rice Green Revolution in SSA (Otsuka and Muraoka 2017).

[10] This restriction is imposed not to violate the stable unit treatment value assumption, so that we can precisely evaluate the pure impact of training.

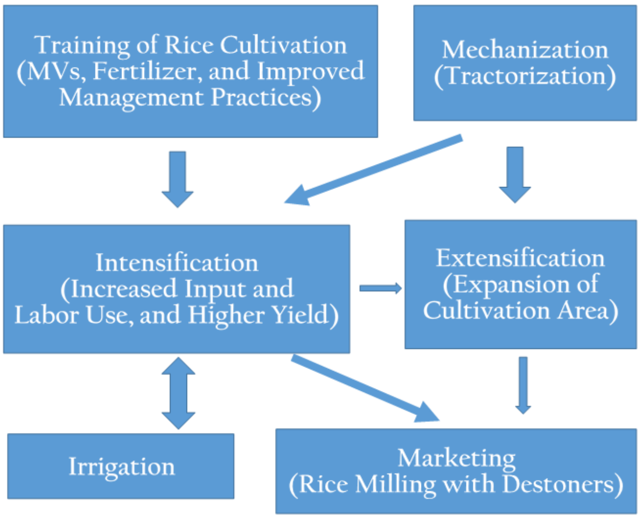
[11] Such a finding suggests that input and output markets as well as land markets began working in SSA (Holden et al. 2009; Yamano et al. 2011; Kijima et al. 2013).

4. Strategy for a Rice Green Revolution in SSA

In this final section, we would like to clarify the central role of training of improved rice cultivation practices in a larger context of formulating the strategy for a rice Green Revolution in SSA. Since the majority of farmers in SSA are smallholders, the development strategy must focus on them if it aims at inclusive growth (Larson et al. 2016). There are, however, concerns that the cultivation area of smallholders is too small to realize substantial productivity gains (Collier and Dercon 2014). Yet, such concerns are inconsistent with the facts that the Asian Green Revolution was realized by smallholders and that maize yield per hectare tends to be higher among small farmers than large farmers in SSA (e.g., Larson et al. 2014). There is no evidence that large farms created by land grabbing perform well (Deininger and Byerlee 2012). Therefore, there seems to be no question that a rice Green Revolution in SSA is possible without changing the dominance of smallholders.

Our analysis strongly suggests that disseminating improved lowland rice production technology and management practices by training smallholders ought to be the key component of the strategy for a rice Green Revolution in SSA. As is illustrated in Figure 2, training on improved rice cultivation must be the first step for the intensification of rice farming in SSA, which accompanies the increased application of chemical fertilizer, labor, and other inputs, the adoption of MVs, and the application of improved management practices.[12] As was mentioned before, the basic difference between tropical Asia and SSA lies in the fact that basic management practices were largely adopted in Asia even before the Green Revolution began, but have not been in most areas in SSA even now. A major constraint is the paucity of extension workers adept at rice production. Therefore, our recommendation is to invest in capacity building of extension workers for acquiring expertise on rice production so that the extension workers can effectively train farmers.

Figure 2. A Conceptual Framework for Evidence-Based Development Strategy



Source: Author

The presence of irrigation also induces the intensification of rice cultivation because irrigation water is a complement to improved rice cultivation practices (see Figure 2). Conversely, the intensification of rice cultivation is expected to stimulate investment in irrigation because the rate of return on irrigation investments increases with the intensification of rice farming.

Although it is often argued, without clear evidence, that large-scale irrigation schemes are not efficiently managed in SSA, it is not necessarily the

[12] In Figure 2, bold lines indicate clear strong causal effects, whereas ordinary lines indicate less clear or weaker effects.

case. For example, as is shown in Table 5, the yield of large irrigation schemes is higher than that of small irrigation schemes in the Senegal River Valley (Sakurai 2015). Also the yield of the large-scale Mwea irrigation scheme, which covers 8,000 hectares, is as high as five tons per hectare, even though basmati rice, which is not a high-yielding variety, is grown. Furthermore, the cost per hectare of constructing irrigation facilities decreases as the size of irrigation scheme increases.[13] Although the productivity gain and cost estimates indicates that large-scale irrigation is more cost-effective than smaller ones, we need rigorous cost-benefit analyses of large-scale irrigation schemes in SSA to make a prudent decision about the scale of irrigation investment.[14]

Table 5. Comparison of rice production performance between large and small irrigation schemes in Senegal

	Large	Small: village-based	Small: private
No. of sample schemes	42	40	38
Size (ha)	1,167	42	33
Paddy yield (ton/ha)	5.22	3.92	4.51
Fertilizer use (kg/ha)	315	350	496
Use of MVs (%)	89	100	94
Tractor use (%)	94	67	82

Source: Sakurai (2015)

There is no question that mechanization, particularly tractorization, contributes to extensification (or the expansion of the cultivation area), as it expedites land preparation. While tractors, including power tillers, are a substitute for draft animals as well as labor in Asia, it is a substitute for manual labor in SSA, because draft animals are unavailable in many areas (Mano et al., 2017).[15] Furthermore, there is a possibility that thorough land preparation by the use of a tractor facilitates intensive cultivation, as is illustrated by the comparison of production performance between tractor users and non-users in Cote d'Ivoire (Table 6). Tractor users cultivate larger areas, employ more hired workers, apply more chemical fertilizer, and adopt improved management practices more often. In the Senegal River Valley it seems that the use of tractors makes it possible to grow rice twice a year. Although we need more evidence on the impact of tractor use on the intensification of rice farming as well as the enlargement of cultivation area in SSA, the diffusion of tractors may well be a prerequisite for promoting a rice Green Revolution over large areas in SSA (see Figure 2).

Table 6. Comparison of rice production performance between tractor-users and tractor non-user in Cote d'Ivoire

	Tractor users	Tractor non-users
Paddy yield (tons/ha)	4.39	3.62
Cultivation size (ha)	0.91	0.62
Family labor use (person-days/ha)	78.0	89.3
Hired labor cost (1,000 FCFA/ha)	119.0	61.0
Chemical fertilizer use (kg/ha)	252	149
Leveling (%)	80	64
Bund construction (%)	85	41

Source: Mano et al. (2017)

Finally, mention should be made on the low-quality of rice produced in SSA, which cannot compete with imported Asian rice (e.g. Demont et al.

[13] This is found in the irrigation project in terms of the total cost of 314 irrigation projects implemented in the latter half of 20th century (Inocencio et al., 2007), and in terms of overhead costs of 117 irrigation projects in SSA (Fujiie et al., 2011)

[14] Research is under way on this issue.

[15] Tractor includes both power-tiller and riding tractor.

2013). An increased supply of rice through both the intensification and extensification of rice farming is expected to enhance efficiency in rice marketing by expanding the size of the market. A commonly held view is that rice is milled without using a destoner in SSA, so that small stones are mixed with milled rice. It is understandable that such rice cannot compete with imported rice without any stones. In Uganda, the milling fee was 33% higher when a destoner was used, which is likely to lead to the higher quality of milled rice (Tokida et al. 2014). According to our ongoing research on rice millers in Mwea in Kenya, basmati rice milled by machines with destoners fetches prices at least 10% higher than rice milled without destoners. The price of milled rice without stones is said to be higher than imported basmati rice from Pakistan. It is found that rice millers who use destoners are more educated and more experienced in rice trading, indicating that human capital plays an important role in the introduction of improved milling technology. A remaining issue is to explore is why so many rice millers have not installed destoners.

Finally, we would like to stress that policies based on the clear understanding of the critical roles played by training of improved cultivation practices, tractorization, and investments in irrigation portrayed in Figure 2 will undoubtedly facilitate revolutionary changes in rice farming in SSA.

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Related publications and information are available at the website below.
JICA Research Institute, An empirical analysis on expanding rice production in Sub Sahara Africa Phase 2
https://www.jica.go.jp/jica-ri/research/growth/growth_20140901-20190331.html

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