Rice Green Revolution in Sub-Saharan Africa

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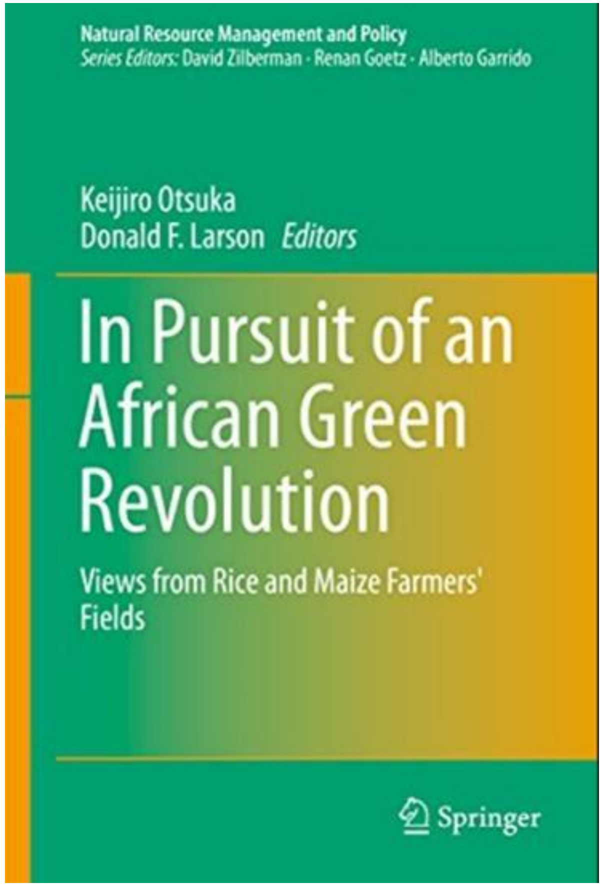
A Major Puzzle

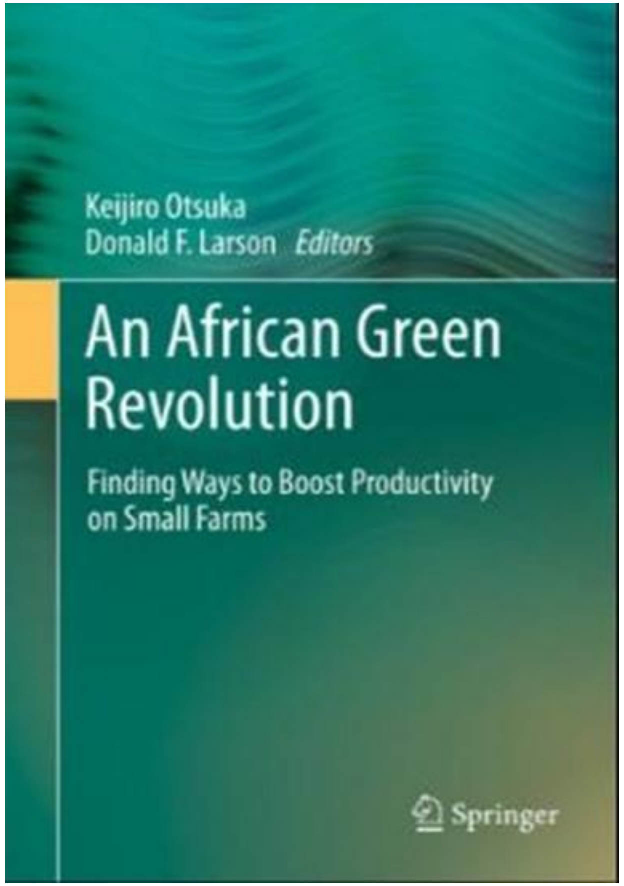
Why has the Green Revolution still not happened in SSA?

- Green Revolution is essential to achieve the first and second goals of SDGs, namely "no poverty" and "zero hunger."
- It successfully took place in tropical Asia a half-century ago.

15 years of case studies in Mozambique, Tanzania, Kenya, Uganda, Ghana, Côte d'Ivoire, and Senegal



Otsuka and Larson (2013)



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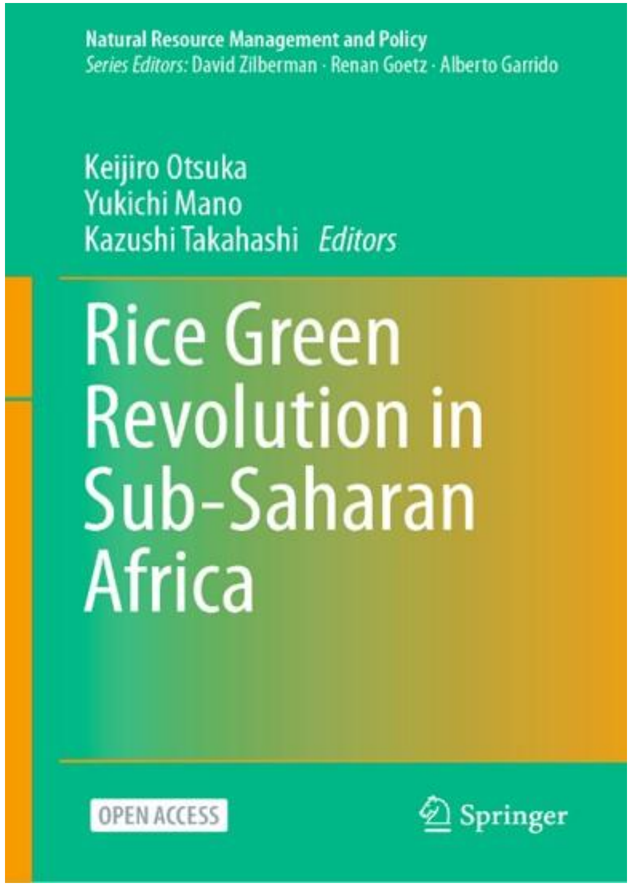
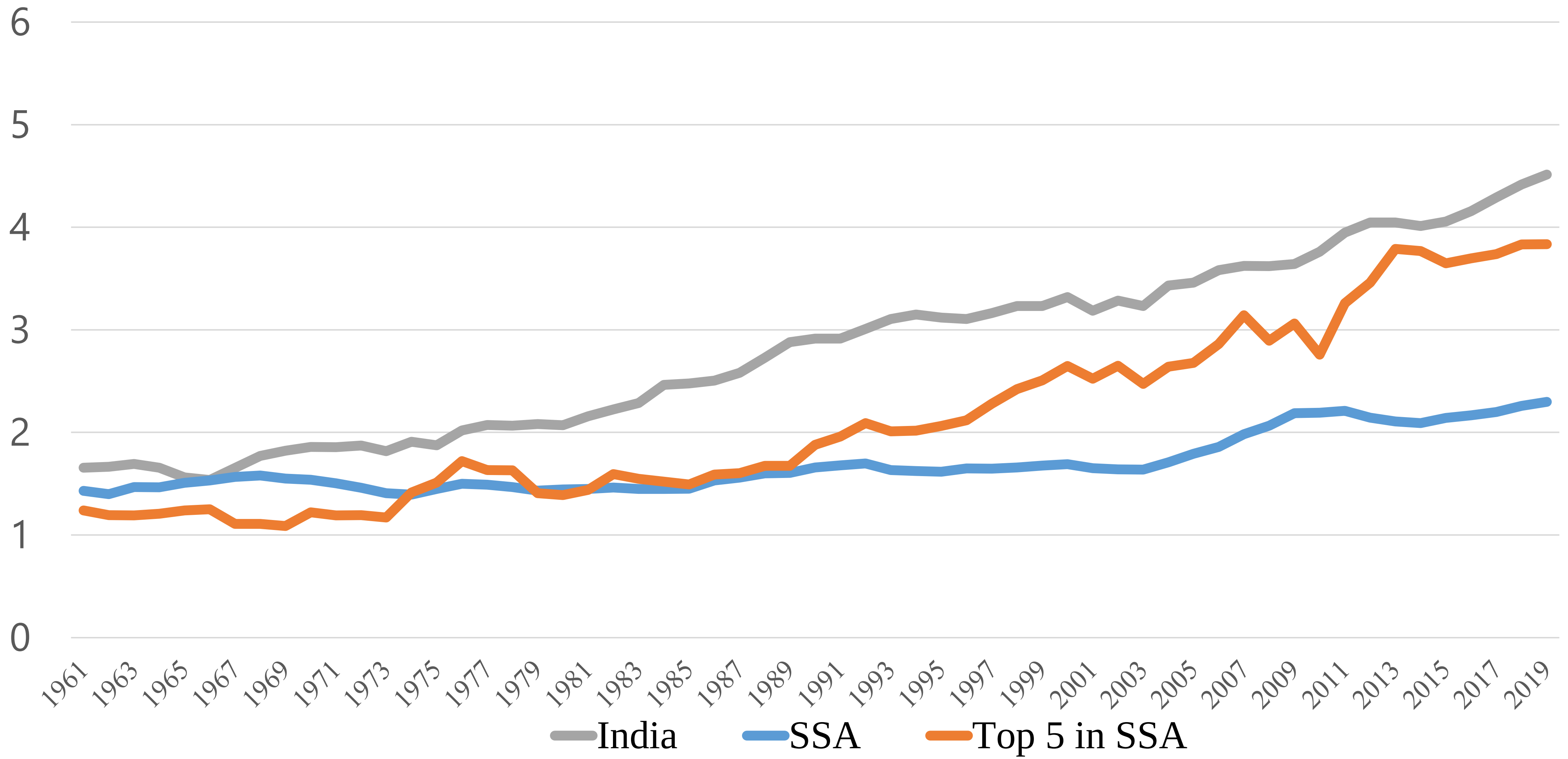


Otsuka, Mano, Takahashi (2023)
Rice Green Revolution in Sub-Saharan Africa: https://link.springer.com/book/10.1007/978-981-19-8046-6 (open access)

Main Messages of 3 Books

- 2013 Book: Rice is the most promising cereal crop in SSA, in view of the high transferability of Asian rice Green Revolution technology.
- 2016 Book: Rice cultivation training programs dramatically increase rice yields in SSA.
- 2023 Book: (1) **Rice Green Revolution is not just a "seed-fertilizer revolution" but also management-intensive**. (2) Yield impact of rice cultivation training programs is sustainable, with significant spillovers from participants to non-participants. (3) Mechanization in rice farming and the introduction of improved milling machines also play critical roles in achieving a full-fledged African rice Green Revolution.

Fig. 1 Changes in Average Paddy Yield in SSA, Top 5 Countries (Kenya, Niger, Senegal, Benin, and Mali), and India (ton/ha)



What can we learn from Figure 1?

1. The small yield gap between India and SSA in the 1960s before the Green Revolution in Asia

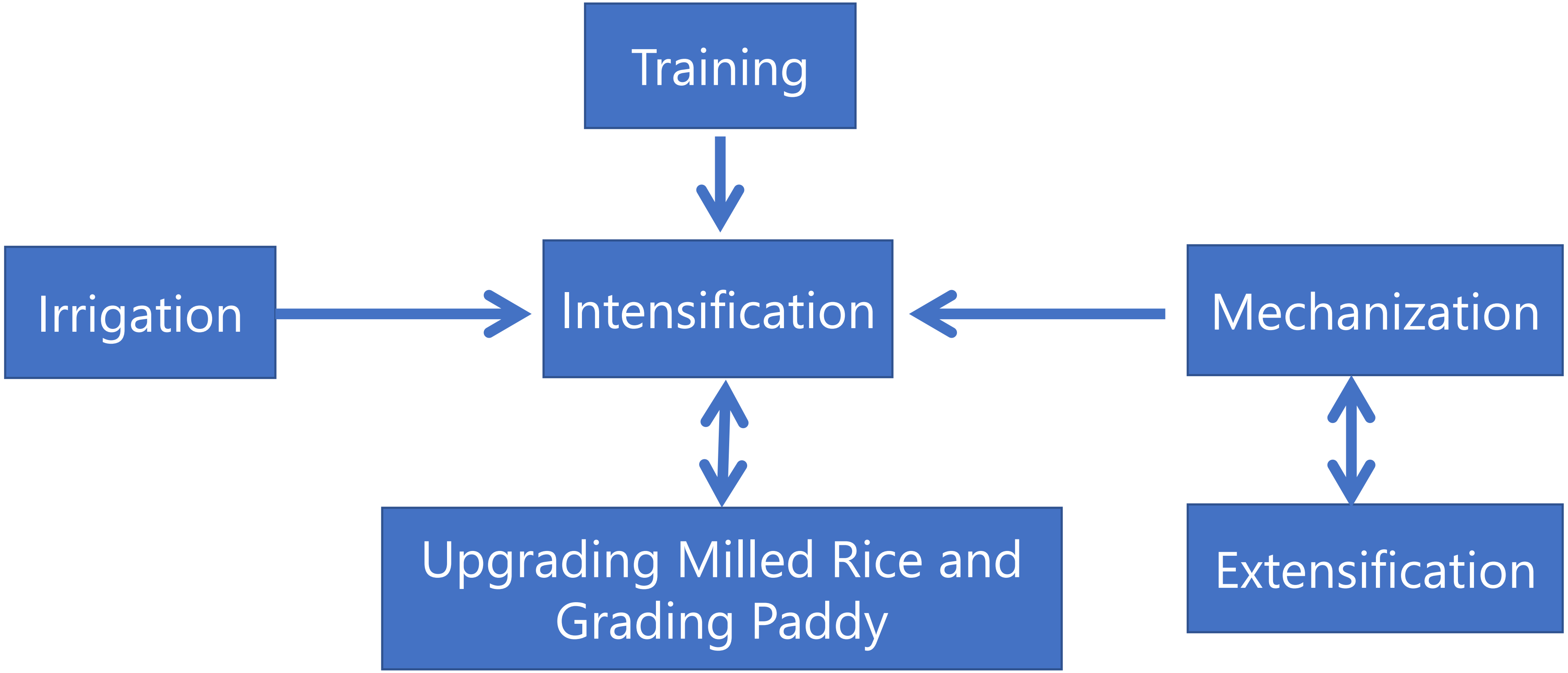
   ➔ The agroclimate in SSA is not particularly unfavorable.

2. The yield gap has widened since the 1970s due to the Green Revolution in India.

3. The average yield in SSA has been increasing since about 2002-03, which seems to be a symptom of the Green Revolution.

4. The average yield of the top 5 SSA countries has been increasing since 1990 and has almost caught up with that of India. **The Green Revolution has already taken place, at least in the top 5 SSA countries!**

Fig. 2 A conceptual framework for achieving a Rice Green Revolution through intensification



1. Rice cultivation training is indispensable

- **Rice Green Revolution is intensive in cultivation management** (not just in the use of improved varieties and inorganic fertilizers).
  - e.g., seed selection, bund construction, leveling, and straight-row transplanting
- Rice cultivation training is therefore **an essential and indispensable entry point** to the rice Green Revolution in SSA.

Paddy fields without bund?

No bund→ No stored water → Growth of weeds

Paddy field without bund

Another paddy field without bund

Paddy field with bund

Paddy field with excessively large bund

Leveling→Even distribution of water→Healthy plant growth

Before and after Leveling

Straight-row transplanting → Easy weeding

Straight-row transplanting

Well-managed paddy field in Tanzania

Our Project: Empirical Analyses of Improving Rice Production in Sub-Saharan Africa (The 2023 book)

- Randomized controlled trials (RCTs) of JICA’s rice cultivation training programs in Mozambique, Tanzania, and Côte d'Ivoire.
- JICA’s rice cultivation training programs in Tanzania and Uganda.
- Improved rice milling methods on the quality of milled rice in Mwea, Kenya.
- Power-tillers to rice farming intensification in Côte d'Ivoire and Tanzania.
- Large-scale irrigation investments in Mwea, Kenya.

Table 1. Changes in average paddy yield and selected technology adoption rates by training status in rainfed areas before and after training in Mozambique (RCT)

	Pre-training	Post-training
1. Paddy yield (ton/ha):		
Training group 1	1.94	1.78
Training group 2	1.53	1.75
No training (control group)	1.97	1.54
2. Plot leveling (%):		
Training group 1	14.1	66.7
Training group 2	18.6	45.5
No training (control group)	24.4	3.8
3. Straight-row transplanting (%):		
Training group 1	1.3	46.2
Training group 2	0.0	35.6
No training (control group)	0.0	0.0

The number of farmers is 78 in group 1 and 101 in group 2, while the number of farmers in the control group is 78. The first group received the training in 2017, while the second group received the training in 2018. Post-training refers to 2018-19.

Table 2. Average yield and technology adoption rates using the 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
No. of observations	25	85	20	59	126	83

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

	2008/09	2011/12	2015/16
	Pre-training	Post training (short)	Post training (long)
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 non-participants are 64, 59, and 53, respectively.

Table 4 Changes in average paddy yield and technology adoption rates by training status in irrigated areas in Côte d'Ivoire (RCT)

	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

Table 5 Comparison of yields and the adoption of selected cultivation practices among key farmers, intermediary farmers, and ordinary farmers in irrigated area in Tanzania

	2008	2009	2010	2011	2012
	Before training	Training year	1 year later	2 years later	3 years later
Key farmers					
Yield per ha (ton/ha)	3.07	4.40	4.81	5.34	4.67
Inorganic fertilizer application (kg/ha)	63.4	115.8	137.7	178.3	131.3
Adoption of leveling (%)	46.1	76.9	81.3	86.7	76.9
Straight-row transplanting (%)	23.1	76.9	93.8	93.3	92.3
Intermediary farmers					
Yield per ha (ton/ha)	2.47	2.57	2.84	4.63	3.93
Inorganic fertilizer application (kg/ha)	22.2	49.0	79.1	103.9	95.2
Adoption of leveling (%)	43.5	70.4	74.2	79.2	62.5
Straight-row transplanting (%)	13.0	44.4	64.5	45.8	58.3
Other farmers					
Yield per ha (ton/ha)	2.57	2.67	2.53	3.58	3.67
Inorganic fertilizer application (kg/ha)	46.5	58.3	69.7	85.8	83.2
Adoption of leveling (%)	54.8	64.1	69.0	76.2	66.9
Straight-row transplanting (%)	11.1	19.0	25.8	26.9	36.9
Annual rainfall (mm)	1,027	869	917	1,547	651

Key findings on improved rice cultivation practices from Tables 1 through 5

- The critical **importance of improved rice cultivation practices in increasing rice yield**, even without improvements in marketing, mechanization, and irrigation facilities.
- Significant and **sustained impacts of rice cultivation training** programs on rice yields, incomes, and profits.
- Case studies in Uganda (Table 3), Côte d'Ivoire (Table 4), and Tanzania (Table 5) suggest a significant **spillover of information** on improved rice cultivation practices from training participants to non-participants.

2. Tractor use facilitates rice farming intensification in sub-Saharan Africa

- Unlike tropical Asia, the use of draft animals is limited in sub-Saharan Africa due to trypanosomiasis, or sleeping sickness (Alsan, 2015).
  - Draft animals allow for thorough land preparation, which facilitates rice farming intensification. Tractors basically replaced draft animals in tropical Asia.
- Hypothesis: **The use of tractors allows for thorough land preparation and facilitates farming intensification in sub-Saharan Africa**.

Two-wheel tractors in Côte d'Ivoire enable thorough land preparation

Table 6. Basic characteristics of HHs by land preparation method

	Tractor	Manual	Diff
HH head female (=1)	0.01	0.02	-0.007
	(0.13)	(0.15)	
HH head age	46.32	44.65	1.67
	(9.62)	(12.12)	
HH head any schooling (=1)	0.66	0.52	0.14*
	(0.47)	(0.50)	
Family size	10.00	9.45	0.55
	(6.25)	(5.93)	
No. techniques trained	7.14	6.54	0.59
	(4.02)	(4.20)	
Asset (000 FCFA)	144.53	80.01	64.51*
	(282.2)	(143.7)	
Plot size (ha)	0.90	0.71	0.19**
	(0.48)	(0.44)	
Obs.	56	80	

Empirical strategies

- Cross-sectional regression with village fixed effects (FE)
  - We apply Oster's (2019) methodologies to test the robustness of significantly estimated coefficient on tractor use to unobservables

- Doubly robust (DR) estimator
  - DR provides a consistent estimate as long as either the propensity score for tractor use or the regression function of outcomes in terms of covariates is correctly specified (Wooldridge, 2010)

Table 7. Impact of tractor use on the application of production factors

	Impact (Village FE)	Impact (Doubly robust)	Mean outcome among Manual
Family labor (000FCFA/ha)	99.35**	101.79***	76.71
	(40.11)	(34.58)	
Hired labor cost (000 FCFA/ha)	45.38**	44.39***	24.86
	(19.00)	(16.60)	
Machine cost (000 FCFA/ha)	55.50***	53.40***	5.36
	(11.03)	(7.01)	
Chemical fertilizer (kg/ha)	86.73*	127.37***	181.6
	(44.86)	(41.50)	

Table 8A. Impact of tractor use on the adoption of improved rice cultivation practices

	Impact (Village FE)	Impact (Doubly robust)	Mean outcome among Manual
No. adopted practices	0.63**	0.47**	3.70
	(0.29)	(0.25)	
Canal construction (=1)	0.12	0.12	0.68
	(0.10)	(0.07)	
Bund construction (=1)	0.34***	0.29***	0.43
	(0.11)	(0.08)	
Leveling (=1)	0.02	-0.09	0.68
	(0.11)	(0.08)	
Seed selection (=1)	-0.02	-0.02	0.86
	(0.08)	(0.06)	
Seed incubation (=1)	0.24**	0.23**	0.45
	(0.11)	(0.09)	
Transplanting (=1)	-0.07	-0.05	0.57
	(0.10)	(0.08)	

Table 8B. Impact of tractor use on family labor use in land preparation, crop establishment, crop care, and harvesting (000FCFA/ha)

	Impact (Village FE)	Impact (Doubly robust)	Mean outcome among Manual
Land preparation	7.52	5.46	9.61
	(6.76)	(4.64)	
Crop establishment	12.47	14.43	15.58
	(13.08)	(8.84)	
Crop care	50.34**	50.98**	25.12
	(21.16)	(18.03)	
Harvesting	28.67**	29.09**	24.24
	(13.81)	(13.20)	

- Land preparation: leveling, bund construction, canal construction.
- Crop establishment: seeding and transplanting.
- Crop care: weeding, fertilizer application, pesticide application, and water control.
- Harvesting: harvesting, threshing, and drying.

Table 8C. Impact of tractor use on hired labor use in land preparation, crop establishment, crop care, and harvesting (000FCFA/ha)

	Impact (Village FE)	Impact (Doubly robust)	Mean outcome among Manual
Land preparation	1.06	0.09	4.73
	(5.69)	(4.91)	
Crop establishment	17.54***	16.21***	2.86
	(5.97)	(4.42)	
Crop care	8.85**	9.55***	2.04
	(4.36)	(3.53)	
Harvesting	28.67**	18.45***	13.29
	(12.66)	(10.40)	

- Land preparation: leveling, bund construction, canal construction.
- Crop establishment: seeding and transplanting.
- Crop care: weeding, fertilizer application, pesticide application, and water control.
- Harvesting: harvesting, threshing, and drying.

Table 9. Impact of tractor use on rice yield, income, and profit

	Impact (Village FE)	Impact (Doubly robust)	Mean outcome among Manual
Rice yield (t/ha)	1.15***	1.22***	3.58
	(0.49)	(0.52)	
Rice income (000FCFA/ha)	84.46	67.06	513.1
	(97.97)	(87.85)	
Rice profit (000FCFA/ha)	30.82	26.51	435.1
	(102.97)	(91.47)	
Total rice income per plot (000FCFA)	41.30	25.96	321.2
	(59.52)	(62.06)	
Total rice profit per plot (000FCFA)	11.05	-3.23	280.9
	(60.56)	(52.02)	

Discussion: Using tractors to facilitate rice farming intensification in sub-Saharan Africa

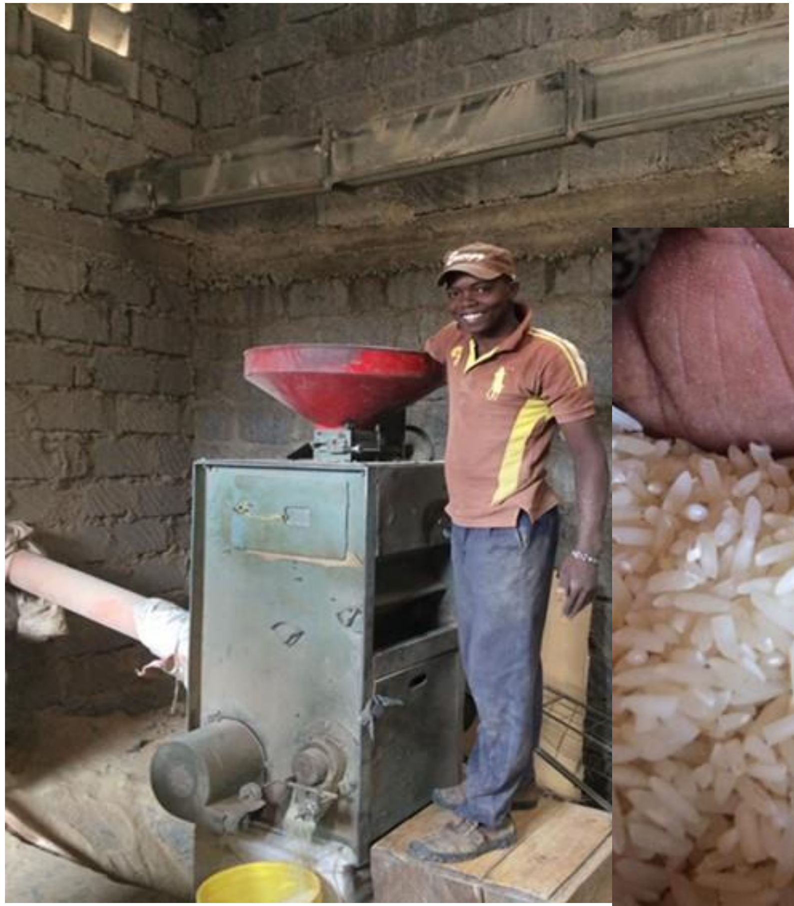
- Induced innovation theory argues that capital substitutes for labor as wages increase (Hayami and Ruttan 1985)
- However, our analysis of rice farming in Cote d'Ivoire suggests a potentially complementary role for capital and labor
- While tractor replaces draft animals in tropical Asia (Binswanger 1978), **tractor replaces manual labor in land preparation, facilitating better water control and rice farming intensification**, in Cote d'Ivoire (and Tanzania as in Cha 9 of Otsuka, Mano, Takahashi (2023))

3. Upgrading milling technologies improve rice quality

- Domestic rice in sub-Saharan Africa often cannot compete with imported Asian rice due to **inappropriate milling machines** (Fiamore et al. 2017; Ragasa et al. 2020)
- Urban **consumers prefer clean rice** (Demont & Ndour 2015; Demont et al. 2017)

- Hypothesis: **Destoners and other improved milling technologies improve rice quality and its competitiveness with imported rice**

Rice milling in Mwea



- **The main task is to provide milling services for farmers & traders**
- Some millers purchase paddy from farmers & sell milled rice to consumers, traders, supermarkets
- Standard milling machine components: **de-huskers** & **polishers**

Upgrading milling machines

- Demand for high-quality rice
- Improved components: **pre-cleaners, destoners, graders, (color sorters)**
- In the early 2010s, some **entrepreneurial millers visited China to introduce the new technologies**

Smaller improved machines in the late 2010s

- In the late 2010s, smaller-scale multi-stage milling machines were introduced

Table 10. Number of rice mills by adoption of distoners

	Total	Nonadopters	Early adopters	Late adopters
No. of millers (% destoner adoption)				
2011	82 (3.7)	72 (0)	6 (50)	4 (0)
2016	103 (14.6)	82 (0)	15 (100)	6 (0)
2018	84 (26.1)	57 (0)	14 (100)	13 (61.5)
2019	95 (34.7)	62 (0)	14 (100)	19 (100)
Exit				
2012-2016	41	40	1	0
2017-2019	53	52	1	0

Fig 3. Market Share of Rice Milled for Customers

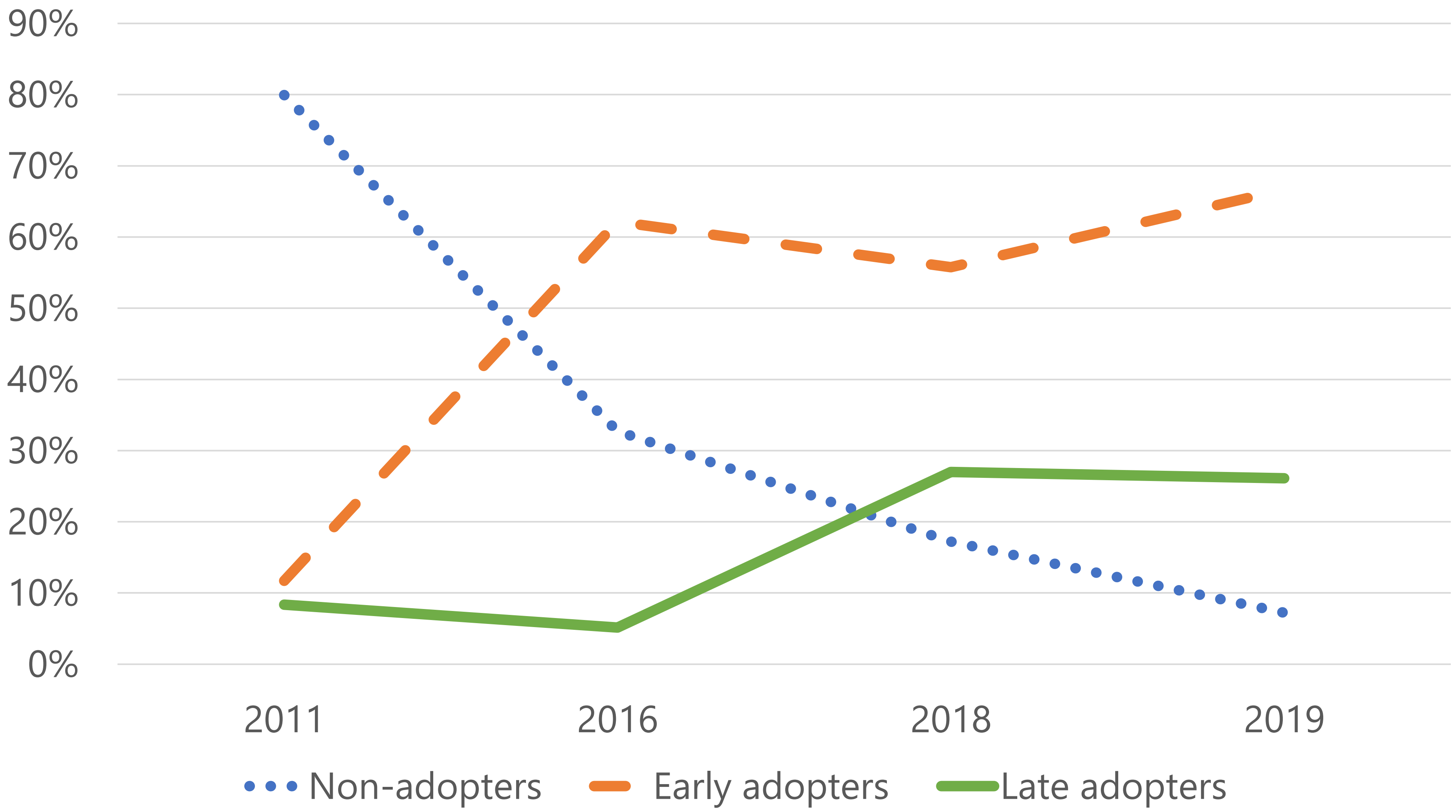
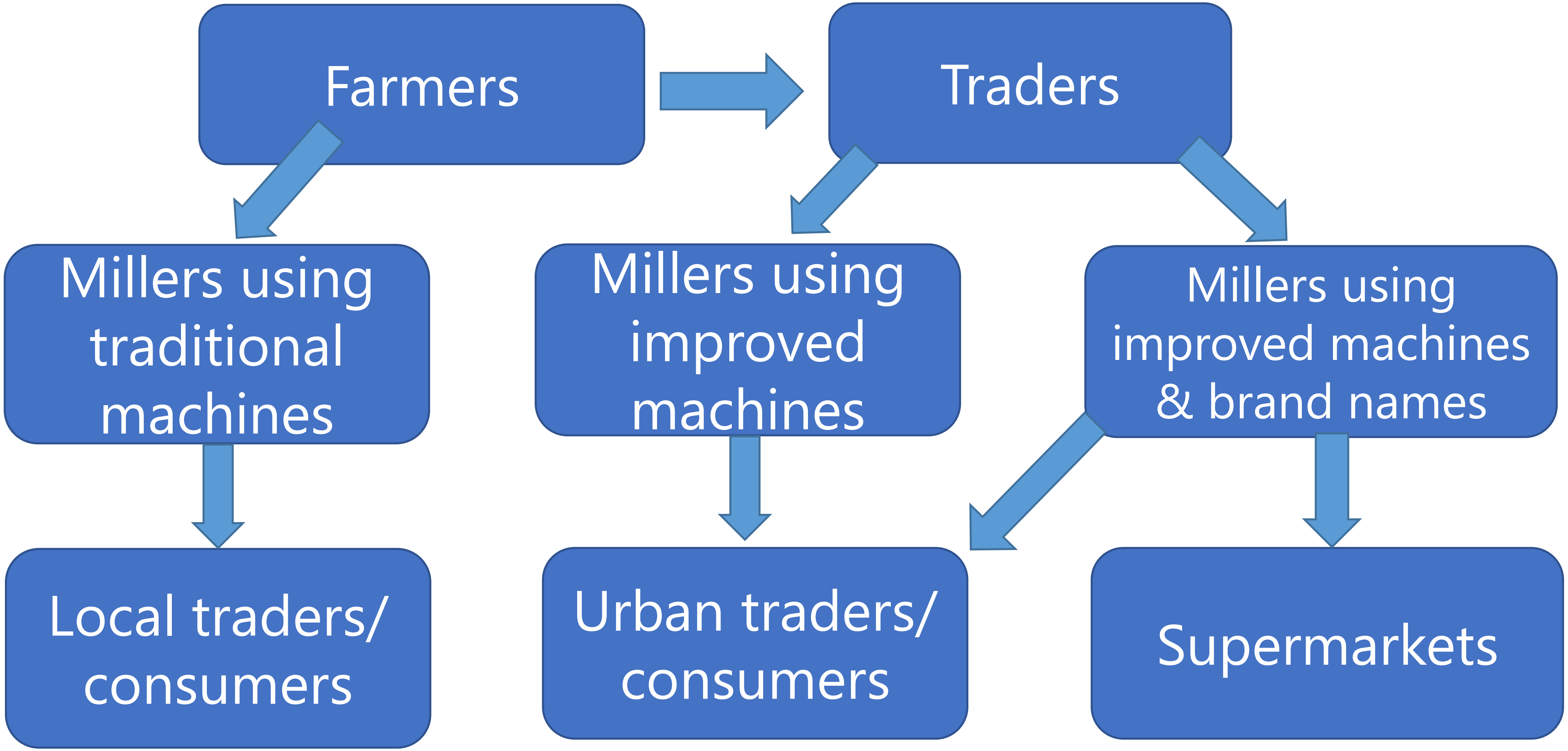


Fig 4. Structural Transformation of Rice Marketing



Empirical strategies

- Doubly robust (DR)
  - DR provides a consistent estimate as long as either the propensity score for tractor use or the regression function of outcomes in terms of covariates is correctly specified (Wooldridge, 2010)

- Endogenous switching regression (ESR)
  - ESR is also often used in the studies of agricultural technology adoption to address the endogeneity bias due to unobserved characteristics (Di Falco et al. 2011; Khonje et al. 2018; Bairagi et al. 2020)

Table 11. Impacts of Improved Milling Technologies

	Milling Fee (Kshs/kg)	Rice milled (ton)	Sell milled rice (=1)	Price of rice (Kshs/kg)	Rice sold (ton)	Capacity utilization	Profit (mill. Kshs)	Profit per capacity (mill. Kshs/kg)	Survival (=1)
ATT (DR)	0.81***	311.18***	0.03	13.34***	145.69***	0.29*	5.90	0.01	0.39***
Early adopter's ATT (DR)	0.80***	414.24**	-0.05	7.65	236.94**	0.41	8.07	-0.07	---
Late adopter's ATT (DR)	0.76***	176.69*	0.25*	15.97***	39.08***	0.12	2.17	0.14*	---
ATT (ESR)	0.43***	437.30***	0.27***	15.25***	144.58***	0.17***	5.76**	0.02	0.74***
ATUT (ESR)	0.54***	322.60***	-0.31***	30.65***	264.45***	0.27***	-2.28***	0.99***	0.49***
Mean outcome among nonadopters	1.89	51.8	0.37	124.4	5.2	0.60	-0.08	-0.04	0.67

ATT = Average treatment effect on the treated, ATUT = Average treatment effect on the untreated

Findings and discussion on improved milling technologies

- **Improved milling technologies improve the quality of domestic rice and its competitiveness with imported rice**
  - Improved Basmati Rice from Mwea: 140-200 Ksh/kg
  - Pakistan Long Grain: 100-120 Ksh/kg
  - Thai Jasmine Rice: 350 Ksh/kg
- **Value chain transformation** with adopters
  - Paddy from local traders
  - Branding
  - Marketing to supermarkets
- Smaller multi-stage rice milling machines reduced the financial burden on potential adopters

4. Concluding Remarks

- Rice cultivation training is indispensable entry point to the Green Revolution in SSA.
- Mechanization and the introduction of improved rice milling technologies are also needed for full-fledged rice Green Revolution in SSA.
- The key strategy for achieving the Rice Green Revolution in SSA is to establish the notion that **the adoption of improved rice cultivation practices is an indispensable entry point**.
- It is the job of our research team to collect data, analyze it, and disseminate critical findings to African policymakers, international organization staff, and leading agricultural scientists and economists.