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Adoption, constraints and economic returns of paddy rice under the system of rice intensification in Mwea, Kenya

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ABSTRACT

A detailed farm survey was conducted in Mwea Irrigation Scheme, Kenya during the 2010/2011 and 2011/2012 main growing seasons to assess the adoption and to quantify the net income advantages of using system of rice intensification (SRI) management over farmer practices (FP) for rice cultivation.

Data were collected through questionnaires and structured interviews with farmers who were practicing both SRI and FP methods of rice production on their farms. Under FP, three seedlings aged 28 days are transplanted in respective hills at random spacing. The fields are then flooded with water throughout the growing period. For SRI practice, factors considered as essential were transplanting only one seedling per hill aged 8–15 days with spacing of at least 20 cm by 20 cm; weeding the crop at least three times at intervals of ten days; and intermittently irrigating the fields. The contributions of using organic manure for fertilization and soil-aeration weed control methods were not considerations in this study since the availability of organic materials and mechanical push-weeders were challenges at the time of study. A total of 40 farmers in 10 units out of the 50 SRI farmers from 18 units of the irrigation scheme were sampled. Benefit–cost relationships were estimated using tabular analysis of all the variable costs and income from production using the survey data.

On average, yield under SRI management increased by 1.6 t/ha (33%), with seed requirements reduced by 87% and, water savings of 28%. SRI required 9% more labor than FP on average, but this factor of production showed great variability; in three Mwea units, labor costs were reduced by an average of 13%. SRI required 30% more labor for weeding than FP in the first season, but this was reduced to 15% in the second season when push-weeders became available. The results showed SRI giving a higher benefit–cost ratio of 1.76 and 1.88 in the first and second seasons, respectively, compared to 1.3 and 1.35 for FP.

The results indicated that SRI practices of planting younger seedlings, with wider spacing and intermittent irrigation, lead to increased paddy rice yields with concomitant rise in the income accruing to farmers. Possibly further increases in net benefit could come with enhanced availability of mechanical weeders and using organic material for fertilization. Up-scaling of SRI in Mwea can be expected to help achieve greater national and household food security

1. Introduction

Rice is the foremost staple food for more than 50% of the world's population (Thakur et al., 2011). There is an upward shift in demand for rice worldwide due to population increase and urbanization, as people change their eating habits (Mishra, 2009), leading to higher market prices for consumers. Between 2006 and 2008, average world prices for rice grew by 217%, compared to wheat which increased by 136%, corn by 125%, and soybeans by 107%. In late April 2008, rice prices hit 24 cents (U.S.) per U.S. pound, more than doubling in just seven months (FAO, 2010; Mittal, 2009; Sing et al., 2007).

In Kenya, rice is currently the third most important food grain after maize and wheat. Its productivity has remained low with marked fluctuations over the years (Table 1), an indication of technological stagnation. Currently, demand for rice is estimated at 320,000 t/y against a national production of 110,000 t/y (MIAD Manager, personal comm. 2011). The shortfall has to be imported at a heavy cost to the country. Annual consumption of rice is increasing at a rate of 12% as compared to 4% for wheat and 1% for maize. The Mwea irrigation scheme currently accounts for 80% of the country's rice production (Republic of Kenya, 2008). Other benefits of rice include employment both on farms and in the market. Rice is very important to the livelihoods of Mwea

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Table 1
Rice production trends in Kenya, 2001–2007.

Year	2001	2002	2003	2004	2005	2006	2007
Area (ha)	13,200	13,000	10,781	13,322	15,940	23,106	16,457
Production (tons)	44,995.5	44,995.5	40,497.9	49,290	57,941.2	64,840	47,256
Unit price (per tons)	26,250	16,060	58,000	65,000	68,000	70,000	53,000
Average yield (bags/ha)	37.9	38.5	41.7	41.1	40.4	31.2	29.4
Yield in tons/ha	3.4	3.5	3.8	3.7	3.6	2.8	2.6
Consumption (tons)	238,600	247,560	258,600	270,200	279,800	286,000	293,722
Import (tons)	201,402	208,944	213,342	223,190	228,206	NA	NA
Total value of imports (billion KSh.)	1.2	0.7	0.65	1.3	0.9	3.3	2.7

Sources: National Cereals and Produce Board; Department of Land, Crops Development and Management; and U. S. Department of Agriculture.

people, with wider economic and food-security implications for Kenyans.

The Mwea Irrigation Scheme covers an area of 9000 ha, with a potential for 4000 ha expansion (Emongór et al., 2009; MIS Manager, personal comm. 2011). The scheme is divided into five sections covering 60 units in total (Fig. 1). Two rice crops are grown annually, the main season occurring between August and December during the short rains, with a long-rains crop grown between January and June. Mwea producers suffer from water shortages during the main growing season and often from blast attack during the long rains season, factors that lead to reduced rice yields in both seasons.

To be able to meet the world's food demand by 2025, it is estimated that rice production has to increase globally by 60% (Fageria, 2007). But there is little scope to increase the area under rice production partly because current practices involve high production costs of fertilizers and protective chemicals (Sinavagari, 2006). A major constraint is that rice crop is the largest consumer of water in the agricultural sector when the sector itself is under pressure to reduce this consumption (Bera, 2009; Mishra, 2009; Prasad, 2007; Prasad and Ravindra, 2009).

Rice production in Kenya is based mostly on the conventional practice of continuously flooding the paddy fields (Republic of Kenya, 2008). Available data indicate that the fertility of Mwea soils is suitable for rice cultivation (Wanjogu et al., 1995). Thus, innovative ways for reducing inputs like water, chemicals, fertilizers and labor while increasing yields on the same area of land need to be put in place to ensure sustainable rice production (Bouman et al., 2005; Mati and Nyamai, 2009).

The System of Rice Intensification (SRI), developed in Madagascar over 25 years ago (Laulanié, 1993), offers an opportunity to improve food security through increased rice productivity by changing the management of plants, soil, water and nutrients while reducing external inputs like fertilizers and herbicides (Berkelaar, 2001; Thakur et al., 2009; Uphoff, 2003; Vermeule, 2009). The system proposes the use of single, very young seedlings with

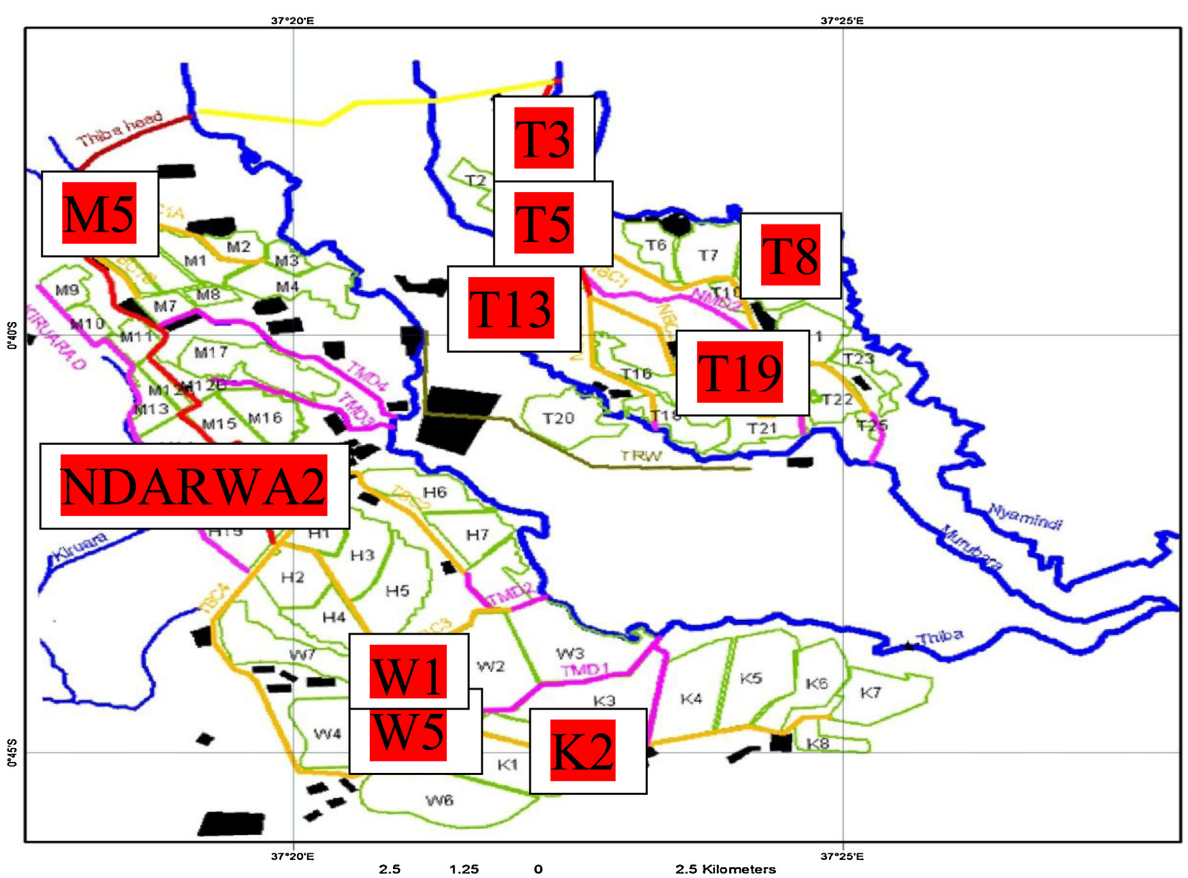

Fig. 1. Map showing all the sections and units within Mwea irrigation scheme. Units with sampled farmers are shown in red boxes.

wider spacing, intermittent wetting and drying, use of a mechanical weeder which also aerates the soil, and enhanced soil organic matter (Uphoff and Kassam, 2009). All these practices are aimed at improving the productivity of rice grown in paddies through healthier, more productive plants in more fertile soil systems by supporting the greater root growth of plants and by nurturing the abundance and diversity of soil organisms (World Bank Institute, 2008; Stoop et al., 2002).

Previous research has shown yield increases with SRI, even on some of the poorest soils, of between 50–100% while irrigation water inputs were reduced by between 25% and 50% (Bera, 2009; Berkelaar, 2001; Sarath and Thilak, 2004; World Bank Institute, 2008). Reduced costs of weeding, land preparation, fertilizer and irrigation have also been reported (Barah, 2009). Despite reports on positive results, SRI practice has been criticized by some who argued that any extraordinarily high yields reported are likely to be the consequence of measurement errors (Sheehy et al., 2004, 2005; Sinclair and Cassman, 2004). This objection did not, however, address the evidence on higher comparative *average* yields, calculated with the same methods with which the conventional yields were measured. Latif et al. (2005) and McDonald et al. (2006) have argued that key SRI management principles have little effect on rice yields, even though there is much evidence in the peer-reviewed literature to the contrary.

Moser and Barrett (2003) deemed SRI as too labor-intensive to be widely adopted. This conclusion, however, is at odd with data from Barrett et al. (2004), Sato and Uphoff (2007) and Sinha and Talati (2007) who found that once farmers gain skills and confidence in the methods, SRI management methods can become labor-neutral or even labor-saving. Surely there are many different results that can be seen with a management system like SRI. For the present, assessments that are location-specific are most important to build up a body of evidence from which broader conclusions can, over time, be drawn.

Little is known about the impact that SRI and utilizing its methods adoption can have on income benefits in the Mwea irrigation scheme or in Kenya as a whole. Since its introduction in June 2009, its adoption has grown steadily from 2 farmers in that year, to 50, then 250 and then over 2000 farmers in 2010, 2011 and 2012, respectively. It is expected that by the end of this year (2013), three-quarters of the 5576 farmers registered in the Mwea scheme will have adopted SRI methods (SRI Mwea Field Assistant, personal comm. 2012).

This study investigated whether SRI practices can increase farmers' rice yields and have significant benefits for their household incomes from rice production. It sought to: (i) compare the yield and income advantages of system of rice intensification (SRI) vs. current farmers' practices (FP) for rice cultivation, (ii) identify the factors influencing adoption or rejection of SRI, and (iii) delineate policy alternatives and strategies for a wider scaling up of SRI.

2. Materials and methods

2.1. Study area

A detailed farm survey was conducted in 18 units of the Mwea Irrigation Scheme in Kirinyaga County, Kenya during the 2010/2011 and 2011/2012 main growing seasons. Mwea Irrigation Scheme has a total of 64 units. The region is classified as tropical with a semi-arid climate, having an annual mean air temperature of 23–25 °C with about 10 °C difference between the minimum temperatures in June/July and the maximum temperatures in October/March. It lies on the equator within latitudes 0°32′ S and 0°46′ S and longitudes 37°13′ E and 37° 30′ E, and has annual mean precipitation of 950 mm, with annual sunshine of 2485 h.

The soils are classified as Vertisols (Sombroek et al., 1982). In the first season, the total rainfall, average temperature and average relative humidity were 238.9 mm, 23.2 °C and 78.6%, respectively. In the second season, total rainfall was 451.5 mm, average temperature 23.4 °C and average relative humidity 76.2%. The sampled farmers were all practicing both SRI and conventional systems of rice production, so that differences between farmers and between farms (soils, climate, etc.) would be essentially controlled for.

2.2. Nature and sources of data

Primary data were obtained from sampled farmers through field survey and structured interviews with the help of pre-tested questionnaires. Secondary data were collected from the Kenya Meteorological Department (KMD), the Mwea Irrigation and Agricultural Development (MIAD) Centre, reports from earlier research, and other current researchers.

2.3. Sampling design

Fifty farmers who were practicing SRI on at least part of their land in the Mwea Irrigation Scheme in 2010 were identified using the total-population, purposive-sampling approach (Doherty, 1994; Stephan and McCarthy, 1958). These farmers were found to be scattered across 18 units within the scheme. As the number of SRI adopters was different from unit to unit, it was not possible to have the same number of farmers from each unit. All of the 50 farmers who had adopted SRI in 2010 were approached to participate in the survey, so there was no selective sampling involved.

2.4. Questionnaire administration

Both hand-delivered questionnaires and structured-interview methods were used to collect data. The questionnaire consisted of both open-ended and close-ended questions. The participants were invited to complete the questionnaire with the researcher, which could ensure the complete filling of questionnaire and clarification of any ambiguous questions (Rundblad, 2006). For the farmers who could not make it to the meeting, questionnaires were delivered to them through the same trained representative, who was also able to clarify the questions (Bareiro and Albandoz, 2001). The main areas of focus during the interviews are shown in Appendix I.

2.5. Data analysis

The economic evaluation was based on input–output data – costs of production and revenue – obtained from farmers through the questionnaires and interviews. Data editing was done after entering data into the computer on an excel sheet and comparing the figures from different correspondents under the same data cluster (Adèr and Mellenbergh, 2008). Any responses where data were missing, invalid or inconsistent were identified, and follow-up contact was made with these respondents to get more complete data in which confidence could be placed (Cochran, 1977). Where errors could be corrected through imputation using the nearest-neighbor method (Wonacott and Wonacott, 1977; Williams, 2003), this was done; and if this was not possible, then the questionnaire was excluded from the survey analysis. Factors considered as criteria when editing the data were: (i) spacing used (at least 20 cm by 20 cm for SRI), (ii) age of seedling (only seedlings 8–15 days old were considered as SRI), and (iii) whether farmers were practicing both systems (SRI and FP, for comparison purposes). Respondents

Table 2
Benefit–cost analysis of SRI and FP for the first season.

Particulars	Unit name [no. of farmers]																				Average costs	
	T13 [8]		T5 [2]		W1 [10]		T19 [5]		Nderwa 2 [1]		T3 [2]		M15 [3]		T8 [2]		K2 [1]		W5 [6]			
	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP
Seed cost (KShs)	444	2500	320	2000	640	2500	400	2200	400	2500	400	2000	250	2000	400	2000	400	2500	600	2250	425.4	2245
Labour cost × 10^3 (KShs)	16.57	15.2	12.8	11.975	18.55	16.98	15.75	17.85	25.13	20.3	14.0	13.2	17.95	16.95	16.35	19.56	17.0	15.25	14.3	15.03	16.84	16.23
Land preparation	4975	4975	4000	4000	4700	4700	4500	4500	4500	4500	4300	4300	4500	4500	4500	4500	7000	7000	6200	6200	4918	4918
Fertilizers	7710	9000	6800	10670	6467	8465	5900	7780	9300	9300	9075	11,400	8400	12,100	5900	5900	7400	10,100	9150	10,750	7610	9547
Insecticide	806	806	200	200	967	967	400	400	600	600	550	550	750	750	400	400	1000	1000	820	902	649.3	657.5
Herbicides	712	712	0	0	633	1266	0	0	400	400	400	400	1000	1000	0	0	600	750	225	450	397.0	497.8
Manure	1500	0	0	0	500	0	0	0	0	0	3000	0	500	0	0	0	2300	0	0	0	780	0
Transport	2720	2250	3600	3280	3900	2400	1500	1500	4500	2325	1800	1150	3300	3300	1500	1120	2400	1650	2150	1850	2737	2083
Land hiring × 10^3 (KShs)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Operation & main-tenance	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Other costs	1360	800	1900	1650	1695	1600	1500	1500	3500	1575	1700	1300	1650	1650	1500	1165	1600	1345	1075	775	1748	1336
Total cost/acre × 10^3 (KShs)	78.8	78.2	71.6	75.8	80.1	80.9	71.9	77.7	90.3	83.5	77.2	76.3	80.3	84.3	72.6	76.6	81.7	81.6	76.5	80.2	78.1	79.5
Total cost/ha × 10^3 (KShs)	194.6	193.2	176.8	187.1	197.7	199.7	177.7	191.9	223	206.2	190.7	188.4	198.3	208	179.1	189.2	201.7	201.47	188.9	198	192.8	196.3
Yield (t/ha)	7.1	5.96	7.2	5.44	6.6	4.94	7.9	5.67	7.4	4.66	6.9	5.14	6.9	5.88	6.6	5.23	5.2	4.1	5.58	4	6.73	5.10
Gross income × 10^3	355	298	358	272	330	247	395	283.5	372	233	342.5	257	346	294	329.5	261.5	259.5	205	279	197	336.7	254.8
Net income × 10^3	160.4	104.8	181.2	84.9	132.3	47.3	217.3	91.57	149	26.83	151.8	68.6	147.7	85.98	150.4	72.25	57.77	3.53	90.06	-1.03	143.8	58.47
Cost/ton × 10^3 (TC/yield)	27.40	32.41	24.7	34.39	29.95	40.42	22.49	33.85	29.98	44.24	27.84	36.65	28.65	35.38	27.18	36.18	38.87	49.14	33.86	50.26	29.09	39.29
Benefit–cost ratio	1.82	1.54	2.02	1.45	1.67	1.24	2.22	1.48	1.67	1.13	1.80	1.36	1.75	1.41	1.84	1.38	1.29	1.02	1.48	0.99	1.76	1.3
No. of irrigations	32	48	30	47	28	39	28	37	32	46	33	40	31	47	33	46	34	47	28	37	30.9	43.4
Savings on costof production (%)	15.5		28.2		25.9		33.6		32.2		24.1		19.0		24.9		20.9		32.6		25.7	

who did not meet these criteria would not be valid for comparison, so they were not included in the analysis.

The technique of tabular presentation was used to assess the costs and returns of paddy crop in the study area. This analysis covered the trial period, from planting to harvesting, and determination of farm-gate price. The percentage change and averages were computed and compared to draw meaningful inferences about economic returns. The different cost items that are included under each cost concept are detailed in Tables 2 and 3.

Data were analyzed statistically using the mixed procedure in SAS 9.1.3 (SAS Institute, 2004). Descriptive statistics were performed on the data to test relationships between variables. For categorical variables, cross tabulation was carried out while for quantitative variables, mean comparisons of quantitative dependent variables were carried out using one way analysis of variance (ANOVA). To determine whether existing differences among the means were statistically significant, post hoc multiple comparisons using least-significant difference (LSD) was employed.

3. Results and discussion

Out of the 50 farmers from 18 units who were initially sampled, 41 farmers from 10 units responded to the questionnaires. After data editing and entering, six questionnaires were found to have gross errors in yield data and land preparation cost. Errors on two of the questionnaires were corrected by the respondents through telephone calls while three errors could be reasonably adjusted by imputation. One questionnaire was excluded from the analysis because inconsistencies could not be reconciled, leaving a sample of 40 farmers from the 50 who had used SRI methods in 2010. Out of the 10 farmers who did not respond, only 2 farmers were from the 10 units where farmers responded while 8 farmers were from the remaining 8 units (a ratio of one farmer per unit). As the total number of farmers within these same units who responded was high (Tables 2 and 3), there was no reason to expect that with an 80% response rate the farmers who did not respond to the questionnaires were significantly different from those who did respond. The parameters examined to measure the sustainability of SRI included farmers' cost of inputs, incomes, adoption of SRI practices, yields, and other benefits.

3.1. Costs of production and net incomes

The costs of production were higher in some units under SRI practice, although across the whole sample the average cost per ha per unit was higher under FP (Tables 2 and 3). SRI gave higher average net economic returns in all units in both seasons (146% and 141%, respectively). The slight percentage reduction in net income (5%) in the second season was partly caused by an improvement in yield under FP for one farmer who had lost money on his conventional production in the first season. In total, SRI required 9% more labor than FP, although in 3 units SIR reduced labor costs by an average of 13%. It was seen that SRI required 30% more labor for weeding than FP in the first season, but this figure was cut in half in the second season, to only 15% more labor, when mechanical push-weeders became available. The combination of wider spacing and intermittent irrigation in SRI provides an ideal environment for weed growth, leading to need for more frequent weeding.

Some studies have shown higher labor requirements of more than 25% in SRI practice (Latif et al., 2005; Thakur et al., 2009). Seed requirements with farmer practices were 62–77 kg/ha, and only 5–10 kg with SRI, an 86% reduction in seed requirements for SRI farmers. These results are consistent with SRI practices in other countries (Anthofer, 2004; Dumas-Johansen, 2009; Menete et al., 2008; Satyanarayana et al., 2007). The reduced cost of seed plus

Table 3
Benefit–cost analysis of SRI and FP for the second season.

Particulars	Unit name [no. of farmers]																				Average cost	
	T13 [8]		T5 [2]		W1 [10]		T19 [5]		Nderwa 2 [1]		T3 [2]		M15 [3]		T8 [2]		K2 [1]		W5 [6]			
	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP	SRI	FP
Seed cost (KShs)	250	2500	320	2000	640	2500	250	2200	250	2500	320	2000	250	2000	350	2000	250	2500	320	2250	320	2245
Labour cost(10^3 (KShs)	16	13.2	12.3	11.98	17.55	16.98	15.05	17.85	19.73	20.3	14.0	13.2	15.95	16.95	14.5	19.56	16.4	15.25	14	17.02	15.5	16.23
Land preparation	4975	4800	4000	4000	4700	4700	4500	4500	4500	4500	4300	4300	4500	4500	4500	4500	5000	5000	5200	6200	4618	4700
Fertilizers	6710	9000	6800	10,670	6467	8465	5900	7780	9300	9300	9075	11,400	8400	12,100	5900	5900	7400	10,100	8150	12,750	7410	97,46.5
Insecticide	0	806	200	200	967	967	400	400	0	600	550	550	750	750	400	400	0	1000	820	902	408.7	657.5
Herbicides	712	712	0	0	633	1266	0	0	0	400	400	400	0	1000	0	0	0	750	0	450	174.5	497.8
Manure	2000	0	500	0	500	0	1000	0	500	0	3000	0	500	0	1000	0	2300	0	1000	0	1230	0
Land hiring × 10^3 (KShs)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Operation & maintenance	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Transport	2720	2250	3600	3280	3900	2400	1500	1500	3500	2325	1800	1150	3300	3300	1500	1120	2400	1650	2150	1850	2637	2082.5
Other costs	1360	800	1900	1650	1695	1600	1500	1500	3500	1575	1700	1300	1650	1650	1500	1165	1600	1345	1075	1005	1748	1359
Total cost/acre × 10^3 (KShs)	76.7	76.07	71.6	75.8	79.05	80.9	72.1	77.7	83.3	83.5	77.15	76.3	77.3	84.25	71.5	76.6	77.35	79.6	74.7	84.4	76.78	79.52
Total cost/ha × 10^3 (KShs)	189.5	187.8	176.8	187.1	195.2	199.7	178	191.9	205.6	206.2	190.5	188.4	190.9	208	176.5	189.2	191	196.53	184.5	208.5	187.8	196.3
Yield (t/ha)	7.4	5.84	7.3	5.69	6.6	5	8.1	5.75	6.9	4.66	7.1	5.29	7.21	5.62	7.41	5.23	5.5	4.2	6.98	5.4	7.1	5.3
Gross income × 10^3	370	292	364.5	284.5	329.5	250	405	287.5	345.5	233	355	264.5	360.5	281	370.5	261.5	273	210	349	271.5	352.3	263.6
Net income × 10^3	180.6	104.2	187.7	97.4	134.3	50.3	227	95.57	139.9	26.83	164.5	76.1	169.6	72.98	194	72.25	82.01	13.469	164.5	63.03	164.4	67.2
Cost/ton (TC/yield)	25.60	32.16	24.26	32.88	29.62	39.94	21.98	33.38	29.76	44.24	26.83	35.61	26.47	37.02	23.82	36.18	34.98	46.793	26.43	38.39	26.97	37.66
Benefit–cost ratio	1.95	1.55	2.06	1.52	1.69	1.25	2.27	1.50	1.68	1.13	1.86	1.40	1.89	1.35	2.10	1.38	1.43	1.07	1.89	1.30	1.88	1.35
No. of irrigations	10	16	12	17	10	14	10	17	10	14	11	16	15	22	15	20	13	17	10	15	11.6	16.8
Savings (%)	20.4		26.2		25.8		34.2		32.7		24.7		28.5		34.2		25.2		31.2		28.3	

For Tables 2 and 3, Labor costs include, nursery and land preparation, weeding, harvesting. Other costs include cost of packing sacks and transport from the farm to the store.
Total income was calculated by multiplying the total yield (paddy) by a gate price of Ksh 50 (determined by the government).
Costs and prices considered in the calculations were for cultivation, sowing, seeds, fertilizer, herbicide/insecticide, weed control, irrigation, bird scaring, harvesting, transport.
Benefit–Cost ratio was calculated by dividing the gross income by total cost at 14% discounted rate, which was calculated based on the interest rate of bank loaning.
Net income (KShs/unit/ha) = Gross income (KShs/unit/ha) – Total production cost (KShs/unit/ha). SRI practice = (349,900 – 187,848) = 162,052; FP = (263,550 – 196,339) = 67,211. The same farmers were interviewed in both years (for consistency).
% Savings on cost of production = 100 (cost of production per ton under FP–cost of production per ton under SRI)/cost of production per ton under FP.

Table 4
Summary of crop yields, input costs, and incomes for the two practices in both seasons.

Parameter	Season 1		Season 2	
	SRI	FP	SRI	FP
Yield (ton/ha)	6.74[a]	5.04[b]	6.85[a]	5.24[b]
Total cost/ha × 10^3 (KShs)	192.85[a]	196.33[a]	187.85[a]	196.34[b]
Gross income × 10^3 (KShs)	336.65[a]	254.8[b]	352.25[a]	263.55[b]
Net income × 10^3 (KShs)	143.8[a]	58.47[b]	164.4[a]	67.21[b]
Cost/ton	29.09[a]	39.29[b]	26.97[a]	37.67[b]
Benefit–cost ratio	1.76[a]	1.3[b]	1.88[a]	1.35[b]

Values with the same letters in a row under the respective seasons are not significantly different by LSD at the 0.05 level across both practices.

water savings of 26% compensated for the labor cost in SRI practice compared to FP. SRI crops were irrigated fewer times than with farmer practice in part because its grain matured earlier by an average of 10 days, but also, farms under FP were irrigated more times than SRI plots, which were left to dry out rather than have standing water on the fields. Cost of irrigation was lower in the second season due to higher rainfall. The water saved, when irrigation is necessary for a successful crop, can be used to irrigate more crop area, hence an increase in food production.

The results of economic analysis showed that SRI gave a significantly higher benefit–cost ratio of 1.76 and 1.88 compared to 1.31 and 1.35 for FP in the first and second seasons, respectively (Table 4). Barah (2009) reported similar ratios and even higher values in some of the districts that he studied in India. A wide range of reductions in cost of production with SRI for different countries is elaborated in Uphoff (2005) and Sinavagari (2006). The higher B/C ratio recorded in the second season can be explained by higher yields, low cost for seeds and fertilizers, and high savings on water with SRI practice. The inter-unit variations in water use depended on farmer's personal practices (the number of days that an SRI plot is left dry is not fixed), but particularly due to inadequate and unreliable distribution of water in the entire scheme.

It was also observed that farmers reduced their use of fertilizers and opted for more manure application with SRI practice during their second season. As stated, SRI is not a fixed technology and farmers are encouraged to adjust practices according to their conditions (Zhao et al., 2009). Mechanical weeders were used for weeding in the second season once they became available. This made a cost saving for SRI since the weeders take less time even though there is slightly more cost than with hand weeding.

A statistical analysis of these parameters is shown in Table 4.

3.2. Yields

The survey results showed that average SRI yields were significantly higher than FP in both seasons ($P < 0.0001$) in both seasons (Table 4). The average yields by unit varied from 5.2 t/ha to 8.0 t/ha under SRI, and from 4.1 t/ha to 6.0 t/ha for FP for both seasons. The increase in average yields varied from 26.8% to 33.3% for both seasons under SRI across the units. Average yields from various units for both practices are shown in Tables 2 and 3. Average yields from FP were in general higher than the normal average yields in Mwea scheme of 3.5–5.0 t/ha (MIAD Manager, personal comm. 2010). The somewhat higher yields achieved with conventional methods in this study compared to the usual averages in Mwea may have been due to the farmers' application of some SRI practices, such as intermittent irrigation and planting fewer seedlings per hill along with other usual farmer practices, or possibly it was better farmers who were the first to try out SRI practices (Table 5). Farmers getting higher yields with their regular practices have been reported by other researchers, such as Stoop et al. (2002), Anthofer (2004), Husain et al. (2004), Kabir and Uphoff (2007) and Thakur (2010).

Table 5
Total number of SRI adopters since its introduction in Mwea scheme.

Year	2009	2010	2011	2012
No. of farmers	2	50	250	2700

Source: SRI MIAD office database.

3.3. Other benefits of SRI

Because of early transplanting, farmers were able to harvest their SRI crop 1–2 weeks earlier than their FP crop. Many of these farmers are now planning to diversify their farming system by supplementing their rice crop with short-duration crops like tomatoes and beans.

The use of a mechanical weeder in SRI practice has led to more gender balance in terms of labor expenditure because men are now participating more in rice farming with FP, especially weeding. The men find use of the weeder more suitable and acceptable since they do not have to bend as in hand weeding. This shift can allow children to attend school more regularly as hand weeding has been traditionally reserved for women and children. This change was seen in trials in Tamil Nadu in 2004 (Satyanarayana et al., 2007).

3.4. Adoption and constraints in SRI method of rice production

The number of SRI adopters has risen steadily since its introduction in Mwea in 2009 (Table 5). This could be attributed to the positive results posted by earlier adopters and also as a result of awareness creation through the project and government support.

Adoption levels of various SRI practices are shown in Table 6. Complete application of all the suggested practices is considered complete adoption, while adoption of only some of the practices is called partial adoption. It can be observed that wider spacing was the most accepted practice because farmers were encouraged to use a rope instead of fabricating a grid. SRI farmers also found it easy to follow the recommendation of preparing the nursery next to the field so as to transplant the young seedlings quickly. There was a

Table 6
Adoption level of SRI practices by sampled farmers.

No.	Suggested practices in SRI practice	Adoption level			
		Complete		Partial	
		1st season	2nd season	1st season	2nd season
1	Seed rate of 5 kg/ha	10 (25%)	28 (70%)	30 (75%)	12 (30%)
2	Transplanting seedlings aged 8–15 days	5 (12.5%)	30 (75%)	35 (87.5%)	10 (25%)
3	Careful transplanting of seedlings with soil intact with roots	30 (75%)	40 (100%)	10 (25%)	0 (0%)
4	Wider spacing (20 cm × 20 cm, 25 cm × 25 cm or 30 cm × 30 cm)	40 (100%)	40 (100%)	0 (0%)	0 (0%)
5	Weed management	3 (7.5%)	34 (85%)	37 (92.5%)	6 (15%)
6	Water management	12 (30%)	32 (80%)	28 (70%)	8 (20%)
7	Organic manure application (10 t/ha)	5 (12.5%)	13 (32.5%)	35 (87.5%)	27 (67.5%)

Fig. 2. Effect of strong wind on rice under SRI and FP. Plots, grown with same variety of rice were exposed to the same wind pressure.

high level of adoption of this practice (75% and 100%) in seasons 1 and 2, respectively. Use of mechanical weeders was ranked last, mostly because they were not readily available at the start of the survey.

During the introduction of SRI, farmers were advised to continue using synthetic fertilizers if they did not have access to manure (Laulanié, 1993). Since chemical fertilizers were readily available in the scheme, most farmers opted to use them rather than manure (Also, the government supported SRI farmers with free fertilizers as a way of encouraging its wide adoption).

Most farmers were skeptical about the reduced seed rate and age of seedlings at first, but this gradually changed as they slowly appreciated, through education, the importance of this practice for root growth and tiller development (Satyanarayana, 2004) and the subsequent contribution to yield.

A key principle of SRI practice is more careful management of and economizing on water. Due to unreliable and unequal distribution of water within the scheme, few farmers took this as a key issue because they feared that they would not get water when they needed it. This, however, changed in the second season after the water managers were requested to give special consideration to SRI farmers. Poor drainage was also mentioned by farmers as a hindrance to this practice. Similar challenges have been experienced in Cambodia (Anthofer, 2004).

3.5. Reasons for practicing SRI

All the farmers who had adopted SRI method of paddy rice production identified increase in yield was their main reason for the adoption. Reduction in cost of seeds was ranked second, while reduction in water requirements and less fertilizer costs were ranked third and fourth, respectively. Farmers also indicated that resistance to wind damage (lodging) was a consideration in SRI adoption (Fig. 2). This analysis is shown in Table 7.

Although the percentage of savings on seed was higher than the increase in yields, the net income from yield increase (KShs 97,190/ha) was much higher compared to the savings due to reduced seed cost (KShs 4960/ha). This is the reason that farmers gave first priority to yield increase for their SRI adoption. However, farmers also found seed-saving appealing as one of the elements of SRI reduction in external inputs (Stoop et al., 2002).

Most farmers still use chemical fertilizers, and this did not affect their adoption of SRI. Fertilizers were made available to SRI farmers at the time of the survey, so that the message of organic fertilization with SRI did not get much attention. It should also be noted that the government subsidizes water costs for the farmers so water-saving is not a big issue. Farmers pay a flat rate of KShs 5000/ha per season to MIS and can then use water when and as available without making any more payments. However, beginning next year this will change when the government starts charging farmers for irrigation water through the Water Resources Management Authority (WARMA). This may make more full adoption of SRI more attractive.

3.6. Constraints in practicing SRI method of paddy cultivation

The challenges to SRI adoption as seen by farmers are presented in Table 8. The main constraint was its high labor requirement, especially for weeding as a result of higher weed infestation. This constraint, however, became less salient during the second season when the mechanical weeders became available, and also as farmers tried to follow SRI practices more closely. The specific constraint most pertinent in the study area was poor soil drainage in some units, which limited many farmers' interest in adopting SRI methodology as its benefits are greatest where there can be predominantly aerobic soil conditions. There was also a constraint in finding a mechanical weeder design and construction appropriate for the heavy soils in Mwea. This may be one of the site-specific SRI constraints to be dealt with. Farmers have to try out and adapt the various practices proposed in order to know which ones are suitable for their conditions. These variable practices include plant spacing, water scheduling, and weed management.

Table 7
Reasons given by farmers in Mwea scheme for their adopting SRI.

Reason	Rank			
	R1	R2	R3	R4
Increase in yields	40a	0.1d	0.1d	0.1d
Reduced cost of seed	0.1b	32a	5b	3c
Less water requirement	0.1b	5b	32a	3c
Less fertilizer requirement	0.1b	3c	3c	34b
Less effect of strong winds on rice	0.1b	0.1d	0.1d	40a

Values with the same letters in a column are not significantly different by LSD at the 0.05 level. R1 = Very high, R2 = High, R3 = Medium, R4 = low.

Table 8
Constraints for SRI adoption.

Reason	Rank			
	R1	R2	R3	R4
Weed menace	31^a	7^c	1^d	1^d
Availability of mechanical weeders	6^b	24^a	7^b	3^b
High labor requirement for weeding as a result of 1 and 2	2^c	8^b	28^a	2^c
Poor land drainage	2^c	1^d	2^c	35^a

Values with the same letters in a column are not significantly different by LSD at the 0.05 level. R1 = Very high, R2 = High, R3 = Medium, R4 = low.

4. Conclusions

This study has shown that SRI is capable of producing considerably higher rice yields (by at least 2 t/ha, depending on how closely the basic principles are followed), with substantial saving on water usage, reduced production costs, as well as increased net income (over 140% more) compared with current farmer practice.

The improvement in net earnings from SRI practices was due to a combination of reduced seed rate, less water, and less labor accompanying attainment of higher production. The relative advantages from SRI are expected to become greater when farmers must start paying for the water for their rice crops since the expenditures for water will be much lower with SRI practice.

There has been a recognizable demonstration effect in Mwea, as many interested farmers have learned the practices from the initial SRI farmers, and they have then in turn also taught others. This has succeeded because of the way that SRI was introduced into the Mwea community through experimental trials, demonstrations on farmers' fields, involvement of the Ministry/Scheme management, distribution of training materials and farmer data sheets for record-keeping, support through field assistants, and use of the media. The sharing of information is very open, through many channels, and farmers feel involved in the process of evaluation and dissemination. The rate of SRI adoption seen in Mwea is an indication that farmers have confidence in its benefits and sustainability.

SRI has been through many controversial discussions about its potential to increase yields and lower production costs beyond Madagascar where it originated. There has been some criticism of it not being standardized for the same application everywhere. This study indicates that by following even some of the SRI principles, farmers are able to increase their rice yields as well as to improve their benefit–cost ratio. In a world with high risks of food shortages, SRI can enhance food security for Kenya, and it should therefore receive more attention regarding research projects, public recognition and policy support.

5. Policy implications and recommendations

(1) Paddy yields in the Mwea scheme were increased by about 33 per cent under SRI methods, even without farmers using the full set of recommendations. SRI has been seen to be an important strategy for dealing with water-scarce situations in rice production, and therefore deserves carefully planned supportive interventions, including infrastructure improvement. The government is currently supporting awareness-promotion of SRI in the other rice-growing schemes in the country through the National Irrigation Board (NIB). The government could also give incentives like offering a 10% higher price per kg or per bag for paddy rice grown with at least some specified minimum of SRI practices (including water saving methods for sure) given the improvements in grain quality that result. In other countries, when SRI paddy rice is milled, there is about 15% higher out-turn of polished rice because of less chaff (fewer unfilled grains) and less breakage of grains in milling (Xu et al., 2005). This effect seen in Sri Lanka, Cuba, India and China would justify a premium price paid to farmers for SRI rice, as an incentive and as compensation for higher grain quality. Otherwise, millers capture all of this benefit.

(2) Formation of strong a SRI research network among researchers working in different rice schemes within the country, along with active participation of the line departments (for example, the Ministry of Agriculture, the Ministry of Water and Irrigation, the Ministry of Finance and the Ministry of Planning), recruitment of extension officers having knowledge of SRI principles and methods (or prepared to be trained in these), and use of mass media, especially use of radio stations that broadcast in local languages. These measures can popularize and encourage the widespread adoption of SRI practice.

(3) SRI encourages use of organic manure. If well adopted, there is a big market for 'SRI organic rice'. In any case, since almost any decomposed biomass can be made into effective compost for SRI production, whether there is animal manure in it or not, steps should be taken to promote the growing of green manures and other vegetative biomass for making compost that will enrich soil fertility and improve soil structure and functioning through organic amendments. This is a precedent that could improve Kenyan farmers' soil across the board since they cannot get full benefit from inorganic (chemical/synthetic) fertilizers without sufficient stocks of soil organic carbon that nurtures the life in the soil, which is the foundation for soil productivity and for its sustainability.

(4) Increased cost of production due to high labor requirement particularly for weeding, was the major constraint identified for initial practice of SRI methods. This is partly a function of moving up the learning curve. Still, it would be helpful to researchers from learning institutions to fabricate and test, with farmers, different models of mechanical weeders, including power-operated ones, suitable to different soil conditions in the country. Some farmers have been in the forefront in fabrication of weeders, and this should be encouraged through incentives. There is growing experience with appropriate implements for SRI practice in other countries. Kenyan authorities and NGOs should avail themselves of such knowledge and models through international contacts, which can be facilitated through the SRI International Network and Resources Center (SRI-Rice) at Cornell University. Soil-aerating weeders have the double benefit of controlling weeds and actively aerating the soil surface, so that the life in the soil which depends on a balance of oxygen and water can thrive and benefit the crop, enhancing yield and health of plants with addition of extra nutrients.

(5) As farmers, NGOs and researchers in other countries, including neighboring Ethiopia, are adapting SRI ideas and methods to raise the productivity of other crops, such as wheat, finger millet and teff (ISD, 2011), agencies in Kenya should undertake the same kind of experiments with farmers to assess what other agricultural improvements can be made for more productive, resource-conserving cropping so as to enhance food security across a wider swath of agriculture.

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Appendix A. QUESTIONNAIRE FOR THE ECONOMIC ANALYSI OF SRI PRACTICE.

QUESTIONNAIRE FOR THE ECONOMIC ANALYSI OF SRI PRACTICE.

NAME OF FARMER:……………………………PHONE:…………………….UNIT:……
SEASON:……………………………………….DATE………..……………......................

No.	Activity	Quantity		Cost (Ksh)	
		SRI	FP	SRI	FP
1	How many acres did you plant				
2	What was the age of the seedlings				
3	What spacing did you use				
4	Cost of Operation and Maintenance				
5	How did you prepare your nursery a. Ordinary b. Bio-cha c. Padong				
6	Land preparation costs a. Rotavation/Ploughing b. Leveling (how many times)				
7	Seeds: a. How many kgs per acre b. Cost per kg				
8	Transplanting: a. How many people b. How long did it take c. Cost per person per day				
9	Fertilizers a. Basal fertilizer i. Type used ii. How many Kgs iii. Cost per kg iv. How many people v. How long did they take vi. Cost per person b. Top dressing i. First - Type used - How many times - How many Kgs - Cost per kg - How many people - How long did they take - Cost per person ii. Second - Type used - How many times - How many Kgs - Cost per kg				

	- How many people did you employ - How long did they take - Cost per person Manure: a. How many Kgs per acre b. Cost per Kg c. How many people d. Cost per person				
10	Watering: a. How many times b. How many people c. Cost per person per day				
11	Weeding: a. Did you use manual or weeder b. How many times did you weed c. How many people d. How long did they take e. Cost per person				
12	Herbicides: a. How many liters b. Cost per liter c. How many times d. How many people e. How long did it take f. Cost per person				
13	Insecticide a. How many liters b. Cost per liter c. How many times d. How many people did you employ e. How long did it take f. Cost per person				
14	Bird scaring a. How many people did you employ b. How long did they work c. Cost per person per day				
15	Harvesting a. How many people did you employ b. How long did it take c. Cost per person d. How many bags/Kgs per acre e. Cost of transport from farm f. Post harvest handling/bag				
16	Any other cost				

17. Out of the SRI principles you have been taught, which ones do you practice?

18. Do you think SRI is a method you would like to continue with?.....................Explain............

19. Has anyone come to you for information on SRI?

20. Using the scale given below, please rank the following factors for adoption of SRI.

a) Increase in yields

b) Reduction in cost of seed

c) Less water requirement

d) Less fertilizer requirement

e) Less effect of strong winds on rice

Scale: R1=Very high; R2= High; R3= Medium; R4=Low

21. Similarly, use the same scale above to rank the listed constraints as you have faced them in the adoption of SRI.

a) Weed menace

b) Availability of mechanical weeder

c) High labor requirement for weeding due to factors a and b above

d) Poor land drainage

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