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Water Productivity under the System of Rice Intensification from Experimental Plots and Farmer Surveys in Mwea, Kenya

由水田試驗區及農民調查探討肯亞Mwea地區水稻強化栽培系統之水資源生產力

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ABSTRACT

Field experiments were conducted in 2010 and 2011 during the main growing seasons at Mwea Irrigation Agricultural Development Center in the Mwea irrigation scheme, Kenya. Trials compared water savings and water productivity for Basmati 370 rice variety grown under System of Rice Intensification (SRI) management with reduced water applications (alternate wetting and drying, AWD) vs. conventional practice of continuous flooding (CF).

During these years, a detailed farm survey was conducted to assess the yield improvements and water savings made by farmers using SRI crop and water management methods compared to usual farmer practices (FP) for rice cultivation. Data were collected through questionnaires and structured interviews from farmers who were practicing both SRI and FP methods of rice production on their farms.

For this study, the factors considered as defining SRI were transplanting only one seedling per hill, aged 8-15 days, with spacing at least 20cm x 20cm; weeding the crop at least three times at intervals of ten days; and intermittently irrigating the fields. Contributions that could be made by using organic manure for fertilization and by soil-aerating weed control, as recommended for SRI, were not considered due to limited availability of organic materials and mechanical push-weeders at the time of the study.

SRI gave the highest yields and water savings for both field trials and farmer surveys. In the field trials, average yield was increased by 1.7 t/ha while farmers reported average increases of 1.6 t/ha. The measured and reported savings of irrigation water were 31% and 30%, respectively. Average water productivity was similarly found to be higher with SRI management, raised by 140% and 100%, respectively, in experimental plots and farmer survey reports. These findings are consistent with similar evaluations in other countries.

The results clearly indicated that SRI practices (planting younger seedlings, with wider spacing and intermittent irrigation) increase paddy rice yields with higher water productivity at both plot and farm levels. Possibly further increases in water productivity could come with still better water management by farmers and more organic materials for soil fertilization and soil-aerating weeding.

From the study results, it is calculated that 3,857 additional hectares could be irrigated in the Mwea scheme using the water that could be saved with SRI management, Further, 54,000

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tons more paddy could be produced annually from the scheme if SRI methods were used throughout. Up-scaling of SRI in Mwea can be expected to help achieve greater national and household food security.

Keywords: Basmati 370, farmer practice, Mwea irrigation scheme, rice, System of Rice Intensification (SRI), water productivity.

摘　　要

現地實驗為肯亞Mwea灌溉計劃(MIS)的一部分，其於2010年及2011年主要生長季進行，設置於Mwea灌溉農業發展中心。實驗比較香米(Basmati 370)在水稻強化栽培系統管理方法(System of Rice Intensification, SRI)分別結合乾溼交替之減水應用(alternate wetting and drying, AWD)及傳統連續漫淹(continuous flooding, CF)情況下之節水量及水資源生產力。

研究期間進行了詳細的農田調查，以評估農民採用水稻強化栽培系統作物及用水管理方法後相較於一般農民水稻耕作作法(farmer practices, FP)之產量提升及節水量。本研究藉由對SRI 與FP兩種方法皆有應用於水稻生產的農民進行問券調查及結構式訪談採集資料。

本研究中，定義SRI的因子為每培土只插一株秧苗，間隔為20公分乘以20公分，在10天以內至少為作物除草3次，並且實行間歇性灌溉。因受限於研究期間有機物質及機械式推除草機的取得，本研究中不考慮SRI建議的使用有機肥料和以土壤通氣控制雜草。

現地實驗和農民調查的結果中SRI之產量增加和節水量均為最高。現地試驗中平均產量增加了1.7噸/公頃，而農民回報則為1.6噸/公頃的平均增幅。灌溉用水的量測和回報的節水量則分別為31%和30%。SRI方法下平均水資源生產力也同樣較高，在試驗田和農民的調查報告中分別增加了140%和100%。這些發現與其他國家的評估結果是一致的。

上述結果顯示，水稻強化栽培系統管理方法(種植幼苗、保留較寬的間距和間歇性灌溉)在試驗田及農田皆可增加水稻產量且具有較高的水資源生產力。若農民實施更佳的水分管理、施用有機肥料或以土壤通氣控制雜草，可能更進一步提高水資源生產力。

根據研究結果，利用SRI方法節省之用水量，可提供Mwea計劃中額外3,857公頃的農田灌溉。此外，若此方法應用於Mwea地區全域，每年從該計劃產生的稻米可以增加54,000噸以上，因此擴大SRI在Mwea地區的應用規模可望幫助加強國家和家戶之糧食安全。

關鍵詞：香米(Basmati 370)，農民水稻耕作作法，Mwea灌溉計劃，稻米，水稻強化栽培系統(SRI)，水資源生產力)。

1.0 INTRODUCTION

Rice is arguably the world's most important food crop as it is a major food grain for more than a third of global population. It is also the greatest consumer of water among all crops, using about 80% of the total irrigated freshwater resources. In Kenya, rice is the third most important cereal after maize and wheat, but it is rapidly gaining in popularity, and annual demand (estimated at 325,000 tons) exceeds the national rice production (110,000 tons) by about 200% (FAO 2013).

Kenya's Mwea Irrigation Scheme (MIS) is the country's largest source of rice. Paddy production there depends on a large and continuous supply of water as its farmers try to keep their rice paddies continuously flooded. Various challenges such as competition for water among farmers within and outside the irrigation scheme are resulting in reduced yields, however. To meet national demand for rice with the limited water resources in a sustainable way, new ways of crop production are needed. The System of Rice Intensification (SRI) has been introduced in Mwea as an opportunity to reduce water requirements while at the same time increasing the yields of rice.

The Mwea scheme covers an area of 9,000 ha, with a potential for 4,000 ha expansion (Emongór et al. 2009). The scheme is divided into 5 sections covering 60 units in total. Two rice crops are grown annually, the main season occurring between August and December during the short rains, alternating with a long-rains crop grown between January and June. Mwea rice producers suffer from water shortages during the main growing season and often from blast attack during the long-rains season. These factors lower rice yields in both seasons.

Rice production in all of Kenya's irrigation systems is based mostly on the conventional practice of continuously flooding the paddy fields (Republic of Kenya 2008). However, this method is not sustainable due to the competition for water among farmers within and outside the scheme (Mati et al. 2011). Innovative ways for efficient use of water need to be put in place to ensure sustainable rice production (Bouman et al. 2005; Mati and Nyamai 2009; Mishra 2009).

The System of Rice Intensification (SRI) developed in Madagascar over 25 years ago (Laulaniè 1993) offers this 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. 2010a; Uphoff 2003; Vermeule 2009). The system proposes the use of single, very young seedlings with 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 the rice crop grown in paddies through healthier, more productive soil and plants by supporting greater root growth and by nurturing the abundance and diversity of soil organisms (Stoop et al. 2002). Previous research has shown yield increases of 50-100%, or more, while irrigation water inputs are reduced between 25% and 50% with SRI (Berkelaar 2001; WBI 2008).

Little is known about the impact that SRI and its practice of intermittent irrigation can have on water savings in the Mwea irrigation scheme or in Kenya as a whole, along with raising rice production. This study investigated whether SRI practices, particularly transplanting quickly and carefully one young seedling per hill, with alternate wetting and drying and wider spacing, could have significant effects on plant growth and subsequently on water productivity in Mwea.

2.0 MATERIALS AND METHODS

2.1 Study area, climate and soils

Mwea Irrigation scheme, located about 100 km southeast of the capital Nairobi, is situated in Kirinyaga South District, Kirinyaga County, Kenya, bounded by latitudes 37°13’E and 37°30’E and longitudes 0°32’S and 0°46’S. 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. Annual mean precipitation is 950 mm, with annual sunshine of 2,485 h.

The entire scheme has an area of 12,282 ha, of which 9,000 ha have been developed for paddy production. The scheme is served by two rivers, the Nyamindi and Thiba. The water is drawn from the rivers by gravity through weirs and is distributed using unlined open channels to the farms. The soils are classified as Vertisols (Sombroek et al. 1982). The topsoil contained 0.014% available N, 29 ppm available P, and 0.042 meq/100g available K, and 1.13% organic carbon, and had a pH of 6.3 at the start of the experiment.

2.2 Field experiments

Field experiments were conducted during the main growing seasons in 2010 and 2011, between August and December. The experimental design was a two-way factorial with complete randomized block (CRB) layout and three replications. Each plot was surrounded by consolidated bunds and lined with plastic sheets installed to a depth of 0.3 m to prevent seepage and nutrient diffusion between plots, with 1m wide channels for irrigation.

In both seasons, there was no precise plant spacing for the CF practice, but it was generally 10 cm by 10 cm. Rice was grown under two alternative treatments, the main factors being SRI crop management having no continuous flooding, and conventional flooding (CF). Growing Basmati 370 rice variety on the randomized plots was then a sub-factor, having three replications. Basmati 370 is an aromatic, short-duration (120 days), low-tillering variety. It is generally low yielding, but has a higher market price than most other varieties.

2.2.1 Land and nursery preparation and treatments

Land preparation for both continuous flooding (CF) and SRI was standard wet tillage and harrowing. This was done by first flooding the fields for three days, then puddling them to soften and mix the mud (Wanjogu et al. 1995).

In 2010, the plot sizes were 3 m × 3 m, and the spacing for SRI practice was 20 by 20 cm. The topsoil contained 0.014% available N, 29 ppm available P, 0.042 meq/100g available K, and 1.13% organic carbon. It had a pH of 6.3 at the start of the experiment. The allocation of treatments among plots was done by using random numbers.

Both the plot size and the crop spacing were increased in 2011, when plot sizes measured 5 m × 5 m and the crop rows were 25 cm by 25 cm. This reduced plant population further, by 36%. Available N, P and K in the topsoil were, respectively, 0.021%, 32 ppm and 0.041 meq/100g; organic carbon was 0.96%; while pH was 6.2. The allocation of treatments was done as previously, again using random numbers.

Preparation of the nursery for SRI practice was different from that for CF practice except that fertilizer applications were the same for both practices, so soil amendments were not a factor evaluated in the trials. For SRI, a plastic sheet was laid on a flat area near the experimental site, and a 3 cm thick layer of soil (seedbed) was spread on the sheet. The purpose of the plastic sheet is to prevent seedling roots from growing deep into the soil because then most of the roots would be stuck and cut at the time of transplanting.

The SRI nursery was sown sparingly with 5 kg/ha of treated and pre-germinated seed and was covered with a thin layer of soil to protect the seeds from birds. The nursery was then watered daily to keep the soil moisture saturated, except on days when there was rainfall, but no flooding. The nursery was adjacent to the main field so that transplanting could be performed quickly to minimize stress for the young plants (WBI 2008).

For CF practice, a bed was prepared within the swamp and was left with a thin film of water. Seeds were spread randomly at a rate of 62 kg per ha. The seeds were similarly covered with a thin layer of soil for protection against birds, and the nursery was then flooded throughout the entire period of seedling emergence and initial growth.

2.2.2 Crop management

For SRI practice, 8-day-old seedlings were transplanted at a rate of one seedling per hill. At 8 days, seedlings were still in their second phyllochron of growth as recommended for SRI practice (Stoop et al. 2002). For CF practice, 28-day-old seedlings were transplanted on the same day at a rate of three seedlings per hill. This is the conventional way of growing rice in Mwea scheme.

Plots for both sets of treatments received the same basal fertilizer supply of 125 kg/ha di-ammonium phosphate (DAP) and 62 kg/ha muriate of potash (MoP) one day before transplanting. All plots received an additional 375 kg/ha of sulphate of ammonia (SA) with split applications of 125 kg/ha at 10, 30 and 60 days after transplanting (DAT), as elaborated by Wanjogu et al. (1995). No herbicide, insecticide or chemical disease control measures were used.

2.2.3 Weeding in the two seasons

Due to wider spacing and intermittent irrigation, there were generally more weeds in SRI plots than the CF plots. For SRI, mechanical weeding is recommended to control weeds effectively and provide aeration to the soil. However, the rotary weeders recommended for SRI practice were not available at the time of the first trial. So SRI plots were weeded four times while CF plots were weeded three times during their growing seasons.

The next year, CF plots were weeded three times manually as in the first season. However, rotary weeders were used with SRI practice in 2011, so the SRI plots received the prescribed active soil aeration in their trials. Rotary hoes also mix weeds into the soil as green manure. For proper management of the weeds in SRI plots, the plots were irrigated two days before the start of each weeding, starting 10 days after transplanting. This operation was repeated 3 times, after every 10 days which brought the total number of weedings to 4.

2.2.4 Water measurement and application

Water was supplied through a concrete channel to a plot channel and subsequently to the plots. Trapezoidal Parshall flumes were installed at the gates provided for each plot during the construction of bunds for the purpose of supplying and measuring water for both practices (Herschy 1995). Water measurement for the CF plots was made only during irrigation, while for SRI plots the water was measured when irrigating and when draining off excess water.

The amount of water applied was estimated for free flow by reading both the water height and the time taken for the water to flow through the Parshall flume and into the plot to reach the required level (ASTM D1941-91, 1958). This information was converted to a volumetric measure of water applied per ha for the cropping season (Herschy 1995). Each plot was irrigated separately. All plots were drained at 14 days before harvest to promote ripening of the grain. To calculate the total volume of water used, rainfall amounts were also converted to volume per ha, then summed together with the irrigation water, for the purpose of determining water productivity.

The CF treatments were continuously flooded with water to a depth of 5 cm, except at the end of the tillering stage when the depth was reduced to 3 cm. The SRI plots were kept saturated during the first week after transplanting. After that and up to the panicle initiation stage, plots were irrigated and maintained with a thin layer (2 cm height) of standing water for 2 days and then without standing water for 5 days before they were re-irrigated with river water. At this stage, the cracks on the soil surface ranged between 1-1.5 cm wide, and the moisture content of the soil at 10 cm depth was 32% while moisture at 20 cm depth was 59% on average. From flowering stage to maturity, a shallow standing water of 3 cm in height was maintained.

2.2.5 Agronomic and yield measurements

Crop data were collected from each plot, such as number and age of seedlings and transplanting dates; yield components such as number of tillers, number of panicles, grains per panicle, filled grains, weight of 1000 grains, and final grain yield at harvest.

All plants in an area of 2.5 by 2.5m (first season) and 4.5 by 4.5 m (second season) for each replicate were harvested for determination of yield per unit area. This allowed for two rows of crop round the plots to be left out, reducing any edge effect. The process of harvesting involved cutting the rice plants by hand with a sickle 15 cm above the ground and threshing them immediately on a mat (IRRI 1978a; IRRI 1978b). To get a good estimate of grain yield by minimizing grain damage and quality deterioration, the threshing and cleaning of grains (by winnowing) was done immediately, following the guidelines outlined in Surajit (1981).

The grains were dried within 12 hours of harvest, and moisture content of the grains was measured after threshing by a moisture meter. Grain weight was adjusted to 14% seed moisture content.

Ten hills in each plot were randomly marked at the time of planting for counting tiller number periodically at intervals of 7 days up to the panicle initiation stage. Average tiller number; productive and unproductive, hence panicle number, were determined from the crop harvested from 1 m^2 area per replication. One panicle from each of the ten hills (a total of ten panicles per plot) was clipped and put into a separate transparent paper for data recording. This enabled identification of any loose grains during counting of the grains on a panicle.

Panicle length was measured as the length from the base of panicle to tip of last grain at the top of the panicle (Surajit 1981). Number of grains per panicle and the number of filled and unfilled grains, determined by feel method, were measured for each panicle individually harvested from the sample area. The per cent of ripened grains was calculated by dividing the number of filled grains by the number of total grains.

Three hills from each replicate were randomly selected at the early-ripening stage of each variety for collection of root samples. This was done using an auger of 10 cm diameter to remove soil down to 20 cm deep along with the hill (Kawata and Katano 1976). A uniform soil volume (1,571 cm^3) was excavated to collect root samples from all the treatments. Roots were carefully washed, dried under a shade for two weeks, and dry weight measured (Yoshida 1981).

2.2.6 Water productivity

Water productivity was calculated as grain yield divided by total water supplied into the plot, as rainfall and as applied through irrigation (Bouman and Tuong, 2000). This was expressed as kg/m3. Water saving was figured with reference to irrigation water and was calculated as the difference in irrigation water under the two practices divided by the irrigation water applied under CF practice, as discussed in section 3.1.2 below.

2.3 Field survey

A detailed farmer survey was conducted across the various units of the Mwea Irrigation Scheme during the same period as the trials were being done, to assess water savings and productivity achieved by farmers using SRI management compared with farmers' practices (FP) for rice cultivation, seeking to assess the area of land that could be irrigated by the saved amount of water.

The percentage water saving by farmers was based on the number of irrigations made by each farmer because all the farmers interviewed reported that they applied water to the same level (50 mm) in their fields under both practices. Hence, the essential distinguishing factor in terms of water use was the number of times a farmer irrigated his or her field.

Fifty farmers who were practicing SRI on at least part of their land in the Mwea Irrigation Scheme in 2010 were identified by using the total-population, purposive-sampling approach recommended by Doherty (1994) and Stephan and McCarthy (1958). These farmers were found to be scattered across 18 units within the scheme.

As the number of SRI adopters differed 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. Field assistants made strenuous efforts to gather complete data from all 50. The farmers provided information on amount of water and frequency of application and on yield under the two systems. Ultimately only 40 farmers were able to provide complete data for comparative analysis, giving 80% coverage with no evident bias in their distribution across the irrigation scheme. Details on how the survey was prepared and administered are in Ndiiri et al. (2013).

2.4 Additional area that could be cultivated with water saved

The area that could be irrigated using water saved and subsequently the additional yields were determined based on the results of data analysis as discussed in 3.3 below. Data on the net total amount of water discharged to the farmers' fields for the two seasons was obtained from MIS records, and both the field trials and the farmer survey indicated that there could be 30% water savings through SRI practices, as seen in section 3.2.

With this information, a total amount of water that could be saved on average for the entire scheme was calculated. The difference between total and saved water was used to determine how much water would be needed to irrigate one hectare if farmers followed SRI practices. The amount of 'saved' water was then divided by this per-hectare value to project the extent of additional area that could be put under irrigated rice if all farmers used SRI methods.

2.5 Statistical analysis

Data processing through ANOVA or other analyses was determined by the experimental design (Robert et al. 1969). Yield data were analyzed statistically using analysis of variance (ANOVA) techniques, treating the two water application practices and variety as fixed effects while season and replications were treated as random effects. The ANOVA was conducted using the mixed procedure in SAS 9.1.3 (SAS Institute 2004). To determine the significance of any difference between two treatment means, least significant difference (LSD) was assessed at the 5% probability level. If the LSD was less than the difference in means between two treatments, the two treatments were considered to be significantly different (Littell et al. 2006).

3.0 RESULTS

3.1 Experimental plots

3.1.1 Grain yield and yield components

The SRI plots produced significantly higher grain yield (25%) than CF plots ($P = 0.026$), as seen in Table 1. Also, panicle length was significantly higher ($P = 0.018$) with SRI practice than with CF practices. Among the yield components, grains per panicle, grain-filling percentage, and 1000-grain weight were also significantly higher ($P < 0.05$) with SRI practices (Table 2). SRI panicles had significantly fewer numbers of filled grains ($P = 0.85$) than CF panicles in the first season, and significantly higher 1000-grain weight than CF (0.006) during both seasons. Most of the increase in grain yield in the first season was thus a result of higher grain weight. During the second season, both greater grain filling and 1000-grain weight contributed to the increase in grain yield. The results of root dry weight showed a significant improvement in root growth in the SRI plants ($P = 0.042$); root dry weight per m^2 under SRI practice was almost double that of CF practice. Overall, SRI plots had significant improvement in all the various yield components compared with CF plots as seen in Tables 1 and 2.

3.1.2 Water productivity and water savings

Rainfall received was 245.2 mm and 556.2 mm during the first and second cropping seasons, respectively. The greater rainfall in the second year (2011) contributed to both reduced need for irrigation in that year and to somewhat higher water productivity for the SRI crop. Since the SRI plots were drained of standing rainwater, so the rainfall applied to these plots was calculated to be just 61.3 mm in the first season and 139.0 mm in the second season. During the second season, all the rainfall were utilized under CF practice (Table 3). There

Table 1. Tiller number, panicle length, grain yield, and yield components for Basmati 370 under SRI and CF, 2010 and 2011

	Tillers/m^2		Productive tillers/m^2*		Panicle length (cm)		Grains/panicle		Grain filling (%)		1000-grain weight (g)		Grain yield (t/ha)		Root dry weight (g/m^2)	
Method	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
SRI	831^{a}	711^{a}	788^{a} (94.3)	692^{a} (97.4)	25.2^{a}	25.5^{a}	115^{a}	98^{a}	67.67^{b}	84.3^{a}	23.05^{a}	23.1^{a}	5.93^{a}	7.07^{a}	80.3^{a}	74.99^{a}
CF	775^{b}	656^{b}	668^{b} (86.3)	492^{b} (75.0)	22.4^{b}	23.2^{b}	92^{b}	72^{b}	81.67^{a}	79.6^{a}	21.57^{b}	20.7^{b}	5.27^{a}	5.13^{b}	50.0^{b}	47.65^{b}

*The values in parenthesis are the percentage of tillers that formed panicles, i.e., became productive (effective) tillers.
[a, b] Values with the same letters in a column under the respective seasons are not significantly different by LSD at the 0.05 level across both practices.

Table 2. Evaluation of interaction effects due to season and practice on grain yield and components, 2010 and 2011

	Df	Tiller no.	Productive tillers (%)	Panicle length (cm)	Grains/Panicle	Filled grains (%)	1000-grain wt (g)	Grain yield (t/ha)	Root dry weight (g/m^2)
Season (S)	1	**	**	ns	**	ns	ns	**	*
Practice (P)	1	**	**	**	**	*	*	**	*
S*P	1	*	ns	ns	Ns	**	ns	**	ns

*Values are significantly different by LSD at the 0.05, ** Values are significantly different by LSD at the 0.01. None of the interaction effects calculated for Replications (R) (df = 2) were significant.

Table 3. Water use and productivity for Basmati rice variety under SRI and CF, 2010 and 2011

	Rainfall (m^3/ha)		Irrigation water (m^3/ha)		Water use (m^3/ha)		Water productivity (kg/m^3)	
Practice	2010	2011	2010	2011	2010	2011	2010	2011
SRI	613*	1,390	8,422	5,332	9,035	6,122	0.7	1.1
CF	2,452**	5,562	11,610	8,109	14,062	13,291	0.4	0.4

*Rainfall water was drained from the SRI plots, which is why it is reported as lower than in the CF plots.
**Rainfall amount is different for each variety because of differences in crop duration.

was significant water savings of up to 31% with SRI practice calculated from the experimental plots and reported in the farmer survey as discussed below.

SRI demonstrated significantly higher water productivity -- 0.7 kg grain/m3 in the first season and 1.1 kg grain/m3 in the second. This compared with water productivity for CF of 0.4 kg grain/m^3 in the first season and 0.4 kg grain/m3 in the second season (Table 3). Average water productivity during the two seasons under SRI management was 0.9 kg/m^3 -- 125% more than the 0.4 kg/m^3 average under conventional management.

3.2 Farmers' yields

The survey results for 40 farmers using both SRI and CF methods on the same farms showed average SRI yields to be 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 8.1 t/ha under SRI, and from 4.1 t/ha to 6.0 t/ha for FP across the two both seasons. The increase in average yields under SRI varied from 31 to 34% for the two seasons across the units.

Note that average FP yields in these comparisons are in general higher than usual average yields in Mwea scheme of 3.5-5.0 t/ha (Republic of Kenya 2008). This might be because those farmers who were first to try and evaluate SRI methods were more innovative and serious rice farmers than average and thus already producing above the norm. This suggests that SRI methods, not the complete set, were being compared with some of the best use of present farmer practices. A comparison of results from the on-station field trials (2.2) with those obtained from farmers in the field survey (2.3) regarding to water savings is shown in Table 5. The correspondence turned out to be very close.

Table 4. Yields and water savings under SRI and FP, 2010 and 2011 [N=40, across 10 sites]

	2010		2011	
	SRI	FP	SRI	FP
	Ave. (Range)	Ave. (Range)	Ave. (Range)	Ave. (Range)
Yield (t/ha)	6.7 (5.2-7.9)	5.1 (4.1-6.0)	7.1 (5.5-8.1)	5.3 (4.2-5.8)
No. of irrigations	30.9 (28-34)	43.4 (37-48)	11.6 (10-15)	16.8 (14-22)
Water applied (mm)*	1,545 (1,400-1,700)	2,170 (1,850-2,400)	580 (500-750)	840 (700-1,100)
Water savings (%)	28.9 (17.5-36.2)	--	31.0 (23.5-42.1)	--

*As farmers reported applying the same amount of water (50 mm) for both practices each time they irrigated, the amount of water applied was calculated as the number of irrigations × 50 mm. Water applied in m^3 ha^{-1} = amount of water in mm × 10, so water savings (in %) = 100 (number of irrigations under FP – number of irrigations under SRI) / number of irrigations under FP. Ranges shown reflect the averages calculated for the 10 different sample sites. FP = farmer practice.

Table 5. Savings on irrigation water (%) for Basmati rice variety from field experiments and farmer survey during the two growing seasons

Data source	Savings on irrigation water (%)		Average savings on irrigation water (%)
	2010	2011	
Field experiments	27.5	34.2	30.9
Farmer survey	26.2	32.6	29.4

3.3 Additional area that could be cultivated with SRI management practices

These data generated from both sources permit us to calculate how much additional paddy area could be cultivated for irrigated rice to meet Kenya's growing and unsatisfied demand for this food crop if SRI water management were used throughout the Mwea irrigation scheme. We can also estimate how much additional rice would be produced with SRI crop management methods on this area, based on the empirical results from this study, figuring also what impact this could have for Mwea rice farmers' incomes. These calculations are shown in Table 6.

4.0 DISCUSSION

4.1 Expansion of rice cultivation area with SRI management

A statistical analysis of farmer yields that was done (not shown here) showed no significant difference in yields among the units and farmers for both practices. The following assumptions were made for calculating how much additional area could be cultivated with irrigated rice given 30% reductions in water issues with SRI water management presented in 3.3:

a) Soil within the Mwea Irrigation Scheme is essentially uniform, and therefore all farmers are expected to get almost the same yields if other factors like fertilizer application, irrigation, planting date, weed control, and other cultural practices are kept constant.
b) All the water released is used on farms, with no losses to other uses, and all farmers will get an equal share of water at the same time.

If these assumptions do not hold, the calculations reported above would have to be adjusted accordingly. The water saving and increased production and income are great enough that the question would anyway be how much advantage would be gained rather than whether there would be hydrological, agronomic and economic benefits. The gains from SRI crop management were seen in the analysis of agronomic parameters.

Table 6. Water savings with SRI management and area that could be cultivated with saved water, extra yield and additional income

Total water discharged per season (m^3)	Reduction of 30% in water issues with SRI (m^3)	Area that could be irrigated with savings (ha)	Yield from additional area per season (tons)	Yields from additional area per year (tons)	Total increase in income from paddy for farmers (Ks) $\times 10^6$	Total cost of production for the paddy (Ks) $\times 10^6$	Net increase in income from paddy for farmers (Ks) $\times 10^6$
137,725,920*	41,317,776	3,857	27,000	54,000	2,700	1,571	1,129

*Average for 2010 = 153,752,256 m^3/ha and 2011 = 121,699,584 m^3/ha.
Area irrigated by saved water = 30% water savings m^{-3} * 9000 ha / (average water discharged per season - 30% water savings). Average yield of 7 t/ha per farmer per season with SRI management was used to calculate yields from the additional area (ha irrigable with saved water) * 7 t/ha. Total increase in income was calculated by multiplying the total increase in yield (paddy) by a gate price of Ksh 50 (determined by the government). Net income (Ks) = Gross income (Ks) - Total production cost (Ks) (Ndiiri et al. 2013).

4.2 Yield and yield components

Yields for Basmati 370 in the Mwea scheme are normally 3-5 t/ha (Republic of Kenya 2008). It normally takes 130 days to mature. There was an average difference of 6 days between harvesting dates for SRI and CF plots. In these trials, SRI plants took about 4% longer to mature and the CF plants about 8% more time than usually expected from this variety. This could be explained by the low temperatures during the ripening phase in the first season and higher rainfall in the second season. High rainfall towards the end of the second season delayed harvesting since all the plots were soaked with water.

The results showed that using SRI methods increased significantly the components of yield and the final grain yield. The yield components that contributed to the increase in yield were more productive tillers, longer panicle length with greater number of grains, and enhanced 1000-grain weight with SRI practice. This analysis of crop performance matches that reported in the literature, for example, by Thakur et al. (2010b).

4.3 Water savings and water productivity

Water savings and water productivity were definitely higher under SRI practice (Tables 4 and 5). For this, a 2 cm layer of irrigation water was periodically added to the field after every 5 days. The water usually disappeared about three days after irrigation, although this period was shorter on days when the temperatures were high. The high water productivity under SRI management indicated that continuous flooding of rice plants under water is not essential for obtaining high rice yields (Chapagain and Yamaji 2010); 28% and 33% water savings were made in this study during the first and second seasons, respectively.

Bhuiyan and Tuong (1995) and Sato and Uphoff (2007) concluded from their analyses that about 40-45% of water normally used in irrigated rice can be saved by applying water in small quantities to keep the soil saturated throughout the growing season without sacrificing rice yield. Keisuke et al. (2007), Singh et al. (1996) and Zhao et al. (2010) recorded reductions in irrigation water by 40-70%, 20-50%, and over 50%, respectively while increasing yields under alternate wetting and drying compared to continuous flooding of rice crop. Chapagain and Yamaji (2010) reported increased water productivity (1.74 grams/l) under SRI practice compared to (1.23 g/l) for CF practice, and Thakur et al. (2011) reported similar results.

Somewhat lower water productivity was reported by farmers practicing SRI compared to the level calculated from experimental plots under SRI. This reflected the farmers' applying with the same amounts of water for both practices every time they irrigated, not keeping to the SRI recommendation of applying just a 2 cm layer of water.

5.0 CONCLUSIONS

This study has shown that SRI crop and water management practices are capable of producing considerably higher rice yields with savings in water usage compared with conventional water management practices of continuous flooding. Conversion of SRI management can address some key constraints for rice production in Kenya as well as in many other countries.

The improvement in grain yield under SRI practices was attributable to changes in all the components of a rice plant, below and above the ground's surface. SRI practices with alternate wetting and drying in particular improves the growth of roots as indicated by the higher dry root weight from SRI crops.

There is need to produce more food and particularly more rice due to high demand that could go unmet because of limited land and water resources. That SRI management can raise outputs at the same time that water requirements are reduced makes it a promising method for rice cultivation in Kenya and elsewhere.

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