Improving land and water productivity in basin rice cultivation in Kenya through System of Rice Intensification (SRI)

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Abstract: Improving the yield of rice (*Oryza sativa* L) in existing irrigated areas rather than further expansion is more likely to be the main source of growth for the crop in Kenya, especially due to limited land and water resources. In order to achieve this, there is need to identify and adopt solutions that are environmentally more sustainable. That is, the production systems adopted should reduce water consumption and increase productivity. A study was carried out to evaluate whether the System of Rice Intensification (SRI) could increase water productivity and crop yield relative to the conventional production system of continuous flooding. The effects of SRI on total water use, growth characteristics and yield of three rice varieties were investigated at Mwea Irrigation Scheme of Kenya on vertic clay soils. The production practices of SRI were found to be beneficial to rice growth and yield. SRI gave higher average grain yield (14.85 t/ha) than the conventional flooded system (8.66 t/ha) at $P=0.006$, while the average yield across production systems was 15.89 t/ha, 11.26 t/ha and 8.10 t/ha for BW196, NERICA1 and Basmati370 varieties respectively, with $P<0.001$. There was a 24% saving in irrigation water by SRI, while land productivity (LP) and water productivity (WP) increased by 71% and 90% respectively compared to the conventional flooded system. Overall, SRI production system gave better yield and productivity results than the conventional flooded system. This was probably as a result of better phenotypic expressions due to the innovative soil-water-crop management practices of SRI that change the environment where rice is grown.

Keywords: SRI, production systems, water productivity, land productivity, Mwea, Kenya

Citation: Nyamai, M., B.M. Mati, P.G. Home, B. Odongo, R. Wanjogu, and E.G. Thuranira. Improving land and water productivity in basin rice cultivation in Kenya through System of Rice Intensification (SRI). Agric Eng Int: CIGR Journal, 2012, 14(2): Manuscript No. 2094.

Received date: 2012-03-25 **Accepted date:** 2012-05-23
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1 Introduction

Competition for fresh water is putting a lot of strain on the water available for irrigation, especially for such highly water intensive crops as rice (*Oryza sativa* L). This notwithstanding, rice is a staple food for over a half of the world's population, making it an important crop. As the global population increases, so will the demand for rice (Satyanarayana, 2005). In some rice growing countries in Africa, such as Kenya, this demand is likely to exert pressure on existing rice producing schemes, brought about by the already present challenges of water scarcity due to adverse effects of climate change and variation. For such countries and indeed many more within the Sub Saharan Africa (SSA), increasing the productivity of rice in the existing schemes rather than further expansion of irrigated areas is likely to be the main source of growth for the crop, due to limited arable land, low usage of efficient production practices and water scarcity (IPCC, 2007). There is therefore need to adopt production systems that ensure a sustainable use of land and water resources, through increasing productivity while reducing on water use. Paddy production has either stagnated or in some places fallen (Sinha and Talati, 2007).

In the Mwea Irrigation Scheme (MIS) of Kenya, there has been a marked fluctuation of the mean crop production which has been attributed to, among other factors, an increase of area under a low yielding but higher market value variety, soil chemical and physical degradation due to continuous mono-cropping, and an over-reliance by farmers on production techniques that are inefficient. As early as 1995, there was already an identified need to increase production per unit area through the adoption of more water efficient practices within the MIS (Wanjogu et al., 1995). Rice production has hitherto been characterized by enormous inputs of seed, water, chemical fertilizers and labour, making it an expensive venture for the small scale farmers who comprise the tenants of the scheme. However, as recently as 2009, a System of Rice Intensification (SRI) was introduced to the farmers of MIS through a multi-institutional collaborative research project (Mati et al., 2011) geared to seeing the farmers improve their crop yields.

The component practices making up SRI are said to radically depart from the norm in rice production, altering the micro-environment in which rice is grown to the effect of increasing yield and achieving water savings (Berkelaar, 2001). Built on the premise of "growing more on less" (World Bank Institute, 2008), SRI gives more yield per unit input of water, seed, and fertilizer (Laulanié, 1993a). This has been confirmed by reports of trials from Madagascar and other countries that have adopted the system of 50%-100% increase in yield (Stoop, Uphoff and Kassam, 2002) while irrigation water use reduced by between 25% and 50% or more (Satyanarayana, Thiyagarajan and Uphoff, 2007). Despite the successes, SRI has also generated debate (McDonald, Hobbs and Riha, 2006; Sinha and Talati, 2007; Menete et al., 2008), sceptics (McDonald, Hobbs and Riha, 2008; Dobermann, 2004) as well as some failed field trials (Stoop, 2005). Nevertheless, the merits of this new method of rice farming have been demonstrated in over 30 countries around the world (WBI, 2008).

Since SRI affects the soil-water-plant-nutrient continuum, its adaptation is likely to vary by location depending on the soil, climatic, socio-cultural and socio-economic conditions. Its adoption needs to be preceded by research to evaluate its potential to adapt to the local conditions. This paper addresses this by presenting an attempt to assess the potential of SRI to improve land and water productivities through an exploratory field study conducted at the MIS. The objectives of the study were: (1) to assess the crop growth and yield parameters under SRI in comparison to the conventional paddy management method; (2) to determine the yield potential of SRI for three varieties grown at the MIS; and (3) to quantify total water use (TWU) under SRI compared to the conventional methods.

2 Materials and methods

2.1 System of Rice Intensification (SRI)

SRI is best seen as a production system (Stoop, Adam and Kassam, 2009) defined by a set of innovative agronomic and soil-water management practices that create optimal growing environments for rice plants so that their genetic potentials are better expressed (Satyanarayana, Thiyagarajan and Uphoff, 2007). The fundamentals of SRI are described by Uphoff (2003) as comprising: (1) early (8-15day-old seedlings) and quick, shallow (1-2 cm) transplanting - this preserves the mature plant’s growth potential while avoiding trauma to the roots; (2) transplanting single seedling per hill, with (3) wider spacing in a grid pattern – these two help to achieve ‘the border effect’ for the whole field; (4) alternate wetting and drying (AWD) of the soil to induce aerobic conditions within the paddy soil for increased microbial activity; (5) use of a pushed rotary weeder for increased active aeration of the soil, and (6) enhancing soil organic matter as much as possible by use of compost, manure, and other organic fertilizers.

2.2 Site description

The study was conducted during the August – December 2009 season at the Mwea Irrigation Agricultural Development (MIAD) Centre research station. The soil type at the experiment site was Vertisol (Sombroek, Braun and van der Pouw, 1982). The top 20 cm of the soil had 0.014% available N, 29 ppm available P_2O_5 (Olsen), and 0.042 meq/100g available K, 1.13% organic carbon with the pH value of 6.3. Meteorological data was collected during the rice season from September 2009 to February 2010 at the MIAD weather station (Table 1).

Table 1 Climatic conditions during the growing period of rice in the MIAD experiment station

Year	Month	Total rainfall (mm)	Temperature (°C)			Relative humidity (%)	Evaporation (mm/d)
			Max.	Min.	Mean		
2009	Sept.	0.0	29.4	19.2	24.3	76.0	8.3
	Oct.	185.2	29.1	20.9	25.0	77.8	8.2
	Nov.	128.4	28.0	19.7	23.9	80.8	6.8
	Dec.	103.5	27.6	18.9	23.3	78.8	5.8
2010	Jan.	76.9	28.2	18.3	23.3	78.4	6.5
	Feb.	117.5	29.5	19.2	24.4	79.1	7.1

2.3 Experimental design

The experiment was a split plot factorial in randomized complete blocks design, with four replications. Production system (”package of practices”) was assigned to the main plot factor at two levels, conventional flooded (CF) and SRI. The details of the main plot treatments are furnished in Table 2. Three different varieties (Basmati370, BW196 and NERICA1) were assigned to sub plots.

Table 2 Comparison between the major agronomic components of SRI and conventional production systems of rice as applied in the Mwea experiment

Production system	Age of seedlings (d)	Transplants /hill (Number)	Hill spacing (cm)	Hills/m^2 (Number)	Water management	Fertility management (kg/ha)	Weed management

CF	25	3-5	15 × 15, variable	44-55	Continuous flooding	400Manure; 60N 60P 40K basal; 70N top dressing	Two rounds hand weeding
SRI	14	1	25 × 25	16	Alternate wetting and drying	Same	One round rotary, two rounds hand

2.4 Field and water management

Land preparation for both SRI and CF was standard wet tillage and harrowing. After transplanting, the CF main plot was kept flooded at 3 cm depth till panicle initiation (PI), after which the depth was raised to 10 cm. The alternate wetting and drying (AWD) method was used as the irrigation method in SRI main plot. The plot was first flooded to 3 cm depth a day before transplanting. After transplanting, the plot was left to dry for seven days until cracks appeared in the soil. Flooding was then done to 3 cm depth and the field left again to dry for seven days. This cycle of alternate wetting and drying was repeated five times till panicle initiation (PI) stage. From PI to 14 days before harvest, the SRI plot was flooded immediately after the disappearance of ponded water. For both plots, a 14-day dry period was observed before harvesting to allow for maximum transfer of nutrients to the grains. The amount of irrigation (excluding water applied during field preparation) to each main plot were measured using cut-throat (Parshall) flumes. To prevent seepage between plots, plastic sheets were installed in the bunds down to a depth of 100 cm.

2.5 Sampling procedure and data collection

Agronomic measurements were taken from 10 randomly selected hills in each treatment plot. The data on changes in the number of tillers per hill, leaves per hill and plant height were recorded from the selected plants at intervals of one week from 14 days after transplanting (DAT) to PI. Yield components such as panicles per m^2, grains per panicle, percentage of filled grains and weight (g) of 1000 grains were determined at harvest from one sq. meter quadrat placed at the centre of each treatment plot.

2.6 Statistical analysis and other calculations

Plant height, number of leaves per hill and number of tillers per hill were analyzed using the Repeated Measures analysis of variance (ANOVA) procedure in GenStat software (GenStat, 2011). This was because the three variables were measured on a weekly basis, repeatedly, and on the same subjects, for the entire vegetative phase of each variety. Harvest data, which comprised all the yield components, was subjected to the standard ANOVA in GenStat. Where the F-test in the ANOVA showed significant differences, means were separated using the Least Significant Difference (LSD) value. Water productivity (WP) was calculated as the ratio of grain yield to total water used (TWU) through irrigation and rainfall, expressed in kg/m^3 (Pereira, Cordery and Iacovides, 2012). Land productivity was calculated as grain yield per unit area of land in t/ha.

3 Results and discussion

3.1 Effect of production system on crop growth

The numbers of tillers per hill and leaves per hill were significantly affected by the interaction between production system and variety, with $P<0.001$ (Figure 1). All three varieties exhibited higher tiller and leaf numbers under SRI. However, average plant height was influenced by inherent varietal characteristics only (P<0.001). The average plant height was 100 cm, 88 cm, and 55 cm for Basmati 370, NERICA 1 and BW 196, respectively.

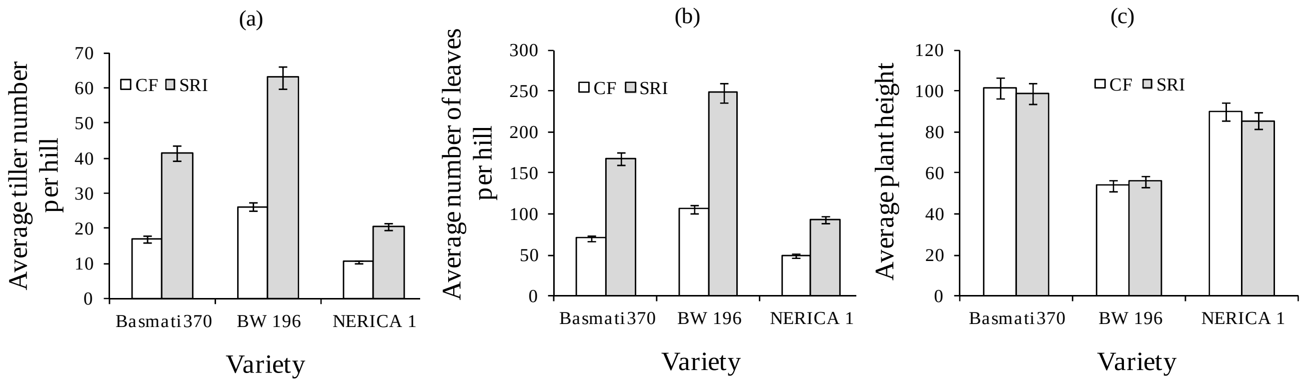

Figure 1 Effect of production system on average number of tillers, leaves, and plant height of three rice cultivars in MIS (Mwea Irrigation Scheme).

3.2 Effect of production system on yield components

There were significant differences in the number of panicles per m^2 due to the interaction between production system and variety with P<0.001 (Table 3), with SRI increasing panicles per m^2 for all varieties.

Table 3 Effects of treatments (production system and variety) on yield components

Treatments	Yield component				
	Panicles/ m^2	Grains/ panicle	Filled grain ratio (%)	1000 grain weight (g)	Grain yield (t/ha)
Production system (PS)	***	NS	NS	NS	**
CF	247.1	177.8	0.78	26.41	8.66
SRI	460.2	176.8	0.75	26.19	14.85
	(6.87)	(7.29)	(0.03)	(0.17)	(0.68)
Variety (V)	***	**	*	***	**
Basmati370	361.2b	162.5a	0.69a	20.21a	8.10a
BW196	495.9c	145.0a	0.77ab	28.91b	15.89b
NERICA1	203.9a	224.5b	0.83b	29.77c	11.26a
	(13.44)	(12.40)	(0.03)	(0.18)	(1.24)
PS*V	*** (16.98)	NS	NS	NS	NS
CV (%)	10.8	19.8	12.3	1.9	29.8

Note: *, **, ***: Significance at 5%, 1% and 0.1% level respectively; CV: coefficient of variation; standard error of means (s.e) in brackets; Means with the same letter in the columns are not significantly different at 0.05significant level.

Number of grains in a panicle, percentage of filled grains and grain weight (weight of 1000 grains) were significantly influenced by variety only, while grain yield was influenced by both production system (P=0.007) and variety (P=0.003) albeit independently. SRI increased grain yield by 71% for all the varieties averaged together.

3.3 Differences in irrigation water use (IWU) due to production system

IWU in the SRI main plot treatment was 84.24 m^3 per 240 m^2 main plot area (equivalent to 3,510 m^3/ha) compared to 111.02 m^3 (4,626 m^3/ha) in the conventional practice. The difference translated to a saving of 24% in irrigation water when rice was grown using SRI practices. Table 4 shows the total amounts of water applied to the individual main plots (production systems) as well as the contribution of rainfall. The total rainfall during the study period was 611.5 mm. Rainfall equivalent volume per main plot was obtained by multiplying total rainfall by the area of the main plot (240 m^2) and then dividing by 1000.

Table 4 Irrigation water use (IWU), rainfall contribution and total water use (TWU) in conventional flooded and SRI production systems

Production system	IWU (m^3)	Saving on irrigation water (%)	Rainfall Sept. 2009 – Feb. 2010 (m^3)	TWU (m^3)
CF	111.02	-	146.76	257.78
SRI	84.24	24	146.76	231.00

3.4 Effect of production system on land productivity (LP) and water productivity (WP)

SRI had higher WP than the conventional flooded system (Table 5). SRI increased WP by 90% while LP was increased by 71%.

Table 5 Water productivity (WP) and land productivity (LP) according to production system

Production system	Total water used (m^3)	LP (t/ha)	WP (kg/m^3 water)
CF	257.78	8.66	0.81
SRI	231.00	14.85	1.54

3.5 Discussion

In this study, the production practices of SRI improved the growth vigor and yield of three rice cultivars in Mwea. While varieties differed in the rate of production of tillers and panicles genetically, altering the soil-water-plant environment in SRI seemed to modify the extent of tillering and panicle production, and this interaction between the genotype and the environment, or simply *G x E* (Satyanarayana, Thiyagarajan and Uphoff., 2007), resulted into better phenotypical expression, a phenomenon explained by Datta (1981) and confirmed in Ceesay et al., 2006. Increasing the number of panicles per unit area during the vegetative phase of the plant was critical for increasing grain yield. The condition of the plant during this phase determines the tiller number, which also reflected the potential number of panicles (Datta, 1981). It also determines the condition of functional leaves in the reproductive phase. In turn, the plant's condition during the reproductive phase determines the number and size of spikelets (Tanaka, 1976).

Water productivity of a production system was calculated as the total grain yield per unit of total water used to produce that yield in the respective production system. The results showed that the practice of alternate wetting and drying under SRI had potential to save the water by up to 24% while at the same time increasing yield by up to 71%, thereby literally growing more on less. Similarly, Hatta (1967) arrived at the conclusion that considerable savings in irrigation water were possible without any loss in rice yield under alternate wetting and drying conditions. These results contradict claims by Bouman and Tuong (2001) that water-saving irrigation increases productivity but decreases yield.

Most of the soils of Mwea fall under the class of montmorillonitic clays that crack when dry (Sombroek, Braun and van der Pouw, 1982). Upon irrigation of the SRI main plot therefore, a considerable fraction (though not measured in this study) of the water applied was lost to deep seepage as these cracks were first filled up. This could explain the saving of 24% (equivalent of 1,116 m^3/ha) as influenced by the vertic soils of the local area, which was less than that reported in some trials such as Senthilkumar et al. (2008) and Ceesay et al. (2006), who report savings by SRI of up to 60%. The water saving, however, was similar to that obtained by Zhao et al. (2011).

The improved performance of rice under SRI in Mwea can be explained by understanding the conceptual framework of the new production system, and how its practices affect the soil-water-plant-nutrient continuum. An attempt was made in this study to break up this continuum into: (1) Time; (2) above-ground; (3) and below-ground domains, and discuss the component practices of the production system under the respective domain(s) they fall.

3.5.1 Time domain

SRI seedlings were transplanted 14 days after sowing (DAS) while CF seedlings were transplanted 25 DAS. Early transplanting ensures that the plant maximises on the tillering potential under the phyllochron concept. This concept applies to the gramineae species under which rice falls (Nemoto, Morita and Baba, 1995). A phyllochron is the period of time between the emergence of one phytomer (a set of tiller, leaf and root which emerges from the base of the plant) and the emergence of the next (Berkelaar, 2001). Under optimal conditions, the vegetative growth phase of a rice plant may last as long as 12 phyllochrons before onset of anthesis (Laulanié, 1993b). For maximum tillering to occur, the plant needs to complete as many phyllochrons as possible during the vegetative phase. In Mwea, this tillering potential greatly affected yield because invariably, higher tiller number per unit area was also the potential for higher panicle number per unit area. Other studies have shown that plants transplanted late seemed to lose their potential for prolific tillering, leading to reduced grain yield (Nemoto, Morita and Baba 1995).

3.5.2 Above-ground domain

Under SRI, each hill was transplanted to a single seedling, with a wider plant spacing of 25 cm by 25 cm. This practice lowered plant density, effectively reducing inter-plant competition for light, air as well as moisture and nutrients, and further contributing to increased number of tillers and leaves per hill. Solar energy is important for photosynthesis. The potential ability of a population of leaves to photosynthesize, and the capacity of grains to accept the photosynthates, influence dry matter production, which in turn influences grain production (Tanaka, 1972). Given this relationship, the increased leaf and tiller numbers due to SRI greatly enhance the entire mechanism of plant food production both above-ground (at the leaves) and below-ground (at the roots).

Increase in tillering ability of rice under wider spacing has been reported in Menete et al. (2008) where tillers per plant on average increased by 39% by increasing spacing in an SRI experiment from 20 cm by 20 cm to 30 cm by 30 cm. Similar findings have been reported by Zhu et al. (2002) and Ceesay et al. (2006). However, increasing spacing reaches a threshold which is determined by the fertility of the soil (Berkelaar, 2001).

3.5.3 Below-ground domain

Perhaps the most important principle of SRI with far reaching effects on crop growth and yield is that of active aeration of the soil. In Mwea, this was achieved through alternate wetting and drying (AWD) method of irrigation and the use of a pushed rotary weeder. Aerobic conditions are healthy for increased soil microbial activities, which further induce an increased breakdown and subsequent release of nutrients available for plant uptake within the rhizosphere. This has been demonstrated by research (Barison and Uphoff, 2011; Zhao et al., 2011). Re-wetting dry soil facilitates mineralization (Birch, 1958; Ceesay, 2006), a process which can be greatly inhibited by hypoxic conditions in the soil. Scientists have also shown that anaerobic conditions inhibit root growth and rooting depth (Berkelaar, 2001; Stoop, Uphoff and Kassam, 2002).

The use of a pushed rotary weeder facilitates further aeration as well as the mixing of green manure into the soil. The uprooted weeds are added into the soil as immature plant materials with low carbon to nitrogen (C/N) ratios. It has been documented that such materials decompose rapidly (Hodges, 2010) and in some cases actually contribute to soil nitrogen levels.

The preceding discussion reveals that proper management of the below-ground environment forms a support basis for the success of any agronomic practices, inputs and processes taking place above-ground. In arguing against SRI, critics dismiss the impressive yields as emanating from poor research (Dobermann, 2004; Sheehy et al., 2004; Sinclair and Cassam, 2004) and that the energy required to achieve such high yields is beyond the thermodynamic capabilities of plant photosynthesis and crop use of solar energy (Sheehy, Sinclair and Cassman, 2005). They assume that the entire process of leaf photosynthesis and plant growth performance can be adequately explained in terms of above-ground plant organs and radiation, without taking account of root systems and the biological environment below-ground (Uphoff, Kassam and Stoop, 2008). In order to have more tillers, plants need to have enough root growth to support new growth above ground. But roots require certain conditions of soil, water, nutrient, temperature and space for growth (Berkelaar, 2001). When applied in a unitary system, the SRI practices alter the soil-water-plant-nutrient continuum to allow for better phenotypic expression.

4. Conclusions and recommendations

Results from the study showed that under SRI production system compared to CF, more yield per unit area of land is attained simultaneously with improved WP. SRI in Mwea has potential to increase yield of rice regardless of its genotype because of its ability to induce better phenotypic expressions of the rice plant. To achieve this however, proper soil and water management is critical during the vegetative phase of the crop. At the early stages of the plant, the soil-water-plant interactions play a critical role in determining better crop growth and yield increase, as was demonstrated by the results on panicle number per unit area and grain yield, which were increased by 86% and 71% respectively. The other yield components such as grains per panicle, the percentage of filled grains and grain weight were significantly influenced by varietal characteristics.

Adopting cultivation practices that use less water will become very important in the Mwea as water scarcity is likely to become a more significant problem within the catchment due to the adverse effects of climate change. The current demand for water is high throughout the region and in some cases, rivers and distribution systems fail to cope up with extending irrigation area in the Mwea irrigation Scheme. These challenges require to be addressed by appropriate production systems which include increased and economical water use efficient Systems in the rice crop.

SRI is essentially a "new" production system to the Mwea environment, and extensive research would be necessary in order to determine the optimum levels of the components making up SRI for the local environmental conditions.

Acknowledgement:
This research was supported by the African Institute for Capacity Development (AICAD – Kenya), and the National Irrigation Board of Kenya.

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