AFRICA ENVIRONMENTAL REVIEW Journal

ISSN: 1727-8341

AER Journal Volume 3, Issue 2, pp. 190-198, 2019

RESEARCH ARTICLE

Available Online at *http://www.aer-journal.info*

Analysis of Water Use in Rice Production under Paddy System and SRI in Ahero Irrigation Scheme, Kenya

G. Too[1*]; J. K. Kollongei[1]; J. O. Onyando[2] and S. A. Mulindi[1]

[1*]*University of Eldoret; toogideon@gmail.com*

[1]*University of Eldoret*

[2]*Egerton University*

Abstract

Food security in Kenya is a challenge due to increasing demand from the growing population and impacts of climate change among other factors. The impact of climate change is felt on rainfall pattern in terms of seasonal variability and long-term change. Therefore, it is necessary to go beyond the normal intensification of food production to sustainable water management as well as the expansion of irrigated agriculture. The study was formulated to assess the performance of existing conventional paddy irrigation system compared to SRI technology in terms of efficient water use and rice yield and to develop alternative irrigation schedules for better rice production grown under limited water supply in surface irrigation. Randomized complete block experimental design with three replications was adopted to collect field data. The results were used as inputs to the CROPWAT irrigation management model. The model was used to estimate crop water requirements and net irrigation requirement. Results of the study indicated that Irrigation Water Use (IWU) in the SRI treatments was 2316.7 m^3/ha compared to 2966.7 m^3/ha in the conventional practice translating to a saving of 21.9%. On water productivity, SRI system demonstrated significantly higher water productivity (0.5 kg/m^3) compared to conventional system with 0.3 kg/m^3. SRI increased Water Productivity (WP) by 67% while Land Productivity (LP) increased by 59.5%. The FAO-CROPWAT model estimated water requirement for rice as 934.9 mm. The model was also used to determine irrigation schedule in that for SRI rice, the first irrigation was given 19 days before sowing date with 92.2 mm of net irrigation. After these, subsequent irrigations were given after -4, -2, 22, 29,22, 29, 36, 43, 50, 57, 64, 71, 78, 85, 92 and 94 days after sowing date with 90mm, 50mm, and 20mm for the rest of applications except the last application which was given 200mm. The gross irrigation for paddy is 931.7 mm considering an efficiency of 70% during each irrigation supplied. Simulations of irrigation at 100 % critical depletion and refilling the soil to field capacity (100%) resulted to 0% yield reduction and less irrigation water requirement (622.7 mm) though with a greater number of irrigation applications (60). However, irrigating with user defined intervals with respective user defined application depths resulted in a total of 827.2 mm, yield reduction of 2.8% and a reduced rain efficiency of 98.1%. Basing on the findings of this study, SRI technology is capable of producing considerable higher rice yields and much saving on irrigation water use as compared to conventional flooding system. When the irrigation scheduling using CROPWAT is adapted for SRI technology, one is able to adopt better water management system which saves irrigation water.

Keywords: System of Rice Intensification, Surface Irrigation, Food Security, Effectiveness of Water Use, Ahero, CropWat Model

INTRODUCTION

The concern to access sufficient food for an ever-increasing population worldwide has elicited a number of strategies under varied leadership, programmes and partnerships. The current inadequate soil moisture to support crops has resulted to the rising need for irrigation. The challenge of increasing water demand has further been worsened by climate change (Ndiiri *et al*., 2012).

Primarily, irrigation systems promote increment of yields of most crops by between 100 and 400 per cent (FAO, 2009). FAO has predicted that there will be an increase irrigated land in developing countries by the year 2029. However, FAO has also noted that water required for agriculture will only increase by 12% (FAO, 2009) unless the current potential conservation and storage is adequately exploited.

Irrigation in Kenya has been identified as the key to intensification of agriculture and this is contained in several policy papers. Kenya is experiencing food shortages arising from declining farm productivity due to low fertility levels, high input costs, and unreliable weather in the face of an ever-increasing population. This puts food security at stake and more so with the already experienced effects of climate change on food production. It has become necessary to go beyond the normal intensification of food production thinking to sustainable water management as well as the expansion of irrigated agricultural production as the most critical issues for successful adaptation of the agricultural sector to climate change (Nyang'au *et al.*, 2014).

Computer model simulation is an emerging trend in the field of water management. CROPWAT is one of the models extensively used in the field of water management throughout the world (Nazeer, 2009). CROPWAT allows the estimation of crop evapotranspiration, irrigation schedule, and agricultural water requirements with different cropping patterns for irrigation planning (Nyang'au *et al*., 2014). This study aimed at developing irrigation water management system that uses water effectively in surface irrigation.

MATERIALS AND METHODS

Study Area

This study was executed through involvement of field experiments conducted at Ahero Irrigation scheme located in the middle of the Kano plain, 25 km southeast of Kisumu Town, Kisumu County (0°10'28.63" N 34°54'58.68" E) (Figure 1). The climate of the Kano plain is relatively dry and the average temperatures are high during the day and the soil of the scheme is of the black cotton type and is rather fertile. The rainfall pattern of the western Kenya region is characterized by bimodal rainy season, governed by the passage of the sun across the equator and the associated movement of the Inter-Tropical Convergence Zone. The average annual rainfall is approximately 1175 mm, of which 39% is received during the long rain period (March to May), 29% is concentrated in the short rain period (August to November) and 32% is received during drier months. The temperature at Ahero ranges from a monthly mean of 22.1ºC in June to 23.5ºC in March (Nyang'au *et al*., 2014).

Experimental Design and Treatments

The experiment was laid out in a randomized complete block design with three replications. SRI system had four treatments (Table 1) with three replicates each. Spatial allocation of plots was done using random numbers.

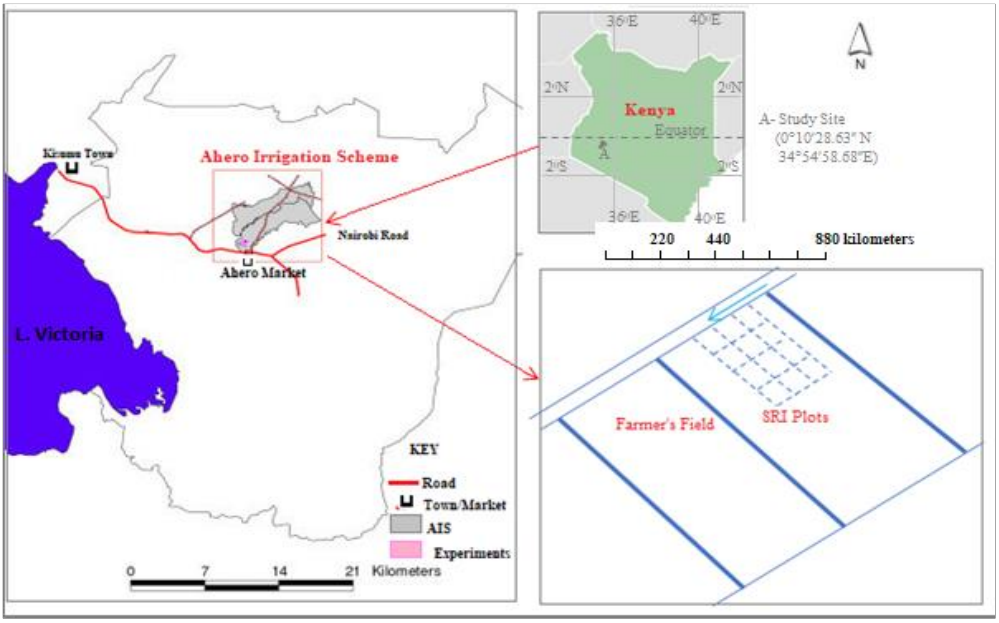

Figure 1: Site Location.

Table 1: Treatments of SRI System

	Seedling transplanting	Spacing	Irrigation	Weeding
Treatment 1 (SS1)	8 to 11 day-old 1 per hill	30 x 30 cm	Intermittent	Mechanical
Treatment 2 (SS2)	8 to 11 day-old 1 per hill	20 x 20 cm	Intermittent	Mechanical
Treatment 3 (SS3)	12 to 15 day-old 1 per hill	30 x 30 cm	Intermittent	Mechanical
Treatment 4 (SS4)	12 to 15 day-old 1 per hill	20 x 20 cm	Intermittent	Mechanical
Treatment 5 (CS)	28 day-old	Randomly	Continuous flooding	Uprooting

Each plot was 5 m x 5 m in size. This square plot size was chosen because it exposes the smallest number of plants to border effects and again this size was larger hence less experimental error and equally manageable in terms of water management (Gomez, 1972). All SRI plots were surrounded by consolidated bunds and lined with plastic sheets installed to 0.3 m deep. SRI plots were located adjacent to Conventional treatments hence there was need to install these plastic sheets to prevent seepage from conventional system.

Field and Crop Management

Land preparation for both conventional and SRI was standard wet tillage and harrowing. This was done one month before transplanting rice for both systems as suggested by Nwite *et al.* (2016) that sufficient time should be provided for puddling process such that hard lumps of soil can be soften and broken more easily. The field was flooded then ploughed after three days. Ploughing was done mechanically. Puddling followed where big soil clods were broken and the field was leveled (Welch, 2010).

Prior to transplanting, seedlings were raised in a nursery using 3.16 kg rice seed. Nursery beds were made 1 m wide each and raised to 10-15 cm high. For SRI practice, 8-day-old seedling was transplanted as treatment one and two under different spacing, thereafter 15-day-old seedling was transplanted after 7 days as treatment three and four. One seedling was done per hill. For conventional system, 28-day-old seedling was transplanted.

The experiment adopted user-defined intervals for SRI technology as suggested by Mati and Nyamai (2009). The SRI plots were kept saturated for the first 7 days after transplanting. After that and up to panicle initiation stage, plots were maintained with a thin layer of 20mm standing water for 2 days and without standing water for 5 days before re-irrigation. The cracks at this stage ranged between 1-1.5 cm on the soil surface. For the remaining days, SRI plots were left saturated. The CF treatments were continuously flooded with water to a depth of 5cm as suggested by Nyirenda *et al*. (2010), except at the end of the tillering stage when the depth was reduced to 3 cm to allow development of tillers.

Manual weeding was done at the nursery and conventional field where weeds were uprooted and mechanical weeder was used on SRI plots thus getting the prescribed aeration recommended for SRI technology. SRI plots were weeded four times, while CF plots were weeded three times during the growing seasons. In the study, basal fertilizer of 125 kg ha^{-1} di-ammonium phosphate (DAP) and 62 kg ha^{-1}muriate of potash (MoP) was applied before transplanting. All plots received an additional 125 kg ha^{-1} of sulphate of ammonia (SA) 10, 30 and 60 days after transplanting (DAT).

Model Description and Input Data

FAO-CROPWAT model was adopted to calculate reference evapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules under various management conditions and scheme water supply. CROPWAT for Windows is a decision support system developed by the Land and Water Development Division of FAO, Italy with the assistance of the Institute of Irrigation and Development Studies of Southampton, UK and National Water Research Center, Egypt. Average maximum and minimum temperatures (°C), relative humidity (%), wind speed (m s^{-1}) and sunshine hours (h) were collected from Ahero Irrigation Scheme weather station to estimate reference evapotranspiration.

On the selected plots crop and soil data were collected. The essential crop information collected include: i) crop type and crop variety ii) first and last planting date iii) first and last harvesting date. Other information includes crop characteristics; length of individual growth stages; crop factors, relating crop evapotranspiration to reference evapotranspiration; rooting depth; allowable depletion levels and yield response factors.

Apart from crop and rainfall data, soil data was required for the calculation of CWR. Gravimetric sampling was done and the following data was estimated for the model; Total Available Water (TAW); Maximum infiltration rate; Maximum rooting depth; Initial soil moisture depletion; Drainable porosity; Critical depletion for puddle cracking; Water availability at planting and Maximum water depth.

In the experiment the model was run to determine irrigation water supply for the rice crop in terms of frequency and irrigation depth, assuring optimal crop growth and efficient water use. In order to develop the irrigation schedule which would fit field requirements, an interactive procedure was followed in which several runs are made with different timing and application options given in Table 2. The results of each run were evaluated in terms of schedule efficiency, eventual yield reduction and rainfall efficiency, providing the information for the next option.

Table 2: Sequences of Model Runs

Run	Timing options	Application options
1	Irrigation at critical depletion	Refill soil to field capacity
2	Irrigation at fixed depletion (40 mm)	Fixed application depth (40 mm)
3	Irrigation at fixed intervals per stage (7 to 10 days)	Fixed application depth (40 to 45 mm)
4	Irrigate at user defined intervals (40/50/60/70/80/90/100 days)	Fixed application depth (45 mm)

Data Analysis

The data for each character was statistically analysed using Analysis of Variance (ANOVA) technique and the significance of the treatment effect was determined using F-test. Significant means were separated by using Least Significant Difference (LSD) test. 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^{-1}.

RESULTS AND DISCUSSION

Reference Evapotranspiration and Rice Water Requirement

CROPWAT model uses Penman-Monteith method for computation of reference evapotranspiration. It is observed from Figure 2 that the reference evapotranspiration was maximum in the month of March (7.20 mm/day) whereas minimum in the month of December (5.43 mm/day).

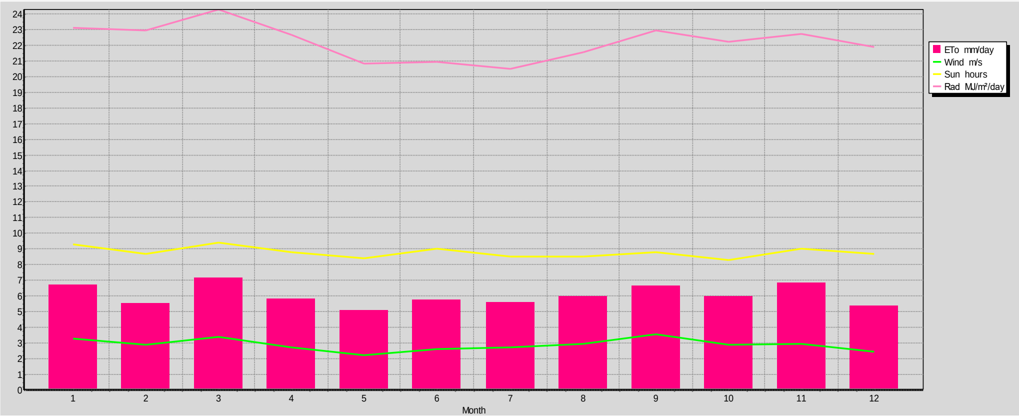

Figure 2: Monthly Variation of ET_0.

Crop water requirement was calculated using equation 1 and the results are represented in Table 3:

$$CWR = ET_o \times Crop\ K_c \qquad \text{Eq. 1}$$

Table 3: Crop Water Requirement of Rice in AIS

Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req.**
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	3	Nurs	1.2	0.68	6.8	37.7	0
Jan	1	Nurs/LPr	1.06	6.94	69.4	30.3	131.8
Jan	2	Nurs/LPr	1.06	7.51	75.1	23.3	194.2
Jan	3	Init	1.1	7.22	79.4	26.4	53.1
Feb	1	Deve	1.1	6.36	63.6	31.3	32.2
Feb	2	Deve	1.14	6.04	60.4	33.7	26.7
Feb	3	Deve	1.2	7.13	57	32.7	24.3
Mar	1	Mid	1.26	8.62	86.2	30	56.2
Mar	2	Mid	1.27	9.5	95	28.8	66.2
Mar	3	Mid	1.27	8.8	96.8	33.2	63.6
Apr	1	Mid	1.27	7.98	79.8	40.9	38.9
Apr	2	Late	1.23	7.18	71.8	46.1	25.7
Apr	3	Late	1.15	6.46	64.6	39.5	25.1
May	1	Late	1.1	5.81	29	15.9	13.1
					934.9	449.8	751.1

ET_c for Rice in AIS is a maximum of 8.62 mm/day during the month of March and minimum of 0.68 mm/day during the month of December whereas the total estimated water requirement for rice was 934.9 mm. Irrigation water requirement was calculated by deducting the effective rainfall from the crop water requirement for rice crop and was found to be 751.1 mm.

Irrigation Scheduling

CROPWAT model was used to schedule irrigation in Ahero Irrigation Scheme basing on climatic data including rainfall, humidity, sunshine hour, temperature and sowing date, soil characteristics, etc. This was done by selecting the scheduling criteria irrigation at 100% critical depletion in irrigation timing option, refill soil moisture to 100% field capacity in irrigation application and irrigation efficiency is 70%.

Table 4: Irrigation Scheduling of SRI rice

Date	**Day**	**Stage**	**Net Irrigation(mm)**
1-Jan	-19	PrePu	92.2
16-Jan	-4	Puddl	90
18-Jan	-2	Puddl	50
11-Feb	22	Dev	20
18-Feb	29	Dev	20
25-Feb	36	Dev	20
4-Mar	43	Dev	20
11-Mar	50	Mid	20
18-Mar	57	Mid	20
25-Mar	64	Mid	20
1-Apr	71	Mid	20
8-Apr	78	Mid	20
15-Apr	85	End	20
22-Apr	92	End	20
24-Apr	94	End	200
Total irrigation	931.7 mm	Total rainfall	523.7 mm
		Effective Rainfall	516.4 mm
		Efficiency Rain	98.0%

Yield Reductions					
Stage	Initial	Dev.	Mid-Season	Late	Season
Yield Reduction factor	1.00	1.09	1.32	0.50	1.10
Yield reduction	7.9	10.2	45.2	3.8	21.7

It was observed from the study of rainfall, crop, soil and evapotranspiration data for SRI rice that the first irrigation was given 19 days before sowing date with 92.2 mm of net irrigation. After these subsequent irrigations were given after -4, -2, 22, 29, 22, 29, 36, 43, 50, 57, 64, 71, 78, 85, 92 and 94 days after sowing date with 90 mm, 50 mm, and 20 mm for the rest of applications except the last application which was given 200 mm. The gross irrigation for paddy is 931.7 mm considering an efficiency of 70% during each irrigation supplied.

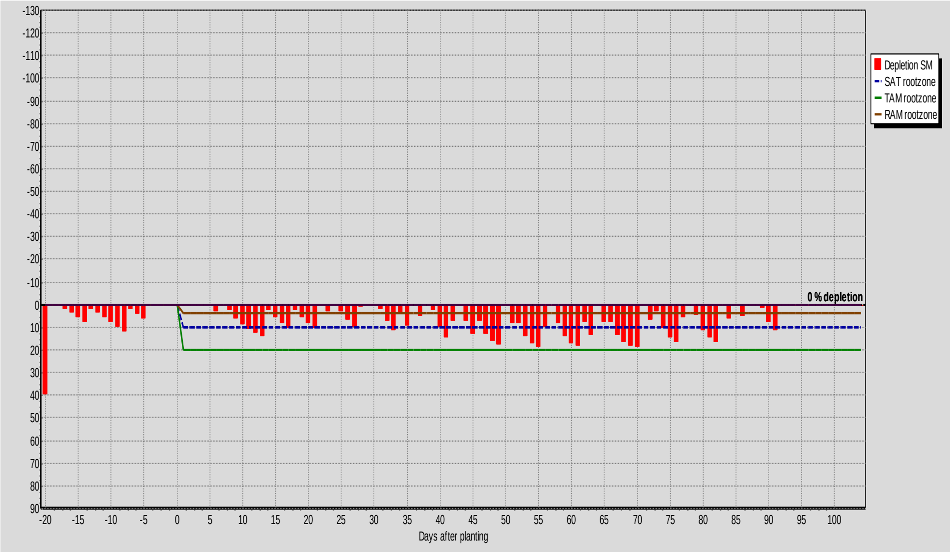

Figure 3: Irrigation Scheduling.

Optimizing Water use in SRI Rice

A number of run was made to optimize the use of irrigation water in AIS. Four runs and its results were as indicated in Table 5.

Table 5: Cropwat Simulations

	Run 1	Run 2	Run 3	Run 4
Total Net Irrigation	622.7	926.6	811.8	827.2
Effective rainfall	523.7	523.7	523.7	514
Efficiency rain	100	100	100	98.1
Yield Reduction (%)	0	0	0.7	2.8
Number of applications	60	20	18	26

The use of Cropwat model can provide useful insights into the design of irrigation studies and parameters selected for irrigation treatments. In the current study, simulations of irrigation at 100% critical depletion and refilling the soil to field capacity (100%) resulted to 0% yield reduction and less irrigation water requirement (622.7 mm) though with more number of irrigation applications (60). However, irrigating with user defined intervals with respective user defined application depths resulted in a total of 827.2 mm, yield reduction of 2.8% and a reduced rain efficiency of 98.1%.

In Figure 4, it is shown that less amount of irrigation (622.7 mm) was would be used when irrigation is done at 100% critical depletion and refilled to field capacity, but when irrigation is done at fixed depletion of 5mm and applied to fixed depth of 40 mm, net irrigation would be 926.6 mm. This implies that Cropwat model is capable of giving the optimum irrigation water required for design purposes.

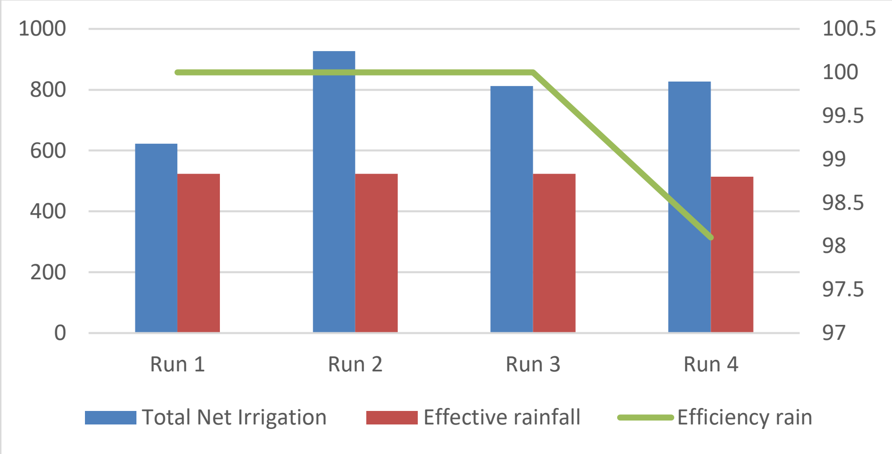

Figure 4: Cropwat Model Simulations.

CONCLUSION AND RECOMMENDATIONS

When the irrigation scheduling using CROPWAT is adapted for AWD under SRI technology where farmers apply water after every 2-3 days, a good amount of water is saved as compared to conventional method. CROPWAT model would precisely simulate and give direction on when and by how much should one apply water to the field only when the crop need. This means therefore that excess water that could have been used in flooding paddy can then be saved and used to increase the area under irrigation. In the study Cropwat model adequately simulated yield reduction as a result of imposed water stress. Simulations at 100% critical depletion and refilling the soil to 100% field capacity gave 100% rainfall efficiency and 0% yield reduction and 622.7 mm net irrigation requirement.

Irrigation scheduling practice using CROPWAT Model that incorporates weather variables, crop evapotranspiration, crop coefficient and soil water balance improves effectiveness in application of water and subsequent use by crops as evidence by the crop yields obtained from the study. This provides an objective way of irrigation scheduling and should be used in planning irrigation systems.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge National Council of Science and Technology (NCST) for funding the project and a rice farmer in Ahero Irrigation scheme for her support.

REFERENCES

FAO of the United Nations. (2009). *Crop prospects and food situation.* February (No. 1). Rome: FAO.

Gomez, K. A. (1972). *Techniques for field experiment with rice*. International Rice Research Institute.

Mati, M. & Nyamai, M. (2009). System of rice intensification: An information brochure used for Training on SRI in Mwea, Kenya.

Nazeer, M. (2009). Simulation of maize crop under irrigated and rainfed conditions with CropWat model. *J. of Agri. and Bio. Sci.*, *4*, 68-73.

Ndiiri, J. A., Mati, B. M., Home, P. G., Odongo, B. & Uphoff, N. (2012). Comparison of water savings of paddy rice under system of rice intensification (SRI) growing rice in Mwea, Kenya. *International Journal of Current Research and Review*, *4*(6), 63-73.

Nwite J. C., Essien, B. A. Keke C. I., Igwe, C. A. & Wakatsuki, T. (2016). Effect of Different Land Preparation Methods for Sawah System Development on Soil Productivity improvement and Rice Grain Yield in Inland Valleys of Southeastern Nigeria. *Advances in Research*, *6*(2), 1-17.

Nyamai, M., Mati, B. M., Home, P. G., Odongo, B., Wanjogu, R. & Thuranira. E. G. (2012).

Improving land and water productivity in basin rice cultivation in Kenya through System of Rice Intensification (SRI). *AgricEngInt: CIGR Journal, 14*(2), 1—9.

Nyang'au, W. O., Mati, B. M., Kalamwa, K., Wanjogu, R. K. & Kiplagat, L. K. (2014). Estimating Rice Yield under Changing Weather Conditions in Kenya Using CERES Rice Model. *International Journal of Agronomy, vol. 2014, Article ID 849496, 12 pages, 2014. https://doi.org/10.1155/2014/849496.*

Nyirenda, M. E., Tarimo, A. K. P. R. & Kihupi, N. I. (2010). *Yield response of different local and hybrid rice varieties to different ponding depths of water. Comprehensive Assessment of Water Management in Agriculture*. Second RUFORUM Biennial Meeting 20 – 24 September 2010, Entebbe, Uganda.

Pereira, L. S., Cordery, I. & Iacovides, I. (2012). Improved indicators of water use performance and productivity for sustainable water conservation and saving. *Agricultural Water Management, 108*, 39-51.

Welch, R., Vincent, R., Auffhammer, M., Moya, F., Dobermann, A. & Dawe, D. (2010). Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. Sustainability Science, PNAS Early Edition, Pp 6.