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Evaluating the Application of Aqua Crop modelling in simulating rice crop performance under System of Rice Intensification (SRI) management

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Abstract- Crop models can be useful as decision support tools for cropping system management, planning and policy analysis. Specifically, modeling of crop yield response to water applications can contribute significantly to the optimization of crop water productivity in irrigated rice cultivation, which consumes about 80% of total irrigation freshwater. Field experiments were conducted in 2010 and 2011 seasons at the Mwea Irrigation Agricultural Development (MIAD) Centre located in the Mwea Irrigation Scheme (MIS), Kenya to compare yields of Basmati 370 variety grown under System of Rice Intensification (SRI) management with reduced water applications vs. conventional practices of continuous flooding (CF). AquaCrop version 4.0 was used to simulate total biomass, grain yields and canopy cover. Model performance was evaluated using index of agreement (d), root mean square error (RMSE), coefficient of efficiency (E), and coefficient of determination (R2). The findings indicated a high potential effectiveness of a calibrated AquaCrop model with a high degree of reliability: R2 = 0.97 for biomass and 0.87 for canopy cover. There was also a good fit between the observed and simulated grain yields, with a deviation of only 4.2% and -5.7% under SRI and CF practices, respectively. That AquaCrop model could be applied successfully to estimate biomass, canopy cover and grain yields, with in Mwea irrigation scheme showed that it can be used as a decision support tool by scheme managers and farmers to explore various management options for maximizing yields.

Indexed Terms- AquaCrop model; Water Productivity; Basmati 370 variety; Kenya; Mwea irrigation scheme; System of Rice Intensification

I. INTRODUCTION

Rice is arguably the world’s most important food crop as it is a major food grain for more than a half of the population. It is also the greatest consumer of water among all crops, using about 80% of the world’s total irrigated freshwater resources. In Kenya, rice is the third most important cereal after maize and wheat, but it is rapidly gaining in popularity as demand is growing faster than for maize and wheat. Current rice production in Kenya’s largest irrigation system, the Mwea scheme, depends on a continuous supply of water to support the crop. With the country’s rapid population growth, and changes in eating habits due to urbanization, annual national demand for rice continues to grow; presently it exceeds production by about 200%. Water limitations and competition for water among farmers within the irrigation scheme and with other uses and users outside are resulting in reduced yields. To meet the demand with the limited water resources in a sustainable way, innovative ways of improving water productivity for the rice crop are needed.

AquaCrop is a water-driven, process-based, multi-crop simulation model. It simulates the attainable crop biomass and harvestable yield in response to using the water available based on a relative-yield vs. relative-water-use paradigm (Steduto et al., 2009). It allows rapid ex-ante analysis of complex combinations of soil, field management, and climatic factors over time before making assessments of and choices among the most promising combinations of practice in the field. By separating evapo-transpiration into crop transpiration and soil evaporation, the model utilizes a simple model of canopy growth and senescence as the basis for estimating the two parameters. Final yield is derived as a function of final biomass and the harvest index, while water stress effects are segregated into impacts on canopy growth, canopy senescence, transpiration, and harvest index (Steduto et al., 2009). More details on functional relationships between the different AquaCrop model components can be found in Steduto et al., 2009, and Raes et al., 2009.

In a water-constrained environment like that of the Mwea irrigation scheme, especially given current climatic changes, there should be some capability to evaluate the possibilities for maximizing yield and biomass through deficit irrigation or other means.

A validated water productivity model such as AquaCrop can provide such capability. Further, with projected future climate changes, such a model could generate yield predictions and improve water use, making it of interest to climatologists, agriculturists, policy makers, planners, practitioners and relief organizations (Araya et al., 2010a). Application of crop modeling to optimize rice production in the Mwea irrigation scheme has not been undertaken previously. So we evaluated how such modeling could complement an assessment of the scalability of System of Rice Intensification (SRI) management at scheme level. SRI is of particular interest because of its adaptability and resilience under climate-change stresses (FAO, 2016; Styger and Uphoff, 2016; Thakur and Uphoff, 2017).

II. MATERIALS AND METHODS

Full information on the study area as well as on the experimental methods can be found in Ndiiri et al. (2012, 2013, and 2017). Here key elements are summarized.

2.1 Description of Study Area

The Mwea Irrigation Scheme (MIS), situated in Kirinyaga South District, Kirinyaga County, Kenya, lies on the equator within latitudes 0o32’S and 0o46’S and longitudes 37o13’E and 37o30’E (Figure 3.1). The region is classified as tropical with a semi-arid climate at an average altitude of 1490 meters above sea level (a.m.s.l.), with an annual mean air temperature of 24°C. There is a difference of about 10°C between the minimum temperatures in June/July and the maximum temperatures in October/March. Mean annual precipitation and sunshine are, respectively, 950 mm and 2485 h.

The soils of much of the rice-growing area in Mwea are Vertisols (Sombroek et al., 1982). These are characterized as imperfectly drained, very deep, dark grey to black, firm to very firm, cracking clay. The scheme lies within three agro-climatic zones with varying moisture- availability ratios. These range from an average value of 0.65 for zone III which reaches towards the highland slopes, 0.50 for the vast area covered by zone IV, and 0.4 for the semi-arid zone V. This zonation is based on ratios between measured average annual rainfall, on one hand, and the calculated average annual evaporation, on the other (Sombroek et al., 1982).

Farming in the Mwea scheme, which has an area of 12,282 ha, started in 1956 with rice being the predominant crop. Of this area, 9,000 ha have been developed for paddy production, with a potential further expansion area of 4,000 ha if there is sufficient water supply (Emongór et al., 2009; MIS Manager, personal comm. 2011). The scheme is served by the Nyamindi and Thiba rivers from which water is abstracted through weirs being then distributed by gravity to the respective farms using unlined open channels.

Two rice crops can be grown annually. The main season occurs between August and December during the short rains, while the long-rains crop is grown between January and June.

2.2 Experimental Data

Field experiments were conducted over a two-year period during the main rice-growing seasons (August-December) in 2010 and 2011 at Mwea Irrigation Agricultural Development (MIAD) Centre located within the MIS to compare yields and water use for three varieties of rice (Basmati 370, BW 196, and IR 2793-80-1) grown under SRI management versus conventional practices with continuous flooding (CF). Yields and production costs of rice under SRI management with its reductions in water application (28%) vs. conventional practices under continuous flooding were compared for Basmati 370, one of the most popular varieties of paddy rice. The AquaCrop model was used to assess these effects at the scheme level.

2.3 Field Trials

The experimental design of trials was a two-way factorial in a Complete Randomized Block (CRB) with three replications. Each plot was surrounded by consolidated bunds and lined with plastic sheets installed at 0.3 m depth to prevent seepage and nutrient diffusion between plots. The bunds were followed by 1m wide channels for irrigation.

2.4 Crop Management

The SRI nursery was adjacent to the main field so that transplanting could be performed quickly to minimize trauma to the young plants (WBI, 2008). For SRI practice, 8-day-old seedlings were transplanted on 8 September 2010 (first season) and on 12 August 2011 (second season) at a density of one seedling per hill. Hill spacing was 25 cm by 25 cm with 16 plants per square meter. At 8 days, the 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.

There were no differences in nutrient management for these trials as 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) 1 day before transplanting. All plots received an additional 125 kg/ha of sulphate of ammonia (SA) 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.

2.5 Water Measurement and Application

Water was supplied through a concrete channel to a plot channel and subsequently to the plots. A trapezoidal Parshall flume was installed at the gate provided for each plot during the construction of bunds for the purpose of supplying and measuring water for both practices (Herschy, 2014).

Water measurement for the CF plots was made only during irrigation while for SRI plots, water was measured when irrigating and when draining off excess water. The amount of water applied was estimated for free flow by reading both water height and the time taken for the water to flow through the Parshall flume and into the plot to the required level (ASTM D1941-91, 1958). This information was then converted to the volume of water applied per ha for the cropping season using equation 3.1 (Herschy, 2014; Bengston, 2010).

$$Q = Ch_{a^n}$$

Equation 3.1

Where; Q = discharge (ft^3/s), C = 0.338, h_a = measuring head (ft.) and n = 1.55

Each plot was irrigated separately. All plots were drained at 14 days before harvest to promote ripening of the grains. To calculate the total volume of water used, rainfall amounts were also converted to volume per ha, then summed together with the irrigation water.

The depth of water in the CF treatments was maintained at 5cm up to the end of the tillering stage when it was reduced to 3 cm. Soil in the SRI plots was kept in saturated condition during the first week after transplanting. Thereafter, these plots were irrigated and maintained with a thin layer (2 cm height) of standing water for 2 days and then without any standing water for 5 days before being 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 at 20 cm depth it was 59% on average. From the flowering stage to maturity, a head of 3 cm of water was maintained.

2.6 Agronomic and Yield Measurements

Crop data were collected on number and age of seedlings; transplanting dates; dates of initial and full canopy cover, flowering, maturity and senescence; plant population at harvest; maximum root length; yield components such as number of tillers, number of panicles, grains per panicle, filled grains, and weight of 1000 grains; and final grain and biomass yields at harvest.

2.7 Soil Moisture Measurements

Soil water tension values for the SRI plots were taken weekly using the installed tensiometers, a day before the addition of irrigation water. These data were used in the determination of soil moisture content just before adding irrigation water when the cracks on the soil surface had reached the size recommended by Stoop et al. (2002). The tensiometers were installed in all SRI plots at the beginning of the season at depths of 10 cm, 20 cm and 30 cm.

2.8 Crop Growth Modeling

AquaCrop is a FAO crop model that simulates attainable yield of crops as a function of water consumption under rain-fed, supplemental, deficit, and full-irrigation conditions. The model parameterization was done using data collected through the field experiments described in previous sections. For simulating biomass and yield, we used measurements of water productivity normalized (WP*) for atmospheric evaporative demand (ETo), and for CO2 concentration of the atmosphere, along with the harvest index (HI) acquired from literature (HIo) (Raes et al., 2009; Raes et al., 2010). The soil-plant-atmosphere continuum and some explicitly-considered management aspects that affect the soil water balance, crop development, and hence final yield were acquired for model parameterization.

2.9 AquaCrop data requirement

Local daily weather model input variables which included daily rainfall, pan evaporation, humidity, wind speed, minimum and maximum temperatures (Table 2.1) were collected from the weather station at the research farm located 500 m from the experimental plots, while soil hydraulic characteristics according to textural class were generated through pedotransfer functions (Saxton and Raes, 2006). Wind speed was measured at the experimental site three times a day (morning, midday and evening) using a hand-held anemometer. For net radiation (Rn), an indicative default value of 0.16 for interior locations was chosen as per the recommendation by Steduto et al. (2009).

Table 2.1: Cumulative rainfall, relative humidity, and monthly averages of maximum (Tmax) and minimum (Tmin) air temperature during the Mwea main crop seasons in 2010 and 2011

Year	Month	Rainfall (mm/month)	Relative humidity (%)	Tmax (°C)	Tmin (°C)	Wind Speed (m/s)
2010	August	7.3	82.3	25.0	16.7	3.3
	September	0	77.5	27.5	18.6	3.8
	October	78.6	77.2	29.5	19.9	5.0
	November	120.6	81.4	27.2	19.8	5.8
	December	39.7	74.5	28.8	18.5	4.2
2011	January	6.3	74.0	29.7	14.5	4.8
	February	33.2	71.0	31.2	18.7	4.7
	August	3.6	79.9	25.9	18.6	3.5
	September	40.3	79.6	28.0	19.0	3.4
	October	180.3	79.2	28.4	19.9	5.1
	November	215.4	80.2	27.4	20.0	5.6
	December	11.9	78.7	28.2	19.0	4.2
2012	January	0	75.6	30.6	16.3	5.2

Source: Kenya Meteorological Department, Mwea Research Station (2010/2011)

The user-specific parameters, considered as management aspects, included the irrigation schedule together with general agronomic and crop development data observed and recorded during the entire course of seasons, following SRI and CF recommendations. These included: transplanting dates, time to recovery after transplanting, size of canopy cover for a single seedling at transplanting, beginning and end of flowering, maximum canopy cover, plant population per hectare, start of senescence, and canopy cover and grain yield at harvest time. The plant population was based on the maximum number of tillers per hill for each practice.

The canopy cover development of the crop was monitored fortnightly by taking photographs above the plants at mid-day. To calculate the percentage of canopy cover, the digital pictures were traced on a graph paper, and the shaded area was divided by total area. This was also compared with the estimates from visual observation (Raes et al., 2009). The maximum rooting depth was determined by observing root distribution in a profile pit.

Soil sampling was carried out horizon-wise from 0 to 0.8 m depth. Horizons were delineated based on near-homogeneity of colour, texture (feel method), and general appearance. In the laboratory, soil texture was determined using the sedimentation method (Sheldrick and Wang, 1993).

2.10 Aqua Crop model calibration and validation

Aqua Crop version 4.0 was used to simulate total biomass, grain yields, canopy cover, and soil moisture availability. The main step in the calibration of Aqua Crop was the determination of the crop WP coefficient, which was derived from the linear regression of the relationship between the above-ground biomass and the accumulated crop transpiration normalized for reference evapotranspiration.

Crop transpiration was simulated directly by the model by using the measured weather, soil, irrigation, and canopy cover data, and thereafter it was estimated through an iterative procedure when other crop parameters such as CGC, CCx, and CDC were calibrated. The crop WP coefficient was derived separately for the vegetative development phase (until flowering) and for the yield formation (after flowering) phase since Aqua Crop distinguishes between these phases. Other crop input parameters included: canopy growth, given as a percentage of canopy cover; flowering period and yield-formation duration; rooting depth growth; soil water extraction pattern; crop coefficients at full canopy; three water-stress response functions (for leaf expansion growth, stomatal closure, and early canopy senescence); aeration stress; and HI adjustment functions.

The initial conservative parameters were chosen based on default values for rice reported in Raes et al. (2009). Soil fertility stress was not considered as a varying parameter during the simulation since blanket fertility management was applied throughout the experiments over the period under consideration. More focus was directed towards the water stress-related parameters. Through repeated simulation runs and output comparisons (biomass and grain yields) of simulated versus observed yields, a set of values was arrived at for conservative parameters which seemed most appropriate and gave satisfactory results of the situations simulated (Table 2.2). Data from the first season were used for this process.

Table 2.2: Conservative and calibrated user-specific crop parameters for rice in Aqua Crop

Parameter	Value	
	Conservative	Management
Soil water depletion factor, canopy expansion	0.00	Upper threshold (p-exp)
Soil water depletion factor, canopy expansion	0.40	Lower threshold (p-exp)
Soil water depletion fraction for stomatal control	0.50	Upper threshold (*p* - sto)
Soil water depletion factor for canopy senescence	0.60	Upper threshold (*p* - sen)
Soil water depletion factor for failure of pollination	0.75	Upper threshold (*p* - pol)
Crop coefficient when canopy is complete	1.15	K_{cb} but prior to senescence
Coefficient of positive impact on HI	Small	Vegetative growth
Coefficient of negative impact on HI	Moderate	Stomatal closure
Allowable maximum increase of specified HI	15	%
H_2O productivity normalized for ET_o& CO_2	19	gram/m^2 (WP*)

H_2O productivity normalized for ET_o& CO_2 during yield formation	100		gram/m^2 (WP*)
User-specific parameters	Values		
	SRI	CF	Units/meaning
Base temperature	16	16	°C
Upper temperature	32	32	°C
Maximum effective rooting depth	0.35	0.30	(m)
Effect of canopy cover in late season	70	50	Canopy Cover (CC) effect on soil evaporation
Canopy size at transplanting by an individual seedling	1	3	cm^2/plant
Number of tillers per hectare	9,280,000	3,333,333	Per hectare
Canopy growth coefficient (CGC)	0.108	0.093	Per day CC increase
Maximum canopy cover (CCx)	95	85	%
Canopy decline coefficient (CDC)	12.8	12.8	% Per day CC decrease
Time from transplanting to recovery	5	10	Calendar days
Time from transplanting to maximum rooting depth	100	60	Calendar days
Time from transplanting to start of senescence	115	130	Calendar days
Time from transplanting to maturity	135	141	Calendar days
Time from transplanting to flowering	70	75	Calendar days
Length of flowering stage	10	10	Calendar days

Building up of Harvest Index	65	66	From flowering (days)
Reference Harvest Index	50	40	%

Model validation was based on the comparison between simulated and observed data for the two treatments during the second season. In particular, the crop growth parameters that were analyzed were biomass growth over the entire season, final biomass and harvestable yield, and water productivity. Water productivity is a crucial component of the analysis since it represents a composite behavior of the model's performance combining the overall output of simulation of crop growth (yield) and a crucial component of soil water balance.

2.11 Evaluation of Aqua Crop model performance

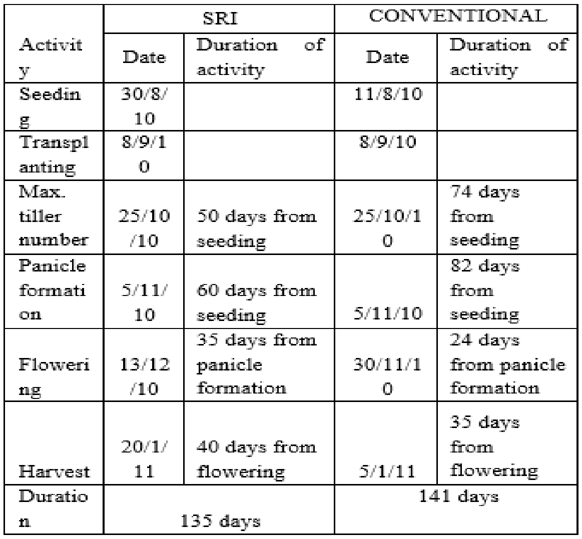
Model performance was evaluated, as noted above, using index of agreement (d) by Willmot (1982), root mean square error (RMSE) (Heng et al., 2009), the coefficient of efficiency (E) by Nash and Sutcliffe (1970), and the coefficient of determination (R2). An R2 value close to 1 means that the dispersion of the simulated values is equal to that of the observations, hence good model performance. RMSE values close to zero indicated a better model fit.

III. RESULTS AND DISCUSSION

3.1 Aqua Crop Model Calibration and Validation for the Basmati 370 Rice Variety

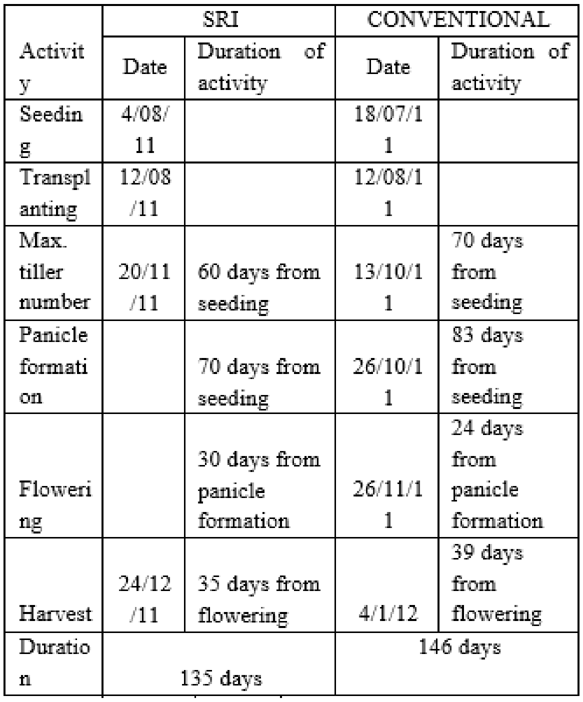
Model results presented are a comparison between simulated and measured values of CC, grain and biomass yields, and soil water content. Data collected in the first season was used for model calibration, while data from the second season were used to validate the model (Tables 3.1a and 3.1b). Model input data are described in the subsequent sections.

Table 3.1a: Phenological data from field experiments (2010/2011) used to for the calibrate AquaCrop model for Basmati 370 rice in Mwea under the two rice-growing practices.



Activity	SRI		CONVENTIONAL	
	Date	Duration of activity	Date	Duration of activity
Seeding	30/8/10		11/8/10	
Transplanting	8/9/10		8/9/10	
Max. tiller number	25/10/10	50 days from seeding	25/10/10	74 days from seeding
Panicle formation	5/11/10	60 days from seeding	5/11/10	82 days from seeding
Flowering	13/12/10	35 days from panicle formation	30/11/10	24 days from panicle formation
Harvest	20/1/11	40 days from flowering	5/1/11	35 days from flowering
Duration	135 days		141 days	

Table 3.1b: Phenological data from field experiments (2011/2012) used to validate AquaCrop model for Basmati 370 rice in Mwea under the two rice growing practices.



Activity	SRI		CONVENTIONAL	
	Date	Duration of activity	Date	Duration of activity
Seeding	4/08/11		18/07/11	
Transplanting	12/08/11		12/08/11	
Max. tiller number	20/11/11	60 days from seeding	13/10/11	70 days from seeding
Panicle formation		70 days from seeding	26/10/11	83 days from seeding
Flowering		30 days from panicle formation	26/11/11	24 days from panicle formation
Harvest	24/12/11	35 days from flowering	4/1/12	39 days from flowering
Duration	135 days		146 days	

3.2 Soil physical properties

In the testing area, there were 5 soil horizons, without any restrictive soil layer that could inhibit root expansion (Table 3.2). The hydraulic properties of the respective soil horizons are shown in Table 3.3.

Table 3.2: Soil texture and carbon content of the experimental site

Soil depth (cm)	Carbon (%)	Sand (%)	Silt (%)	Clay (%)	Texture class
0-5	1.13	54	11	35	Sandy clay
5-17	0.91	51	20	29	Sandy clay loam
17-40	0.79	27	28	38	Clay loam
40-50	0.79	38	27	33	Clay loam/Clay
50-80	0.79	27	33	22	Clay loam/Clay

Table 3.3: Hydraulic properties of the soil used as input to the Aqua Crop model

Horizon	Thickness (cm)	Saturation	Field capacity	Wilting point (Vol %)	Saturated hydraulic conductivity (Ksat) (mm/day)
1	5	50	39	23	100
2	12	50	30	10	250
3	23	50	30	10	250
4	10	50	30	10	250
5	30	50	30	10	250

3.3 Canopy cover

Key stress parameters such as canopy expansion and canopy senescence coefficients were repeatedly adjusted to simulate the measured canopy cover. There was a remarkable match between the simulated and observed canopy covers for both practices. This is a good indication that Aqua Crop is able to simulate canopy cover under full- and deficit-irrigation conditions and at different initial canopy cover values. For SRI practice, RMSE was 15.3% CC, EF was 0.82, d was 0.95, and R^2 was 0.87. On the other hand, for CF practice, RMSE was 9.9% CC, EF of 0.92, d of 0.98, and R^2 of 0.93. The plots for average observed and simulated canopy cover under the two practices are shown in Figure 3.1.

A comparison between simulated and observed canopy cover as a function of days after transplanting (Figure 3.2) shows that for SRI practice, there were deviations from the beginning of the simulation up to the late vegetative stage, and at the end of the season, the observed CC was overestimated by the simulated CC. While under SRI the observed CC was 5%, 24.6%, 62.1%, 68% and 78.8% at 15, 22, 32, 42 and 52 DAP, respectively, the simulated equivalence was 27.3%, 56.1%, 81.7%, 90.4% and 93.5% respectively, for these times in the growth cycle. Observed CC peaked at 62 DAP and attained a maximum CC of 96.4% by 84 DAP, compared to Aqua Crop's predicted 95%. For SRI, the observed canopy senescence and cover decline were slower and less (62% at harvest) compared to what was expected with the simulation (52% at harvest).

For the CF practice, on the other hand, the most noticeable deviation between observed and expected values was at the middle stage where observed CC peaked at 52 DAP, reaching a maximum of 90% at 82 DAP, compared to the simulated maximum value of 85%.

The good match between observed and simulated CC, with 15.3% RMSE, is in agreement with studies by Hsiao et al. (2009) and Saadati et al. (2011) that Aqua Crop can simulate CC in the range of 5.06 to 34.53%.

The initial lag in canopy development under SRI practice is due to the fact that single young seedlings are transplanted at a wider spacing, so there is smaller initial canopy cover, although with accelerated growth the difference is overcome and then reversed. Unlike for CF practice, where Aqua Crop captured the CC dynamics very well, the model did not capture the low water availability effect on CC growth, probably because it employs an exponential growth equation to simulate canopy development for the first half of the growth curve; however, the Ks and P values could not be adjusted since they are conservative. A similar concern of over-simplification has been expressed regarding the stress-response functions based on fractional soil water depletion (the p factor) by Hsiao et al. (2009). The approach employed by Aqua Crop bypasses influences in the process of root water uptake and transport to leaves, as well as the shoot water status, instead linking water stress in plant tissues directly to the total water content relative to the water-holding capacity of the root-zone soil.

3.4 Grain and biomass yields

Figures 3.3 (a) and (b) show the 1:1 linear correlation graphs between observed and simulated dry biomass for the two respective practices. For SRI plants, E was 0.96 and R2 0.94, while for CF practice it was 0.91 and 0.93, respectively, in terms of biomass yield.

There was also a good fit between the observed and simulated grain yields and harvest index (HI) for both sets of practices, with respective deviations of 4.2% and -5.7% under SRI, and of 8.7% and -2.4% with CF practices. WP, however, showed a big shift of 148% and 26% between the observed and simulated values under CF and SRI practices respectively, the observed value being much less than what was predicted by simulation (Table 3.4).

Table 3.4: Comparison between observed and simulated grain yield, biomass, water productivity (WP) and Harvest Index (HI) for the two practices

	Grain yield		Biomass		WP		HI	
	SRI	CF	SRI	CF	SRI	CF	SRI	CF
Simulated	7.4	5	15.4	12.6	1.39	0.99	0.5	0.4
Observed	7.1	5.3	15.1	12.4	1.1	0.4	0.46	0.41
Deviation (%)	4.2	-5.7	1.99	1.6	26	147.5	8.7	-2.4

Observed yields in the first season were low due to low temperatures at the flowering stage, as discussed in the previous sections. Since this was a one-time occurrence, the cold temperature effect was not considered when calibrating the model, although this effect on grain yields was tested as shown in Table 3.5. The results show that a 1°C change in minimum temperature results in 0.6 t/ha reduction in yield on average. The model was therefore calibrated using its default values for the minimum temperature for pollination, which ranges from 8°C to 15°C. The model results presented in Table 3.4, therefore, do not include any temperature effect on biomass and subsequently on grain yields, although the results in Table 3.5 indicate that the model was able to assess this variable.

The mismatch between observed and simulated WP* under CF may be due to high water logging of the root zone, especially during rainfall events, which would significantly reduce ET (Allen et al., 1998). This is also true for SRI from flowering stage to maturity when a shallow standing water of 3 cm was maintained within the plots (Ndiiri et al., 2014).

Table 3.5: Effect of changes in minimum temperature on simulated rice grain yield using Aqua Crop model

Temperature (°C)	8	9	10	11	12	13	14	15
Simulated yield (t/ha)	9.4	9.1	8.5	7.9	7.2	6.5	5.7	5.2
Change in yield (t/ha)	0.3	0.6	0.6	0.7	0.7	0.8	0.5	0.6
Average change in yield (t/ha)	0.6							

3.5 Soil water content

The results for SWC are only for the initial and crop development stages because after panicle initiation, when the crop enters into the mid-season stage, the crop is irrigated continuously, hence, the soil will be at a saturated level. Results of simulated versus observed SWC are shown in Figure 3.4, while results from statistical analysis are shown in Table 3.6. The results indicate that the model simulated SWC slightly better in the 0-10 cm depth than the 10-20 cm depth, although there was a good agreement between simulated and observed data in the two layers.

Table 3.6: Results for the simulation of SWC using the calibrated Aqua Crop model

Depth (cm)	RMSE (mm)	E	d	R^2
0-10	8.8	-0.64	0.68	0.83
10-20	10.3	-1.99	0.71	0.81

A comparison of total water content within the effective root zone (0.35 m) indicates that the simulated SWC matched the trends for the SRI water applications better in the second season compared to the first season (Figure 3.4), although the SWC was overestimated in both seasons. The simulated decline in SWC was also less than measured in the first season. Because the difference in SWC between the simulated and measured values is cumulative, SWC was overestimated at the end of the second stage by a significant amount, about 50 mm.

The SWC was determined at 10 cm, 20 cm and 30 cm depths. All the readings at 30 cm depths were zero, hence only the readings at 10 cm and 20 cm depths were considered for the analysis. The varied response may be explained by the fact that moisture content within the 10-20 cm depth was almost equal to the FC most of the time, while within the 0-10 cm horizon it was below FC and sometimes below WP. These not so different results may be due to the heterogeneity of the Ksat between the two soil horizons.

The overestimation of observed SWC may have been caused by the simplified assumption in AquaCrop (Raes et al., 2009) that drainage is zero when SWC is at or below FC. Although this is normally taken to be the case in irrigation considerations, it is not strictly true conceptually nor according to experimental data (Hsiano et al., 2009). Another possibility is that because the crop coefficient for Tr was slightly higher (1.10) than the default value (1.0), this added to the overestimation. Also, the drainage could have been underestimated, especially at the beginning of the season when there was no rainfall, and only a small amount of water (20 mm) was added to the soil. Another explanation, yet again, could be that evaporation was underestimated because of having young, widely-spaced seedlings in their first and second development stages before the crop attained its maximum root depth and canopy cover.

IV. CONCLUSIONS

Aqua Crop is a model that FAO developed to help predict attainable yield and water productivity (WP) under water-limiting conditions. In this evaluation, there was good performance of the Aqua Crop model in simulating CC, total biomass, grain yield, and soil water content for the Basmati 370 rice variety under both full and deficit irrigation. The model was also able to simulate these parameters in the two seasons under varying rainfall profiles. The model was less satisfactory in simulating the initial canopy cover and SWC under SRI practice where single young seedlings were transplanted at wider spacing, thus having very little initial canopy cover and higher evaporation losses at first. This differential was, however, soon redressed. WP was also overestimated by the model in both practices possibly due to high water logging of the root zone, especially during rainfall events, which would significantly reduce ET.

The findings indicated a high potential for using a calibrated Aqua Crop model with a high degree of reliability: R2 =0.97 for biomass and 0.87 for canopy cover. There was also a good fit between the observed and simulated grain yields, with deviations of only 4.2% and -5.7%, respectively, under SRI vs. CF practices.

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