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M.H.J.P. Gunarathna (✉ janaka78@agri.rjt.ac.lk)

Rajarata University of Sri Lanka

M.K.N. Kumari

Rajarata University of Sri Lanka

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Simulation of sugarcane growth and yield under optimized subsurface irrigation system

M.H.J.P. Gunarathna^{1*} and M.K.N. Kumari¹

¹Faculty of Agriculture, Rajarata University of Sri Lanka, Puliyankulama, Anuradhapura 50000, Sri Lanka

<https://orcid.org/0000-0002-3961-3600> (M.H.J.P.G.); <https://orcid.org/0000-0002-7612-3205> (M.K.N.K)

janaka78@agri.rjt.ac.lk (M.H.J.P.G.); nadeeka@agri.rjt.ac.lk (M.K.N.K.)

Tel.: +94-71-8665585 (M.H.J.P.G.); Tel.: +94-71-7511718 (M.K.N.K.)

*Correspondence: janaka78@agri.rjt.ac.lk (M.H.J.P.G.)

Abstract:

The optimized subsurface irrigation system (OPSIS) is a newly developed subsurface irrigation system to irrigate upland crops. Although it is already evaluated for few crops using field experiments, further evaluation is required. Since field experiments are tedious, expensive, we need an alternative approach to evaluate the OPSIS. A well-calibrated and validated crop model is a fast-alternative option for developing and evaluating agronomic practices. Therefore, this study aimed to develop the modeling capabilities of APSIM to simulate the OPSIS. We conducted field experiments for three growing seasons (main crop and two ratoons), two planting seasons (spring and summer planting), and two separate crops to collect necessary data for calibration and validation processes. We scripted a new module named "OPSIS" to couple OPSIS to the APSIM engine. We parameterized, calibrated, and validated the APSIM to simulate the growth and yield of sugarcane with OPSIS. After firm parameterization and calibration, APSIM-Sugar can successfully simulate the growth and yield of sugarcane with OPSIS. However, the simulation

of soil moisture dynamics and irrigation water use were not up to the standards. Although it gives quite reasonable results for growth and yield simulations of sugarcane, further studies are suggested to develop the simulation accuracy of soil water dynamics and irrigation water use through the OPSIS.

Keywords: calibration; irrigation water use; OPSIS; parameterization; soil moisture dynamics; validation

1. Introduction

The optimized subsurface irrigation system (OPSIS) is a newly developed subsurface irrigation system to irrigate upland crops, such as sugarcane. In soils with low water holding capacity, OPSIS can show comparatively better performances than other irrigation methods (Gunarathna et al. 2017). Solar-powered pump and minimum operational activities of OPSIS help cut down operational costs of irrigation drastically, compared to sprinkler irrigation, the common irrigation method of sugarcane in Okinawa, Japan. When OPSIS is operating, water flows along the perforated OPSIS lines through gravity. With the advancing water along the perforated OPSIS line, water can move to the outside soil based on the water potential. As water moves outside, the soil becomes saturated. After that, the outside soil and inside of the pipe come to an equilibrium. This equilibrium controls the amount and rate of irrigation. Further, the saturated layer starts to move the water upward due to the water potential created by matrix effects such as capillary action created via surface tension. As water moves upward, the moisture content of root zone soil increases and provides irrigation water to the crop. (Gunarathna et al. 2017).

Using field experiments conducted in Itoman, Okinawa from 2013 to 2016, (Gunarathna et al. 2018) reported the advantages of OPSIS over sprinkler irrigation for sugarcane cultivation regarding both sugarcane

yield and WUE. However, they suggested conducting further validation of results using different assessment methods.

A crop simulation model is a vital tool with numerous uses, including evaluating different irrigation management practices. A well-calibrated and validated crop model is a fast-alternative option for developing and evaluating agronomic practices (Saseendran et al. 2008). Hence crop models can act as a time and resource-saving option for researches on technological advances in agriculture. Different authors recorded the application of different crop models to evaluate irrigation methods and strategies. (Saseendran et al. 2008) used the CERES-maize model to determine the optimum allocation of limited irrigation between vegetative and reproductive growth stages and optimum soil water depletion level for initiating limited irrigation. (Abd-El-Baki et al. 2017) used a numerical crop model to determine the optimum irrigation depth for the tomato crop. (Kundu et al. 1982) used the CORNGRO crop model to determine the optimum soil moisture depletion and replenishment levels and timing and amount of irrigation during different crop growth stages of corn. (Mubeen et al. 2016) used the CSM-CERES-Maize model to optimize the irrigation conditions. (Balwinder-Singh et al. 2016) used APSIM to evaluate mulch's effect on the sowing date and irrigation management of wheat in Central Punjab, India. (Sena et al. 2014) used APSIM to determine the optimum transplanting dates for achieving higher yield and water productivity of rice-wheat cropping systems in India's Middle IGP. (Subash et al. 2014) evaluated the different irrigation regimes on rice-wheat cropping systems in IGP using APSIM model. Hence, crop model simulations could be an effective tool to evaluate the OPSIS.

59 1.1 APSIM

60 APSIM (Agricultural Production Systems Simulator) is an open-source (for non-commercial users) crop
61 modeling software, which can use to model the growth and yield of many crops, including sugarcane (Keating et
62 al. 2003; Holzworth et al. 2014). Further, it has modeling functions, which simulate soil water, nutrients, and many
63 more (Inman-Bamber and McGlinchey 2003; Keating et al. 2003; Holzworth et al. 2014; Inman-Bamber et al.
64 2016). Plant models in APSIM simulate major physiological processes such as phenology, water, and nutrient
65 uptake, development of organs and responses for abiotic stresses, etc. Soil models in APSIM simulate water
66 movements such as infiltration, capillary rise, evaporation, surface runoff, and drainage. Simple tipping bucket
67 approach (SOILWAT module, (Probert et al. 1998)) and comprehensive numerical solution using Richard's
68 equation (SWIM module, (Huth et al. 2012)) use to simulate water and solute movements.

69 Further, it simulates soil organic matter decomposition and temperature changes (Holzworth et al. 2014).
70 APSIM allows users to incorporate management interventions by their scripts written in scripting languages.
71 Hence, it is a major advantage in APSIM compared to other crop modeling software (Archontoulis et al. 2014;
72 Holzworth et al. 2014). The uncertainties of predictions from the model generally characterized by the error
73 statistics determined from the prediction of experimental data. Therefore, firm parameterization, calibration, and
74 validation need to reduce the uncertainties of predictions.

75 Therefore, this study aimed to develop the modeling capabilities of APSIM to evaluate the OPSIS. We
76 conducted field experiments and modeling work to parameterize and calibrate the APSIM to simulate sugarcane
77 growth and yield. We conducted field experiments and modeling work to validate the APSIM simulations of yield
78 and growth of sugarcane under our newly developed irrigation method, the optimized subsurface irrigation system

(OPSIS). We evaluated the simulation accuracy of APSIM using different model evaluation criteria during both calibration and validation steps.

2. Materials and Methods

We conducted a series of field experiments to collect the necessary data for parameterization and calibration of the APSIM-sugar model for locally grown cultivar Ni21, which was developed to withstand typhoons. Further, we conducted field experiments with the same cultivar to validate the APSIM to use with OPSIS. All the planting was done following the single-row planting method with 1.3 m spacing between the rows. We conducted all field experiments in farmer-operated sugarcane fields located at Itoman, Okinawa, Japan ($26^{\circ} 7' 59.07''$ N, $127^{\circ} 40' 52.32''$ E). The local climate is classified as Cfa by Köppen climate classification (Rubel and Kottek 2010; Gima and Yoshitake 2016).

2.1 Plant Data

Planting materials of sugarcane cultivar Ni21 that we used in the present experiment was obtained from National Agricultural Research Organization (NARO), Japan and established at Itoman experimental field of Paddy Research CO., LTD, Land Improvement District, and University of the Ryukyus. We maintained two experimental plots as sprinkler irrigated and OPSIS irrigated sugarcane fields grown with local cultivar Ni21. More information about the field experiments is presented by (Gunarathna et al. 2018). We used the data obtained from sprinkler irrigated fields to parametrize and calibrate the APSIM-Sugar model while OPSIS irrigated fields to validate the APSIM to use with OPSIS. We conducted field experiments to observe growth and yield under two

planting conditions: Spring and Summer planting following Okinawa, Japan's local practice. We started the Spring planting in April 2013 and harvested in March 2014. The crop extended to observe the growth and yield of two consecutive ratoon crops which were harvested in January 2015 and January 2016. We started summer planting in October 2013 and harvested in January 2015. We extended only the OPSIS irrigated the crop to observe the growth and yield of the first-ratoon crop, and it was harvested in January 2016. Following the regular fertilizer application practice in Okinawa, we used 350 kg/ha of urea fertilizer for both irrigation methods for the main crop and ratoon crops. For sprinkler irrigation, we added fertilizer in 31 and 62 days after planting or harvesting. However, we applied the same amount of fertilizer for the OPSIS as a ten-split application during the first three months through the OPSIS.

We randomly selected a 5.2 m² area to estimate the fresh cane yield of the spring- and summer-planted main crops and the two ratoon crops. Further, we counted stalks per unit area to calculate stalk densities of different crops at the harvesting. Although the plant height was not used in many studies to calibrate or validate the APSIM sugar model, we used plant height due to other parameters' unavailability for the evaluation. We measured the plant height of the summer-planted main crop and the spring-plant's first ratoon crop at monthly intervals from May 2014 to January 2015 as the distance from the soil surface to the +1 dewlap (de Sousa et al. 2015).

2.2 Soil Data

We used soil samples from six layers as 0-10, 10-20, 20-30, 30-40, 40-50, and 50-60 cm to estimate the lower limit (LL15, mm/mm), drained upper limit (DUL, mm/mm), soil saturation (SAT, mm/mm), bulk density (BD, g/cm³), particle density (TD, g/cm³) and saturated hydraulic conductivity (KS, mm/day). LL15 and DUL were considered the volumetric water content equilibrium to the -1500 kPa and -33 kPa, respectively, and measured

using the centrifuge method (Khanzode et al. 1999; ASTM International 2003; Vero et al. 2016). Measured BD and TD values were used to estimate soil saturation. Saturated hydraulic conductivity was estimated in the laboratory using the constant head method (ISTM International 2000). Further, soil samples were analyzed to estimate soil pH, NO₃-N, NH₄-N levels, and soil carbon. We created a new soil profile for Itoman, Okinawa, and parameterized it using the measured data (Table 1).

Table 1. Soil data used to parameterize Itoman soil profile

Depth	Bulk density	Air Dry	LL15	DUL	SAT	KS	Sugar LL
(cm)	(g/cc)	(mm/mm)	(mm/mm)	(mm/mm)	(mm/mm)	(mm/day)	(mm/mm)
0-10	1.107	0.100	0.277	0.422	0.481	7827	0.277
10-20	1.154	0.100	0.295	0.415	0.48	19712	0.295
20-30	1.310	0.100	0.298	0.453	0.484	10834	0.298
30-40	1.197	0.100	0.300	0.447	0.496	4432	0.300
40-50	1.237	0.100	0.310	0.436	0.511	814	0.310
50-60	1.264	0.100	0.290	0.428	0.522	800	0.290

Soil moisture levels were measured in 5, 15, 25, 35, 45, and 55 cm depths using soil moisture sensors (5TE, Decagon Devices, Pullman, WA, USA) in the OPSIS field to evaluate the soil moisture dynamics of OPSIS. We used first and second ratoons of Spring planting to evaluate the soil moisture dynamics under the OPSIS.

129 2.3 *Irrigation water use*

130 We measured the irrigation water use of the first and second ratoon crops of spring-plant which were irrigated
131 using OPSIS. Flow meters attached to the outlet and inlet of the water column of the OPSIS were used to estimate
132 the daily irrigation amount through the OPSIS. We used first and second ratoons of Spring planting to evaluate the
133 irrigation water use of crops under the OPSIS.

134 2.4 *Climatological data*

135 Daily maximum and minimum temperature, precipitation, radiation, wind speed, pressure, and relative
136 humidity values of Naha, Okinawa, Japan were obtained from Japan metrological agency website
137 (www.jma.go.jp/jma/menu/report.html) for the period of 1/1/1980 to 31/08/2016. Annual average ambient
138 temperature and annual amplitude in mean monthly temperature were calculated using tav_amp utility software of
139 APSIM (<https://www.apsim.info/Products/Utilities>). A new meteorological was parameterized using the data
140 mentioned above.

141 2.5 *APSIM-OPSIS module*

142 We scripted a new module named "OPSIS" to couple optimized subsurface irrigation system to the APSIM
143 engine. The fifth layer was selected as the base layer, where the OPSIS is located. The difference between the SAT
144 and the soil water content (SW) of the layer is identified as the input to the layer. The estimated amount of irrigation
145 through the optimized subsurface irrigation is named "opsis (mm/day)."

146

2.6 APSIM Simulation

APSIM, the Agricultural Production Systems sIMulator is a process-based dynamic crop model that combines biophysical and management modules within a central engine to simulate diverse cropping systems (Keating et al. 2003; Holzworth et al. 2014). The model is driven by daily climate data and can simulate growth, development, crop yield, and soil interactions.

First, we modified the sugar model of APSIM 7.10 by adding a new cultivar, Ni21. Then we parameterize the cultivar parameters using the data obtained from field measurements, published reports on Ni21 cultivar, and experts' views (Table 2).

Table 2. Cultivar and plant-specific parameters used to parametrization and calibration of APSIM-Sugar model

Parameter	Initial values		Values used for simulations	
	(parameterization)		(after calibration)	
	Crop	Ratoon	Crop	Ratoon
Leaf_size 1, 14, 20	2000, 48000, 48000	2000, 48000, 48000	2000, 48000, 48000	2000, 48000, 48000
cane_fraction	0.7	0.65	0.7	0.7
Sucrose_fraction_stalk 0.2, 1	1.0, 0.5	1.0, 0.5	1.0, 0.5	1.0, 0.5
sucrose_delay	0	0	0	0
min_sstem_sucrose	800	800	800	800
min_sstem_sucrose_redn	10	10	10	10

tt_emerg_to_begcane	1800	1800	1900	1900
tt_begcane_to_flowering	6000	6000	6000	6000
tt_flowering_to_crop_end	2000	2000	2000	2000
green_leaf_no	13	13	13	13
tillerf_leaf_size 1, 4, 10, 16	1.5, 1.5, 1.5, 1	1.5, 1.5, 1.5, 1	1.5, 1.5, 1.5, 1	1.5, 1.5, 1.5, 1
rue	0, 0, 1.80, 1.80,	0, 0, 1.65, 1.65,	0, 0, 2.00, 2.00,	0, 0, 1.85, 1.85,
	1.80, 0	1.65, 0	2.00, 0	1.85, 0
Crop_height_max	6000	6000	4000	4000

Then, we simulated the spring planted and summer planted sugarcane growth and yield under sprinkler irrigation from March 2013 to January 2016 and September 2013 to January 2015, respectively. As APSIM underestimated the growth and yield, we modified the RUE like-minded (Gunarathna et al. 2019) and (Sexton et al. 2017). (Dias et al. 2019) also suggested substantial changes to enable APSIM-Sugar to simulate canopy and yield of Brazilian genotypes. We increased the maximum RUE values up to 2.0, confining the findings of (Muchow et al. 1997; De Silva and De Costa 2012). Similarly, we increased the maximum RUE values of ratoon crop up to 1.85, conforming to the gap maintained by APSIM. As Ni21 is developed to withstanding typhoon conditions, plants usually do not show higher plant heights. Hence, we limited the maximum plant height up to 4000 mm from the default of 6000 mm. Further, we calibrated cane fraction (CF) and thermal time from emergence to beginning of cane (EB) by trial and error method to find the optimum values for those parameters (Table 2).

Then, we simulated the spring planted (from March 2013 to January 2016) and summer planted (from September 2013 to January 2016) sugarcane growth and yield under OPSIS. We used fresh cane weight at

harvesting, plant heights of first ratoon crop of spring-plant and main crop of summer-plant, soil moisture levels of top five layers and irrigation water use through the OPSIS to validate the application of APSIM with OPSIS. During the summer of 2015, several typhoons occurred, and substantial crop damages were observed. Therefore, after considering the field observations, historical yield records, and experts' views, the observed yield of the second ratoon of spring plants (both sprinkler and OPSIS irrigated crops) and the first ratoon of summer plants were adjusted, adding 20% of observed yield to the observed yield.

2.7 Model Evaluation

We used different model evaluation criteria such as root mean square error (RMSE; Equation 1), mean absolute error (MAE; Equation 2), coefficient of determination (R^2 ; Equation 3), and Wilmott's agreement index (d; Equation 4) (Willmott 1981) to evaluate the simulation accuracy (Krause et al. 2005; Dias and Sentelhas 2017). Low RMSE and MAE values indicate good agreement between model outputs and observed values, while high R^2 and d also assure the same. The Lin's concordance correlation coefficient (CCC) integrates precision through Pearson's correlation coefficient, which represents the proportion of the total variance in the observed data that can be explained by the model, and accuracy by a bias which indicates how far the regression line deviates from the concordance line (Ojeda et al. 2017). CCC ranges from -1 to 1, with a perfect agreement at 1. It can legitimately calculate accuracy with few observations for agreement on a continuous measure obtained by two methods (Stevenson et al. 2018). We calculated the CCC using epiR package (Stevenson et al. 2018) of R software (R Core Team 2018).

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (S_i - O_i)^2} \quad (1)$$

$$MAE = \frac{1}{n} \sum_{i=1}^n |S_i - O_i| \quad (2)$$

$$R^2 = \left[\frac{\sum_{i=1}^n (O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (S_i - \bar{S})^2}} \right]^2 \quad (3)$$

$$d = 1 - \frac{\sum_{i=1}^n (S_i - O_i)^2}{\sum_{i=1}^n (|S_i - \bar{O}| + |O_i - \bar{S}|)^2} \quad (4)$$

where, S_i and O_i are the simulated and observed value of the parameter (in fresh cane yield (t/ha), plant height (mm), soil moisture (mm/mm) irrigation water (mm/month) respectively; $\bar{O}$ and $\bar{S}$ are the average of simulated and observed values, respectively; and n is the number of observations.

193

194 3. Results and Discussion

195 3.1 Parameterization and calibration of APSIM-Sugar to simulate growth and yield of cultivar Ni21

Initially, we added cultivar Ni21 to the APSIM-Sugar model (XML file) and parameterized using field-measured data (leaf size and green leaf number), available data in published reports, and views of experts (Table 2). After the parameterization, we simulated fresh cane weight and plant height. We observed quite healthy relationships between observed and simulated values. However, APSIM underestimated the fresh cane weight. After the modification of plant parameters (maximum RUE and maximum plant height of main and ratoon crops) and calibration of cultivar parameters (CF and EB), the relationships were further improved (Figure 1). Despite the high variability of cane and sucrose yield affected by weather conditions, nutrient levels, planting time, and some undefined factors, APSIM-Sugar able to simulate good results to fit with the observations in agreement with the results of (Keating et al. 1999), (Cheeroo-Nayamuth et al. 2000) and (Inman-Bamber and McGlinchey 2003). Using data sets of different cultivars grown in different locations, (Keating et al. 1999) showed that APSIM could

simulate the millable stalk weight ($R^2 = 0.72$, $\text{RMSE} = 1.94 \text{ t/ha}$) with fairly good accuracy. (Inman-Bamber et al. 2016) showed the better predictive ability of the APSIM-sugar model after modifying the transpiration efficiency and root water supply. Our study also proves the virtuous ability of APSIM-Sugar to simulate fresh cane weight as all model evaluation criteria show a good fit between simulations and observations ($\text{RMSE} = 3.195 \text{ t/ha}$, $R^2 = 0.93$, $\text{MAE} = 2.74 \text{ t/ha}$). Further, plant height simulations, also showed good agreement with the observations ($\text{RMSE} = 493 \text{ mm}$, $R^2 = 0.87$, $\text{MAE} = 397 \text{ mm}$).

Figure 1. Observed versus simulated a) fresh cane weight; b) plant height of sugarcane cultivar Ni21

In this study, we used higher maximum RUE values than the APSIM usually used. Although it is not a usual practice in APSIM crop modeling studies, we change the maximum RUE values to minimize the gap between simulated and observed values with higher input conditions with novel genotypes. However, we believed that the APSIM may not always use the maximum RUE values as it is always controlled by soil moisture status, nutrient availability, and reduced growth phenomenon (RGP) (Park et al. 2005). RGP reduces RUE, with highly favorable environment conditions as highly favorable conditions may lead to lodging (Park et al. 2005; van Heerden et al. 2015).

3.2 Validation of APSIM to simulate growth and yield of cultivar Ni21 under OPSIS

We simulated the fresh cane weight and plant height of sugarcane cultivar Ni21 under OPSIS using the newly parameterized and calibrated APSIM-sugar model and APSIM-OPSIS module. Results revealed that APSIM simulations show good agreement with observed fresh cane yield and plant height. Further, observed soil moisture dynamics and irrigation water use also showed acceptable agreement between simulated values.

3.2.1 Plant height

In summer-planted sugarcane, APSIM with OPSIS showed a good simulation of plant height (Figure 2). Although it was slightly underestimated during the latter part, model evaluation criteria confirmed that simulation is almost like the observations (Table 3). The first ratoon of spring-plant showed variation between observed and simulated plant heights as APSIM sugarcane under simulated plant height in the crop's early stages (Figure 3). However, in the late stages, the first ratoon of the spring plant showed a higher growth rate in simulation than the observed; therefore, during the harvesting, simulated plant height became slightly higher (4%) than the observed value. Although the simulation accuracy is not good as the summer plant, model evaluation criteria confirmed that simulation is comparable with observations (Table 3). Further, Table 3 confirmed that the plant height simulation of the summer-planted main crop is better than the calibration study results, while the first ratoon crop of spring-plant showed slightly poor performances compared to the calibration results.

Figure 2. Observed versus simulated plant height of summer planted sugarcane crop

Figure 3. Observed versus simulated plant height of spring planted first ratoon crop

Table 3. Evaluation of simulation accuracy of APSIM with OPSIS

Variable (unit)	Planting season	Model evaluation criterion				
	(Crop/ratoon)	R^2	*MAE	*RMSE	d	CCC
Fresh cane yield (t/ha)	All	0.82	4.67	6.08	0.64	0.56
Plant height (mm)	Summer planting (Crop)	0.99	286	306	0.98	0.97

	Spring planting (1 st ratoon)	0.96	582	769	0.91	0.85
Average soil moisture of	Spring planting (1 st ratoon)	0.32	0.047	0.052	0.49	0.16
root zone (mm/mm)	Spring planting (2 nd ratoon)	0.50	0.053	0.056	0.45	0.15
Monthly irrigation water	Spring planting (1 st ratoon)	0.01	11.19	13.18	0.47	0.07
use (mm/month)	Spring planting (2 nd ratoon)	0.22	15.51	17.45	0.27	0.39

*Unit is equal to the unit of the variable

3.2.2 Fresh cane weight

Confirming the virtuous ability of APSIM to simulate fresh cane weight, APSIM under OPSIS simulated fresh cane yield with good agreement to the observations (Figure 4) as all model evaluation criteria shows a good fit between simulations and observations (Table 3). The RMSE value reported (6.08 t/ha) is far enough for a simulation study as it is about 5% of the average observed fresh cane yield. R^2 (0.82) and d (0.64) also confirmed the goodness of fit between observed and simulated fresh cane yield. Further, these validation results are equally good as the results of the calibration study. Similarly, (Mao et al. 2018) showed the ability of locally calibrated APSIM-sugar to simulate cane yield with a high accuracy level.

Figure 4. Comparison of observed and simulated yield of sugarcane under OPSIS

3.2.3 Soil moisture dynamics

Figure 5 shows the variation of predicted and observed soil moisture levels in different soil layers during the first and second ratoons of spring planting. The results showed that APSIM had overpredicted the soil moisture levels, especially the root zone's upper part. Since the soil water movements are much complicated, it is difficult to acquire precise simulations from simple model predictions. In this study, we used a cascading layer approach to estimate the soil water movements. However, this is a simple approach; hence, it may not accurately simulate the soil water movements. Similarly, overestimating APSIM simulated soil moisture in upper levels and quite good simulations in lower layers have been reported (Balwinder-Singh et al. 2011). A crop simulation study, (Marin et al. 2011) reported that calibrated DSSAT/Canegro simulated soil water content with fairly good accuracy as they observed mean RMSE as 0.214 mm. (Archontoulis et al. 2014) reported the ability of APSIM to simulate the soil water dynamics with good accuracy as they reported the RMSE of prediction is 0.032 mm/mm. (Sena et

al. 2014) also observed higher error between observed and simulated soil moisture, and then they calibrated the soil parameters to minimize the error of soil moisture simulations.

Figure 5. Observed and simulated soil moisture variation different layers of the soil during the first and second ratoon crop of spring planting

The SOILWAT module predicted the soil water dynamics of OPSIS operated sugarcane fields with reasonably good accuracy. The overestimation of soil moisture content in the top layers may be due to differences in simulated and actual daily soil evaporation rates and the capillary rise and lower downward movements controlled by the saturated flow parameter (SWCON). The origin of these differences requires further investigation. Therefore, a study focused on comprehensive measurements is required to acquire accurate modeling of soil water dynamics. (Brown et al. 2018) proposed a comprehensive model (WEIRDO, Water Evapotranspiration Infiltration Redistribution Drainage runOff) to simulate soil water dynamics. However, this model only works with APSIM next generation. This study used the classic version of APSIM (APSIM 7.10);

therefore, we cannot use this model. This model may able to comprehend the soil moisture dynamics of OPSIS irrigated fields. Therefore, we are suggesting studying the applicability of this model in future studies.

3.2.4 Irrigation water use

The relationship between the observed and simulated amount of water irrigated as OPSIS during the first ratoon crop of spring-planting are shown in Figure 6. Like the moisture levels in the soil, APSIM overpredicted the irrigation water use by OPSIS.

No studies to compare the irrigation water use as usually APSIM do not simulate the irrigation amount. In this study, we simulated the irrigation water use applied through our newly designed irrigation system named OPSIS. Model evaluation criteria (Table 3) show that the simulations are not comparable with the observed irrigation amount. However, the MAE values show that the estimated errors are 11.2 and 15.5 mm/month for first and second-ratoon crops, respectively. Application of the comprehensive model to simulate soil moisture dynamics may rectify irrigation water predictions as irrigation water use depends on the crop water uses and soil evaporation and percolation losses.

Figure 6. Observed versus simulated irrigation water use through OPSIS of spring-planted first ratoon crop

4. Conclusions and Recommendations

We modified the APSIM-Sugar model to simulate the growth and yield of sugarcane cultivar Ni21, which was developed to withstand typhoons' strong winds. Then we parameterize the cultivar Ni21 using measured values, information published in reports, and expert's views. However, APSIM underestimated the growth and yield of sugarcane cultivar Ni21 under Okinawan conditions. Therefore, the APSIM-Sugar model was modified and calibrated using radiation use efficiency, thermal time from emergence to the beginning of cane and cane fraction. After the calibration, APSIM simulations showed a close relationship with the observations. Then, we validated the APSIM to use with OPSIS. We developed the APSIM-OPIS module to couple OPSIS with the APSIM engine. The simulation results were agreed with the observations. Simulated plant height and fresh cane yield showed good agreement with the observations. However, APSIM showed overestimation for soil water content in upper soil layers and irrigation water use of OPSIS.

Hence, the newly developed APSIM-OPIS module can successfully simulate the crop growth and yield of sugarcane with an optimized subsurface irrigation system. Although it gives good results, further studies are suggested to develop the simulation accuracy of soil water dynamics and irrigation water use through the OPSIS.

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Conflicts of Interest: The authors declare no conflict of interest.

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Figures

Figure 1

Observed versus simulated a) fresh cane weight; b) plant height of sugarcane cultivar Ni21

Figure 2

Observed versus simulated plant height of summer planted sugarcane crop

Figure 3

Observed versus simulated plant height of spring planted first ratoon crop

Figure 4

Comparison of observed and simulated yield of sugarcane under OPSIS

Figure 5

Observed and simulated soil moisture variation different layers of the soil during the first and second ratoon crop of spring planting

Figure 6

Observed versus simulated irrigation water use through OPSIS of spring-planted first ratoon crop