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THE BENEFIT OF USING DRAINAGE WATER OF FISH FARMS FOR IRRIGATION: FIELD AND MODELLING STUDY USING SALTMED MODEL†

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ABSTRACT

This study investigated the suitability and benefits of using drainage water of fish farms (DWFF), instead of canal fresh water (IW), for wheat irrigation. Two water qualities, DWFF and IW, and four levels of N-fertigation rates [100% N (192 kg N ha^{-1} season^{-1}), 80% N, 60% N and 40% N] were tested. The results showed a positive impact when increasing N-fertigation rate on the yield using both DWFF and IW. However, the yield under DWFF was (between 11 and 51% in 2014 and between 8 and 38% in 2015) higher than the yield under the IW treatment. This is due to the additional amount of dissolved biological nitrogen and other nutrients inherent in DWFF. The SALTMED model simulated reasonably well the soil moisture and nitrogen content of all soil layers as well as wheat dry matter, yield and water productivity for all treatments, with R^2 of 0.99, 0.97 and 0.96, respectively. It was concluded that the use of drainage water of fish farms instead of fresh water for irrigation of wheat could help to achieve higher yields while using less irrigation water and less chemical fertilizers. Additional benefits are less drainage to the drainage network and higher income for farmers.

KEY WORDS: fertigation; drainage water of fish farms; yield production; SALTMED.

INTRODUCTION

In semi-arid regions, such as the Mediterranean, water resources are limited and the gap

† L'avantage d'utiliser l'eau de drainage des piscicultures pour l'irrigation: étude sur le terrain et la modélisation en utilisant le modèle SALTMED

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between water supply and demand is widening over time due to the continuous increase in water demand for food, feed and fibre for the ever-growing population. In this region, water resources suffer from over-abstraction. Commonly, good quality water is scarce and water of marginal quality is considered for use in agriculture. Such marginal waters, also known as non-conventional water resources, include agricultural drainage water, brackish ground water, domestic waste water, agro-industry waste water, mining industry waste water and cooling tower waste water. However, the use such relatively poor quality waters requires careful consideration and suitable management (Huibers *et al*., 2005). Many countries have already included wastewater reuse as an important resource in their water resources planning. At present, several semi-arid countries are using wastewater in agriculture, e.g. Egypt, Morocco, Jordon, India, Pakistan, Tunisia, Ghana, South Africa and the Gulf countries.

Meanwhile many semi-arid countries resorted to fish farming as a way to meet the ever increasing demand for protein. Obviously, given the scares water resources in semi-arid areas, the rise of aquaculture exacerbates the water availability issue (Molden, 2007). Nevertheless, fish farms have been established in many semi-arid countries and significantly contribute to the food supply (Bostock *et al*., 2010). In order to maintain sustainability, however, there may be a need to move towards integrated faming systems where the waste of one farming activity becomes a supply to another agricultural activity (Walia and Navdeep Kaur, 2013). In the setting of fish farming in semi-arid areas this could be achieved by using the fish pond effluent for irrigation. There have already been major reviews on the integration of aquaculture into irrigation systems (Murray, 2002). In this context, the Food and Agriculture Organisation of the United Nations (FAO) (2006) reported on 'integrated irrigated agriculture' where the productivity of water may be increased by growing fish in the fresh water of irrigation canals and using that water for irrigation as well as growing fish in the slightly saline drainage water that, eventually, can again be used to irrigate crops. Where fish farms are prohibited from using water in irrigation canals, fish can be farmed in water storage reservoirs and the water can then still be used for irrigation (Van der Heijden *et al*., 2012). This approach is also taken in the Czech Republic where large fish ponds are part of the natural environment (Adamek, 2012). The fish ponds attract wildlife, allow recreational activities and are stores of irrigation water. Fish can also be grown in reservoirs that supply water for hydropower as well as for irrigation. The risk with this approach is that the environment of the fish may be adversely affected as the water level in the reservoirs may fluctuate as the result of water withdrawal (Finlayson *et al*., 2013).

Fish farming drainage water (DWFF) could be a useful resource for irrigation water as well as a good source of organic matter that can improve soil quality and crop productivity, as well as reducing the costs of chemical fertilizer use. Meanwhile, the organic matter content improves the cation exchange capacity of soils, which plays an important role in supplying the plants with the nutrients. Plants are also expected to have a better growth when roots are taking up dissolved nutrients that are excreted directly by fish or generated from the microbial breakdown of fish wastes. (Elnwishy *et al*., 2006).

One can design a field experiment to test a number of treatments. However, that number will be limited by labour and equipment cost. Tested and verified models can be useful in that respect. Once validated against such limited number of treatments, the models can run with 'what if' scenarios depicting the other possible untried treatments in the field and finally select the optimum treatment based on the limited field treatments and the simulated treatments. Therefore, validated models that are able to predict crop growth under different water qualities, irrigation managements and strategies can be very useful tools to improve water use efficiency and productivity without the need for extensive field trials.

The extension services and farmers need models to help them to decide on crop/variety selection, irrigation scheduling (when and how much to irrigate) and the expected yield under a specific irrigation system or strategy when using a certain water quality. This need can only be met with an integrated modelling approach that accounts for water, crop, climate, soil and field management and includes different crops. The SALTMED model (Ragab, 2015) is one of the models that has been developed for such generic applications and has proved its ability to simulate several crops under different field managements. SALTMED model has been developed to account for different irrigation systems, irrigation strategies, different water qualities, different crops and soil types, N-fertilizer applications, fertigation, impact of abiotic stresses such as salinity, temperature, drought and the presence of shallow groundwater and a drainage system.

The current version 2015 would allow real-time simultaneous simulation of 20 fields each of which would have different irrigation systems, irrigation strategies, crops, soils and N-fertilizers. The model simulates the dry matter production, crop yield, soil salinity and soil moisture profiles, salinity leaching requirements, soil nitrogen dynamics, nitrate leaching, soil temperature, water uptake, evapotranspiration, groundwater level and its salinity, and drainage flow. The model has been calibrated and validated with field data by Ragab *et al*. (2005a, b), Golabi *et al*. (2009), Montenegro *et al*. (2010), Hirich *et al*. (2012, 2016), Pulvento *et al*. (2013), Silva *et al*. (2013), Pulvento *et al*. (2015), Ragab *et al*. (2015), Fghire *et al*. (2015) Aly *et al*. (2015), Rameshwaren *et al*. (2015, 2016 a, b), Kaya and Yazar (2016), Arslan *et al*. (2016) and El Shafie *et al*. (2016) and proved its reliability and ability to predict the field measured yield, dry matter, soil moisture and salinity.

The objective of this study was to investigate the suitability and benefit of using drainage water of fish farms (DWFF) in contrast to the commonly used fresh irrigation water (IW) for wheat production under the semiarid conditions of Egypt through a field and modelling study using SALTMED model.

MATERIALS AND METHODS

Location and climate of experimental site

Field experiments were conducted during 2014 and 2015 at the research farm of National Research Center (NRC) (latitude 30° 30' 1.4'' N, longitude 30° 19' 10.9'' E, and 21 m+MSL (mean sea level) at Nubaryia Region, Al Buhayrah Governorate, Egypt. The experimental area has an arid climate with cool winters and hot dry summers. The data of maximum and minimum temperature, relative humidity and wind speed were obtained from the local weather Station at El-Nubaryia Farm, as shown in Figure 1.

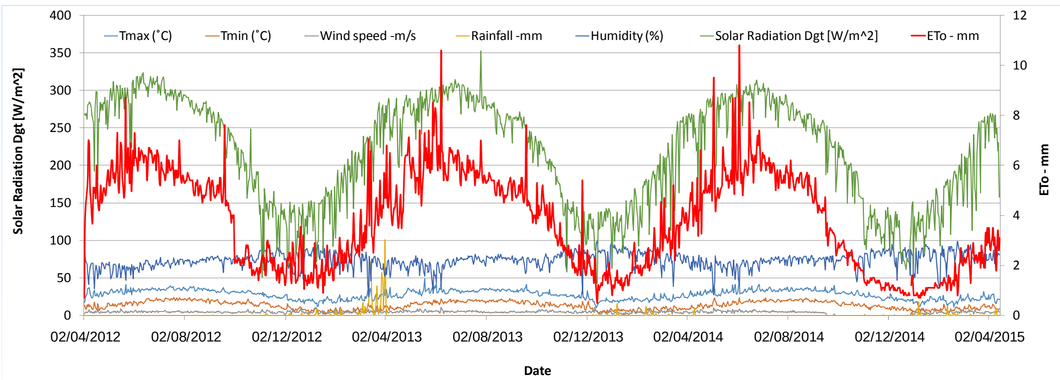


Figure 1. Meteorological data in the research farm of the National Research Center (NRC) in Nubaryia during wheat growth seasons 2014 and 2015.

Physical and chemical properties of soil, drainage water of fish farms and irrigation water

Irrigation water was obtained from an irrigation channel passing through the experimental area. The irrigation water had a pH of 7.35 and an electrical conductivity (EC) of 0.41 dS m^{-1}. The main physical and chemical properties of soil were determined in situ and in the laboratory at the beginning of the field trial (Table I). The main physical, chemical and biological properties of drainage water of fish farms and irrigation water are reported in Table II.

Table I. Main physical and chemical characteristics of the soil of the experimental area.

Soil characteristics	Soil layer (cm)				
	0–20	20-40	40-60	60-80	80-120
Physical parameters					
Texture	Sandy	Sandy	Sandy	Sandy	Sandy
Course sand (%)	47.76	56.72	36.76	35.77	33.34
Fine sand (%)	49.75	39.56	59.40	60.11	62.34
Silt + clay (%)	2.49	3.72	3.84	4.12	4.32
Bulk density (t m^{-3})	1.69	1.68	1.67	1.69	1.65
Chemical parameters					
EC (dS m^{-1})	0.35	0.32	0.44	0.45	0.53
pH (1:2.5)	8.7	8.8	9.3	9.0	9.2
Total $CaCO_3$ (%)	7.02	2.34	4.68	5.01	5.2
Organic matter (%)	0.65	0.40	0.25	0.24	0.21

Table II. Main characteristics of DWFF and IW of the experimental area.

Parameter	Drainage water fish farm	Irrigation canal water (IW)
Electric Conductivity, dS m^{-1}	1.82	0.41
pH	7.05	7.35

Chemical characteristics, concentrations in mg l^{-1}		
Calcium, Ca^{2+}	1.30	1.00
Magnesium, Mg^{2+}	0.70	0.50
Sodium, Na^{2+}	2.50	2.40
Potassium, K^{+}	0.50	0.20
Carbonate, CO_3^{2-}	0.10	< 0.01
Bicarbonate, HCO_3^{-}	0.40	0.10
Chloride, Cl^{-}	3.10	2.70
Sulphate, SO_4^{2-}	1.40	1.30
Nitrogen, N (NH_4^{+}+NO_3^{-})	4.79	< 0.01
Phosphorus, P(PO_4^{3-})	10.2	0.20
Copper, Cu^{++}	0.03	0.02
Nickel, Ni^{++}	0.01	0.01
Zinc, Zn^{++}	1.10	1.00
Biological characteristics, counts as CFU (colony forming units) ml^{-1}		
Total bacteria	1.5 10^4	0.25 10^4
Total faecal coliforms	3.0 10^3	1.8 10^3
Total fungi	500	90
Total free N_2 fixers	600	50
Green algae		
Chlorella sp.	400	85
Scenedesmus sp.	150	10
Pediastrum sp.	120	15
Cyanobacteria		
Oscillatoria sp.	100	10
Nostoc sp.	50	< 1

Experimental design

The planting and harvesting dates for wheat were 15th of November and 15th of April for both seasons 2014 and 2015, respectively. The growth period for wheat was 152 days. The experimental design included eight different treatments of water quality and fertigation rate of nitrogen. Two water qualities, drainage water of fish farms (DWFF) and fresh irrigation water (IW), combined with four rates for chemical nitrogen fertilizing [100% N, 80% N, 60% N and 40% N]. For the 100% chemical nitrogen fertilizer treatment nitrogen was applied at the rate of 192 kg N ha^{-1} $season^{-1}$ (Table III) in the form of ammonium nitrate (33.5% N). The total number of plots was 24 and each plot area was 720 m^2. The 24 plots were divided into three replicates of 8 plots each. The statistical design of this experiment was split design. The soil moisture profile probe access tubes were placed in each plot to measure the soil moisture (Figure 2). Table II shows that the DWFF is richer in nitrogen, phosphorus, and potassium, three elements that are macro nutrients to the plants. The DWFF is also richer in micronutrients like Cu, Ni, Zn. In addition, the DWFF water has more microorganisms and organic matter than the IW water. Overall, the DWFF water looks richer in terms of nutrients and biological activity than the fresh irrigation water, IW.

Irrigation requirements for wheat

Daily irrigation water was calculated using Penman Monteith equation and crop coefficient according to Allen *et al*. (1989). The amount of irrigation water applied was 3220 and 2710 m^3 ha^{-1} $season^{-1}$ for 2014 and 2015, respectively. Sprinkler irrigation system has been used. Total water volumes and amount of applied nitrogen for each treatment are shown in Table III.

Table III. Total water volumes and amount of applied nitrogen for each treatment.

Irrigation treatment	Water received by crop, m^3 ha^{-1}			Nitrogen received by the crop, kg N ha^{-1}		
	Irrigation	Rain	Total	Biological	Chemical	Total
			2014			
DWFF,	3220	770	3990	15	192	207
DWFF, 80%N	3220	770	3990	15	154	169
DWFF, 60%N	3220	770	3990	15	115	130
DWFF, 40%N	3220	770	3990	15	77	92
IW, 100%N	3220	770	3990	0	192	192
IW, 80%N	3220	770	3990	0	154	154
IW,60%N	3220	770	3990	0	115	115
IW, 40%N	3220	770	3990	0	77	77
			2015			
DWFF,	2710	790	3500	13	192	205
DWFF, 80%N	2710	790	3500	13	154	167
DWFF, 60%N	2710	790	3500	13	115	128
DWFF, 40%N	2710	790	3500	13	77	90
IW, 100%N	2710	790	3500	0	192	192
IW, 80%N	2710	790	3500	0	154	154
IW,60%N	2710	790	3500	0	115	115
IW, 40%N	2710	790	3500	0	77	77

DWFF: Drainage water of fish farms, IW: fresh irrigation water N: Nitrogen element, Biological: Biological dissolved nitrogen in drainage water of fish farms

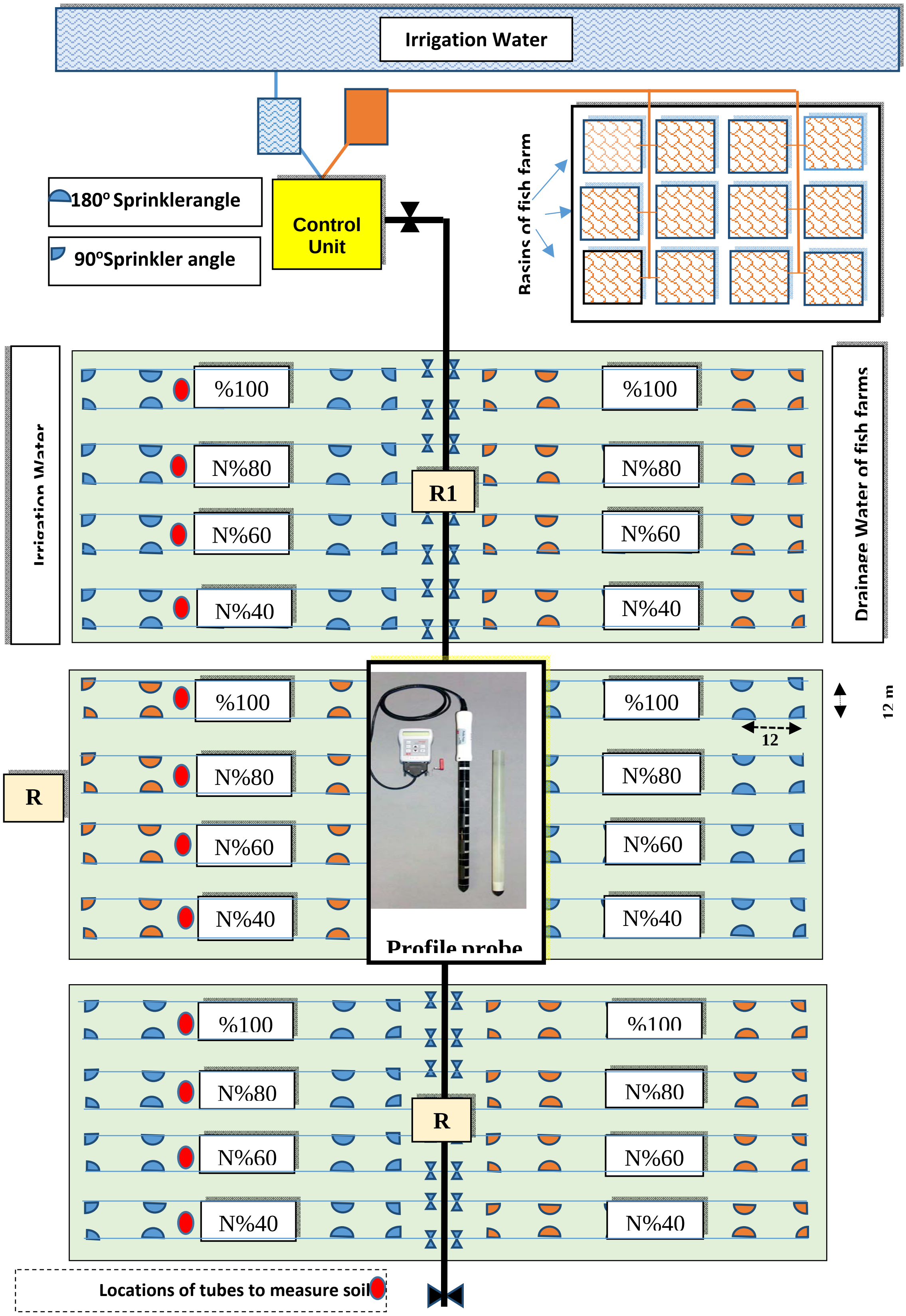


Figure 2. Layout of the experimental design

Acquiring the model parameters

All the samples required for the model calibration and validation were taken during each growing phase. The soil moisture was measured using the profile probes at four depths 0 - 20, 20 – 40, 40 – 60 and 60 – 80 cm depth. All the required climatic variables data were collected on site from the available weather station. Climate data required as input to the model consisted of precipitation, maximum temperature and minimum temperature, the relative humidity, wind speed, and net and total radiation. In addition, dry matter and total leaf area, required to calculate the Leaf Area Index (LAI), were obtained at regular intervals. At harvest, a random sample was taken from each plot to determine grain yield. Other plant parameters, such as plant height, root depth, length of each growth stage and harvest index, were also based on field measurements. Water productivity of wheat was calculated according to James (1988) as follows:

$$\text{WP wheat} = (\text{Ey}/\text{Ir}) \times 100 \quad (1)$$

Where: WP wheat is the water productivity of wheat (kg wheat m^{-3} water), Ey is the economical yield (kg grains ha^{-1}) and Ir is the amount of applied irrigation water (m^3 $ha^{-1}$$season^{-1}$).

SALTMED MODEL

The new version of SALTMED (Ragab, 2015) which accounts for surface and subsurface irrigation, partial root drying (PRD) or deficit irrigation, fertigation, soil nitrogen fertilizer application and plant nitrogen uptake, biomass and dry matter production and nitrate leaching was used in this study. A detailed description of the SALTMED model is provided in Ragab (2015).The SALTMED model is a free download from the Water4Crops EU funded project web site: http://www.water4crops.org/saltmed-2015-integrated-management-tool-water-crop-soil-n-fertilizers/, and from the International Commission on Irrigation and Drainage, ICID, web site: http://www.icid.org/res_tools.html#saltmed_2015

Model calibration

During the calibration, fine tuning of the relevant SALTMED model parameters was carried out against the observed data of the soil moisture, dry matter, and crop yield. For the calibration, DWFF +100%N was selected. Different soil parameters such as soil hydraulic properties including bubbling pressure, saturated hydraulic conductivity, saturated soil water content and pore distribution index, 'lambda', were fine-tuned until close matching between the simulated and observed soil moisture values was achieved. In addition to the soil parameters, other crop parameters such as the crop coefficient, Kc, that is used to predict crop evapotranspiration (ETc), and basal crop coefficient, Kcb, that represents the crop transpiration part of the Kc, were also slightly tuned to find the best fit for each soil layer (Tables IV and V). After achieving a good fit for the soil moisture, only fine tuning of photosynthetic efficiency was needed for dry matter and crop yield.

The goodness of fit expressions used were the root mean square error (RMSE), the coefficient of determination (R^2), and the coefficient of residual mass (CRM). The RMSE values, calculated using Equation 2, indicate by how much the simulations under or overestimate the measurements.

$$RMSE = \sqrt{\frac{\Sigma\left(y_o - y_s\right)^2}{N}} \qquad (2)$$

Where: $\boldsymbol{y_o}$ = predicted value, $\boldsymbol{y_s}$ = observed value, $\boldsymbol{N}$ = total number of observations.

The R^2 statistics demonstrate (Equation 3) the ratio between the scatter of simulated values to the average value of measurements:

$$R^2 = \left\{\frac{1}{N}\frac{\Sigma\,(y_o - \bar{y_o})(y_s - \bar{y_s})}{\sigma y_o - \sigma y_s}\right\} \qquad (3)$$

Where: $\bar{y_o}$ = averaged observed value, $\bar{y_s}$ = averaged simulated value, σy_o = observed data standard deviation, σy_s = simulated data standard deviation.

The coefficient of residual mass (CRM) is defined by Equation 4:

$$CRM = \frac{(\Sigma\, y_o - \Sigma\, y_s)}{\Sigma\, y_o} \qquad (4)$$

The CRM is a measure of the tendency of the model to over- or underestimate the measurements. Negative values for CRM indicate that the model underestimates the measurements and positive values for CRM indicate a tendency to overestimate. For a perfect fit between observed and simulated data, values of RMSE, CRM and R^2 should equal 0.0, 0.0 and

1.0, respectively.

Table IV. Main calibrated and observed input parameters used in the study for DWFF,100% N, wheat, 2014, Egypt

Parameter	Growth Stage	Observed	Calibrated
Cultivation dates			
Sowing date		15 November	
Harvest (day after sowing)		152	
Growth stages duration (days)			
	Initial	29	
	Development	35	
	Middle	50	
	Late	37	
Crop inputs			
Crop coefficient, Kc	Initial		0.70
	Middle		1.15
	End		0.45
Transpiration crop coefficient, Kcb	Initial		0.60
	Middle		0.80
	End		0.40
Fraction cover, Fc	Initial	0.40	
	Middle	1.00	
	End	1.00	
Plant height, h (m)	Initial	0.40	
	Middle	0.80	
	End	0.70	
Leaf area index, LAI	Initial	0.60	
	Middle	3.50	
	End	3.00	
Minimum root depth (m)		0.00	
Maximum root depth (m)		1.00	
Unstressed crop yield (t h^{-1})		4.43	
Photosynthesis efficiency (g MJ^{-1})			2.50
Water uptake threshold	Initial		0.90
	Middle		0. 50
	End		0.75
Harvest index		0.48	

Table V. Main calibrated and observed input parameters used in the study for sandy soil

Parameter	Observed	Calibrated
Saturated moisture content (m^3m^{-3})	0.25	
Field capacity (m^3 m^{-3})	0.15	
Wilting point (m^3 m^{-3})	0.04	
Lambda pore size		0.20
Residual water content (m^3 m^{-3})		0.00
Root width factor	0.30	
Saturated hydraulic conductivity (mm day^{-1})	2900	
Max. depth for evaporation (mm)		50.00
Bubbling pressure (cm)		10.00

RESULTS AND DISCUSSION

Soil moisture

Initially the soil moisture was calibrated with DWFF, 100% N and validated against all the other treatments for two seasons 2014 and 2015. The model calibration simulated the soil moisture for all layers (0-20, 20-40, 40-60 and 60-80 cm depth) as shown in Figure 3 for 2014 season and was validated for 2015 season (Figure 4). The soil moisture of DWFF, 100% N treatment was only shown here, as other treatments received the same amount of water and showed similar results. Overall the model was able to simulate reasonably well the observed data both during the calibration and validation processes. These results are consistent with those obtained by Hirich *et al*. (2012), Silva *et al*. (2013), Pulvento *et al*. (2013), Pulvento *et al*. (2015), Ragab *et al*. (2015), Fghire *et al*. (2015) and Rameshwaren *et al*. (2015).

The model showed slightly higher values for the R^2 during 2014 for the top layer (0-20 cm) and bottom layer (60-80 cm) in comparison to the middle layers under most of treatments (Table VI). In general, the treatments with DWFF showed similar results to the IW. Good correlation between the simulated and observations were obtained for the 2015 season (not shown here). For 2015, the model showed slightly lower values for the R^2 for the top layer (0.83 to 0.87 for 0-20 cm) in comparison to the subsurface layers and R^2 was increased by increasing the soil depth under all treatments (e.g. R^2 ranged from 0.92 to 0.96 for 60-80 cm layer). However, in general, the SALTMED model proved its high sensitivity to simulate the soil moisture changes caused by irrigation events. Overall the simulated and the observed soil moistures for all treatments combined showed a strong correlation for two seasons 2014 and 2015. The implication of good soil moisture prediction is that there is a good chance to also simulate reasonably well those elements, like nitrogen, that simultaneously move with water.

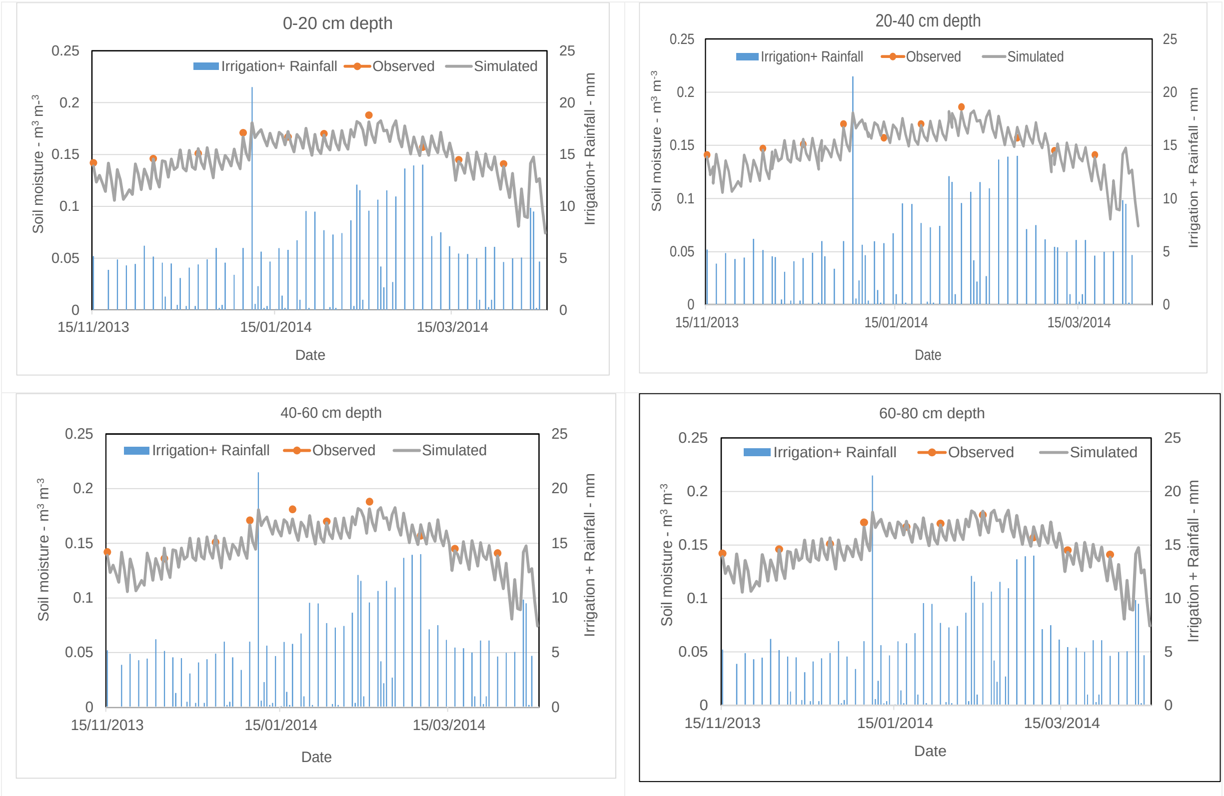


Figure 3. Observed and simulated soil moisture for 0-80 cm depth under DWFF, 100% N (Calibration treatment), 2014

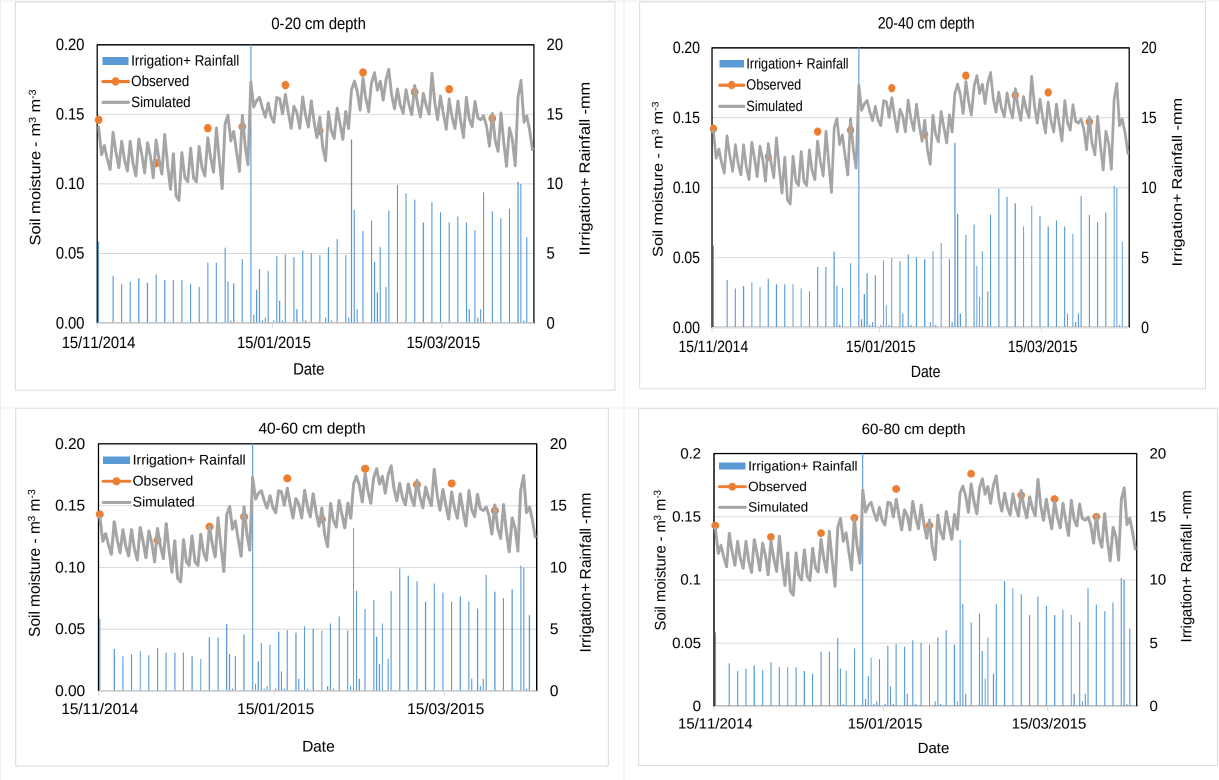


Figure 4. Observed and simulated soil moisture for 0-80 cm depth under DWFF, 100%N, (Selected example from validation treatments), 2015

Table VI. Coefficient of determination, RMSE and CRM for soil moisture in the layers from 0-80 cm, 2014

Soil layer, cm	Correlation parameter	Treatment							
		DWFF				IW			
		100%N	80%N	60%N	40%N	100%N	80%N	60%N	40%N
0-20	R^2	0.89	0.87	0.88	0.88	0.84	0.90	0.89	0.90
	RMSE	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	RCM	0.000	0.004	0.00	0.004	0.000	0.005	0.000	0.000
20-40	R^2	0.82	0.80	0.85	0.84	0.82	0.80	0.83	0.98
	RMSE	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.005
	RCM	-0.009	-0.006	-0.007	-0.003	-0.010	-0.016	-0.012	-0.008
40-60	R^2	0.88	0.87	0.85	0.87	0.88	0.86	0.88	0.89
	RMSE	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
	RCM	0.000	0.003	0.000	0.003	-0.002	0.005	0.003	-0.001
60-80	R^2	0.91	0.91	0.91	0.90	0.90	0.92	0.91	0.91
	RMSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	RCM	-0.010	-0.007	-0.003	-0.006	-0.007	-0.011	-0.002	0.001
0-80	R^2	0.86							
	RMSE	0.005							
	RCM	-0.002							

DWFF: Drainage water of fish farms, IW: fresh water irrigation N-level: fertigation nitrogen level, RMSE: Root Mean Square Error, CRM: Coefficient of Residual Mass, R^2: Coefficient of determination/correlation coefficient

Simulated nitrogen dynamics

The nitrogen dynamic was also simulated for all treatments 100%N, 80%N, 60%N and 40%N for both treatments, DWFF and IW. There was no calibration made against observed nitrogen values. Given the dissolved nitrogen added in fertigation is expected to simultaneously move with water within the soil, it has been assumed that, the successful validation of soil moisture would likely lead to good simulated soil nitrogen concentrations. The model results showed that, the nitrogen concentration of soil layers from 0 - 80 cm for two seasons 2014, 2015 increased by increasing fertigation rate and there was significant impact on nitrogen concentration in soil layers (Figure 5). Nitrogen concentration in soil layers from 0 - 80 cm for season 2014 was lower than nitrogen concentration for the 2015 season. This is mainly due to the larger total water volume (3990 m^3 ha^{-1} $season^{-1}$) in 2014 compared with 2015 (3500 m^3 ha^{-1} $season^{-1}$) in the fertigation period from 20 November to 29 December perhaps resulting in an larger amount of nitrogen leaching out of the root zone in 2014 (Figure 6). Total N-Uptake was also simulated for all treatments. Although, nitrogen concentration in the soil layers of the 2015 season was higher than in 2014, the total N-Uptake was lower in 2015 than 2014, as shown in (Figure 7). This is possibly due to increasing the soil salinity in season 2015 than 2014, especially in the initial stage when plants are usually more sensitive to salinity. The nitrogen uptake of the plant decreased with increasing salinity (van Hoorn *et al*., 2001) as shown in Figures 8 for DWFF treatment. Another cause could be that the increased solubility of nitrogen due to the relatively large irrigation volume added in 2014 led to better N uptake in 2014 than 2015. The total N-Uptake has been improved under DWFF when compared with IW in both seasons 2014 and 2015. This may be due to the additional amount of biological nitrogen and other nutrients that was inherent in fish farm drainage water DWFF with estimated additional nitrogen to be 15 kg N ha^{-1} in 2014 and 13 kg N ha^{-1} in 2015 than IW which lacked such extra biological nitrogen presence and other nutrients as well.

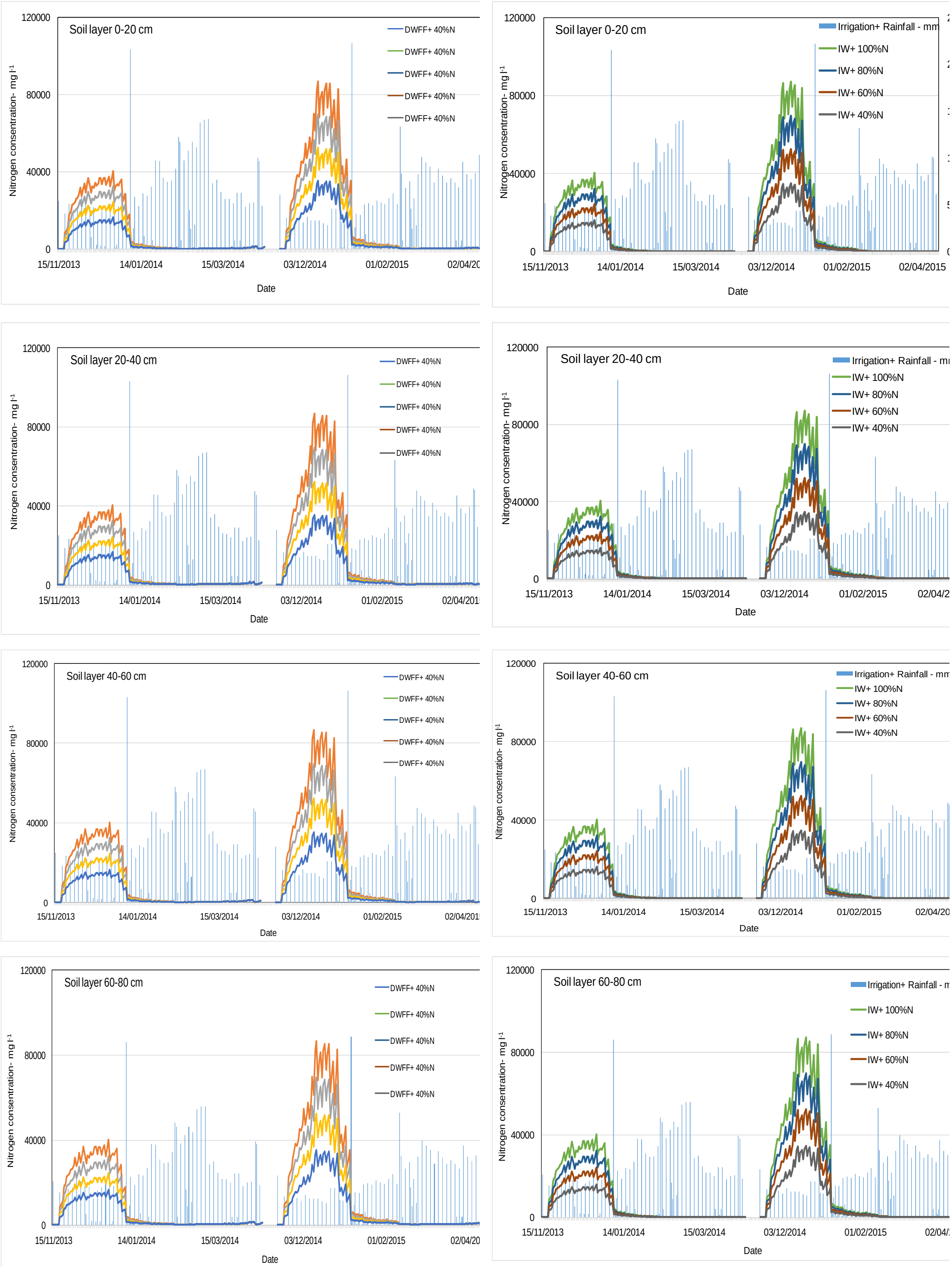


Figure 5. Simulated effect of fertigation rate on nitrogen concentration in soil layer 0- 80 cm for two seasons 2014 and 2015

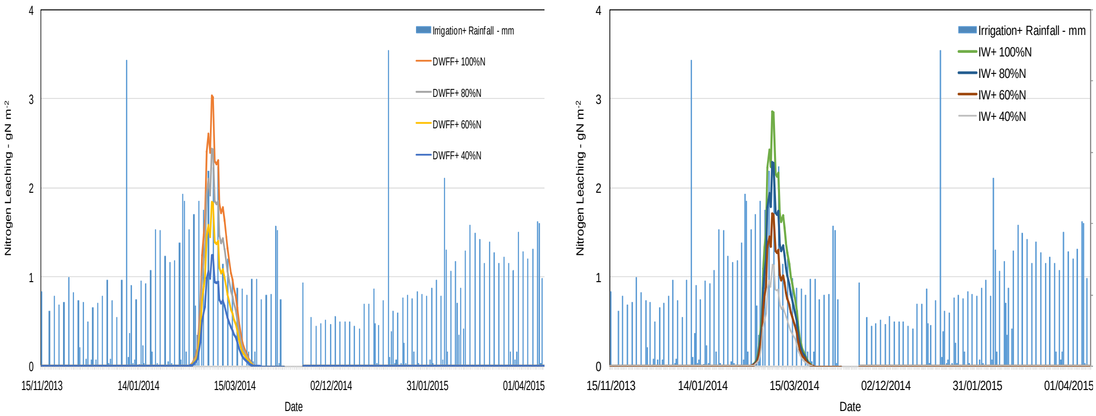


Figure 6. Simulated effect of fertigation rate on nitrogen leaching out of the root zone

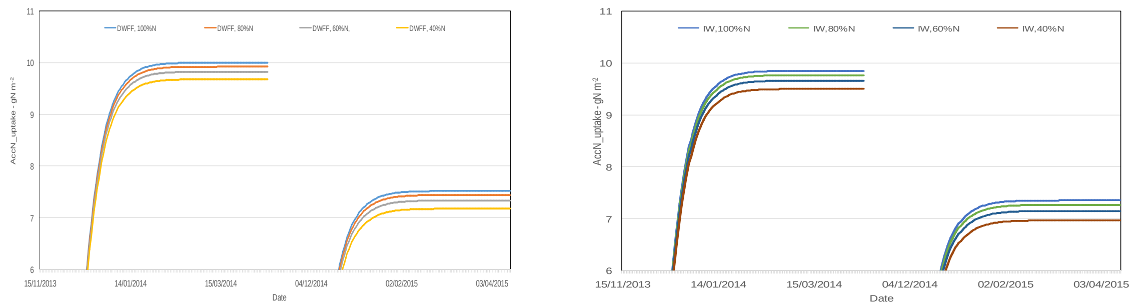


Figure 7. Effect of fertigation rate on accumulated N-Uptake for all treatments during 2014 and 2015

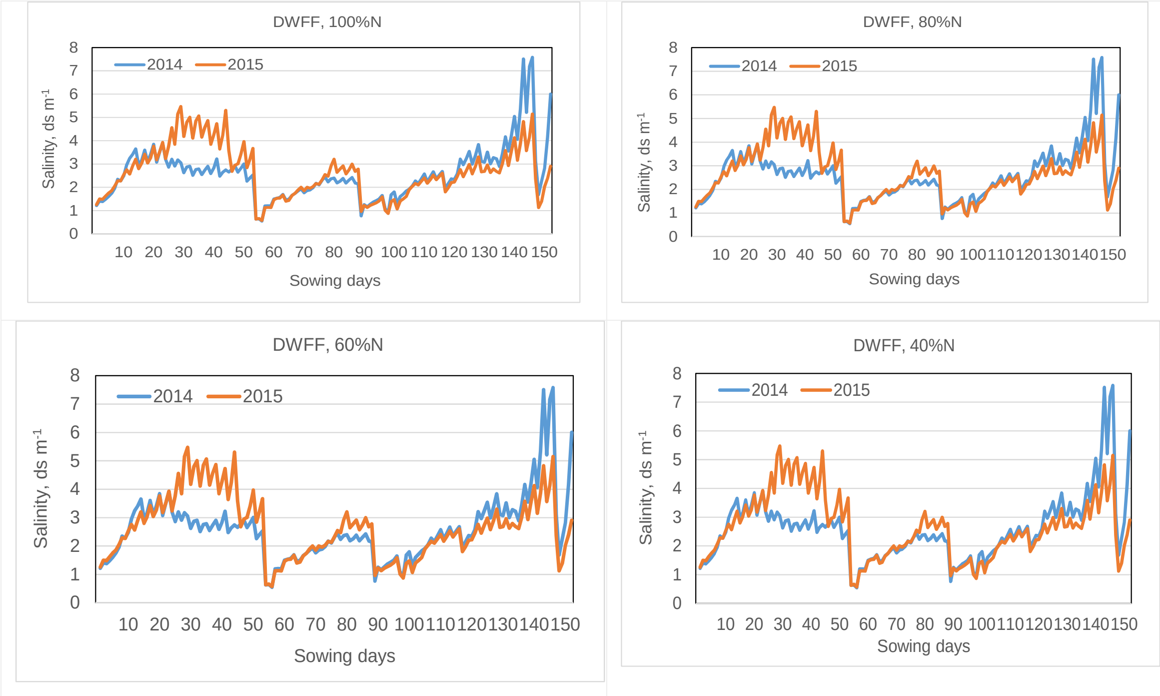
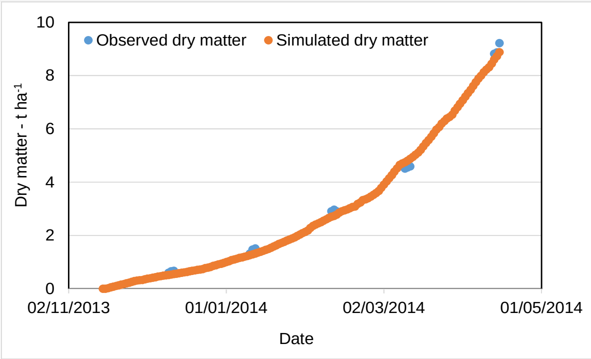


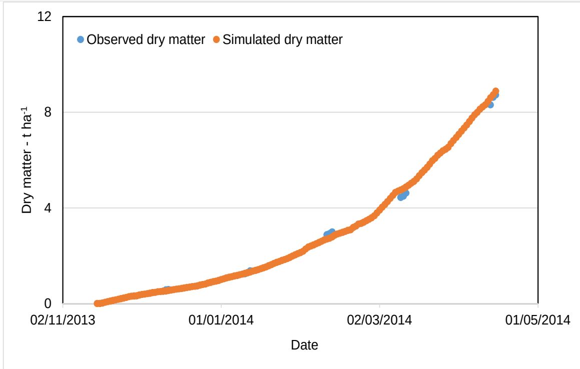
Figure 8. Simulated soil salinity for DWFF for two seasons 2014 and 2015

Dry matter

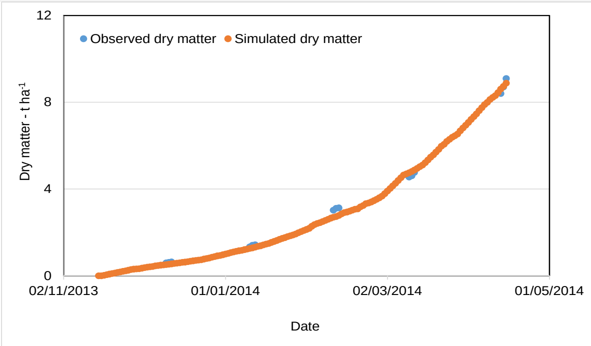
The time series of observed and simulated dry matter under different treatments for the wheat crop were simulated, 100% N and 40%N treatments (highest and lowest N input treatments) are shown as examples in Figures 9 and 10 for 2014 and 2015, respectively. There were no significant differences between dry matter values under all treatments during the two seasons, 2014 and 2015, but there were significant differences between harvest index values under all treatments during the two seasons 2014 and 2015 (Table VII). The observed and the simulated dry matters were in good agreement at all stages for all treatments. The correlation analysis between the observed and the simulated dry matter shows that the model was able to simulate the total dry matter with R^2 of 0.99 for all treatments during the two seasons 2014 and 2015.



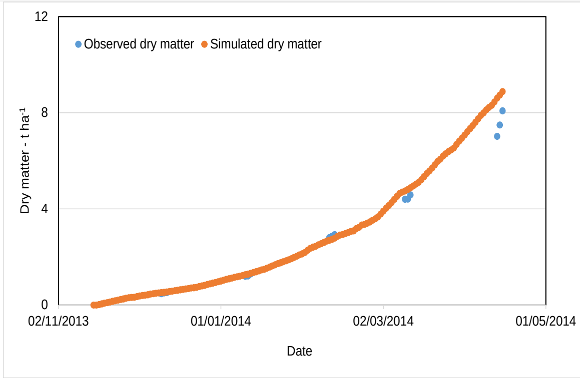
DWFF, 100% N



DWFF, 40% N

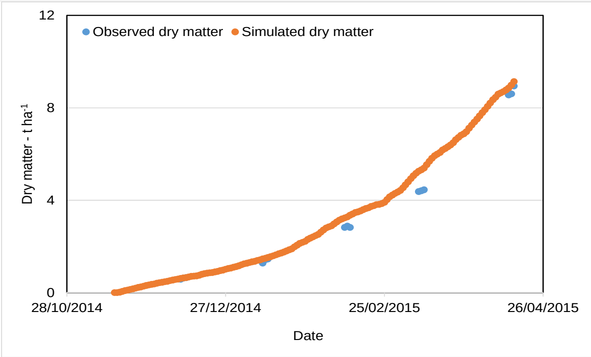


IW, 100% N

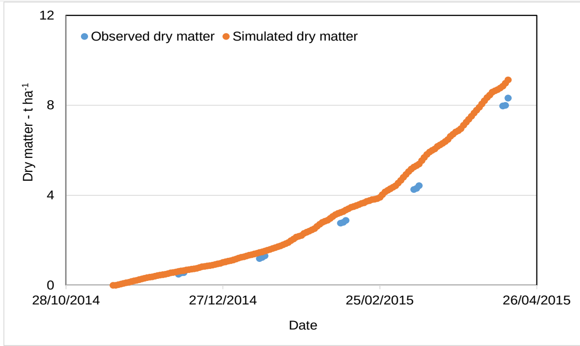


IW, 40% N

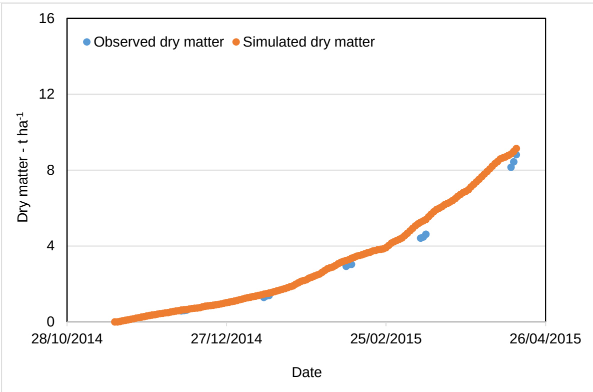
Figure 9. Observed and simulated dry matter for different treatments, 2014



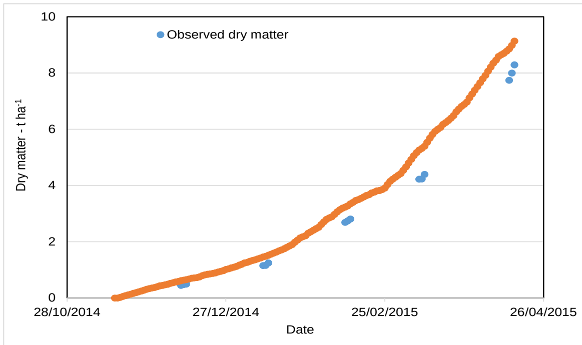
DWFF, 100% N



DWFF, 40% N



IW, 100%N



IW, 40%N

Figure 10. Observed versus simulated dry matter for different treatments, 2015

Crop yield

Table VII and Figure 11 show the impact of fertigation rates under DWFF and IW on the crop yield of wheat during 2014 and 2015. There was a positive impact on the yield by increasing of fertigation rate under DWFF treatments and IW treatments in both seasons 2014 and 2015. The yield under DWFF treatments was higher than the yield under IW treatments. The experimental results indicated that there was a positive impact from increasing the N-fertigation rate on the yield using both DWFF and IW in both seasons. However, the yield under DWFF was (between 11 and 51% in 2014 and between 8 and 38% in 2015) higher than the yield under the IW treatment. The biggest difference was associated with the lowest Nitrogen treatment. This is possibly due to the additional amount of dissolved biological nitrogen and other nutrients inherent in DWFF. It is worth noting here that there is an additional amount of dissolved nitrogen inherent in DWFF (15 kg N ha^{-1} in 2014 and 13 kg N ha^{-1} in 2015) in addition to more phosphorus, potassium (two macro nutrients for crops). These results are in agreement with other reports that suggest that integrated rice-fish farming is ecologically sound because fish improve soil fertility by increasing the availability of nitrogen and phosphorus (Giap *et al.*, 2005; Dugan *et al.*, 2006). In general, crop yield as well as the total N uptake increased by increasing the fertigation rate. The statistical analysis indicated that there were significant differences between crop yield values under all treatments during the two seasons 2014 and 2015. The yield was found to be decreasing in the following descending order for seasons 2014 and 2015: DWFF 100% N > DWFF 80% N > IW 100% N > IW 80% N > DWFF 60% N > DWFF 40% N > IW 60% N > IW 40% N.

Figure 12 shows good correlation between observed and the simulated crop yield for all treatments during the two seasons with R^2 of 0.97 for all treatments.

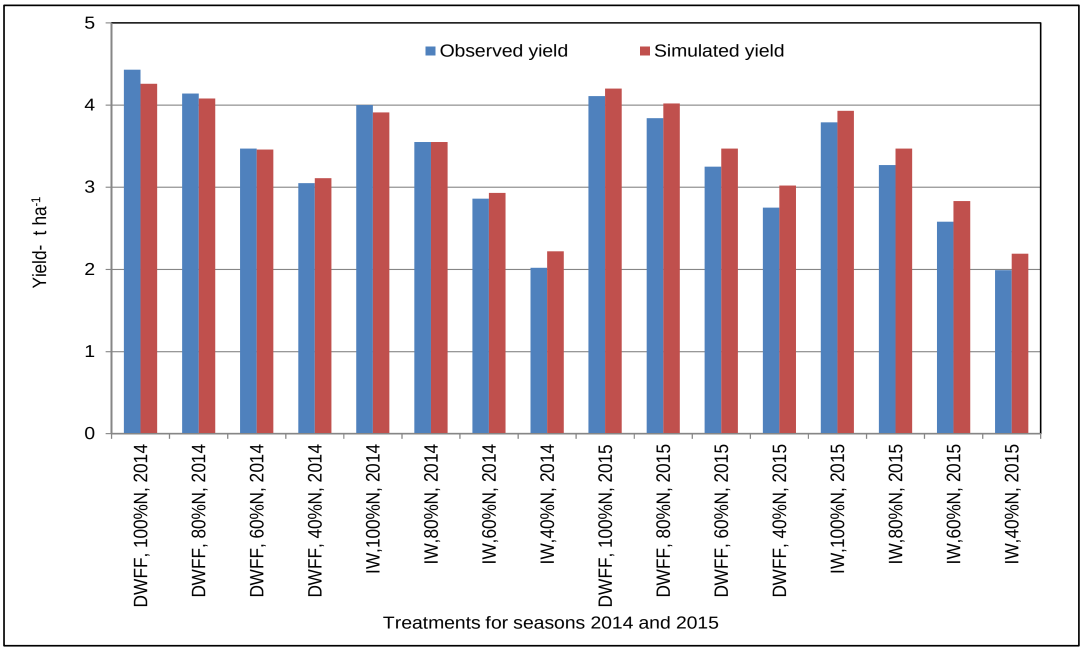


Figure 11. Observed and simulated yield for all treatments for seasons 2014 and 2015

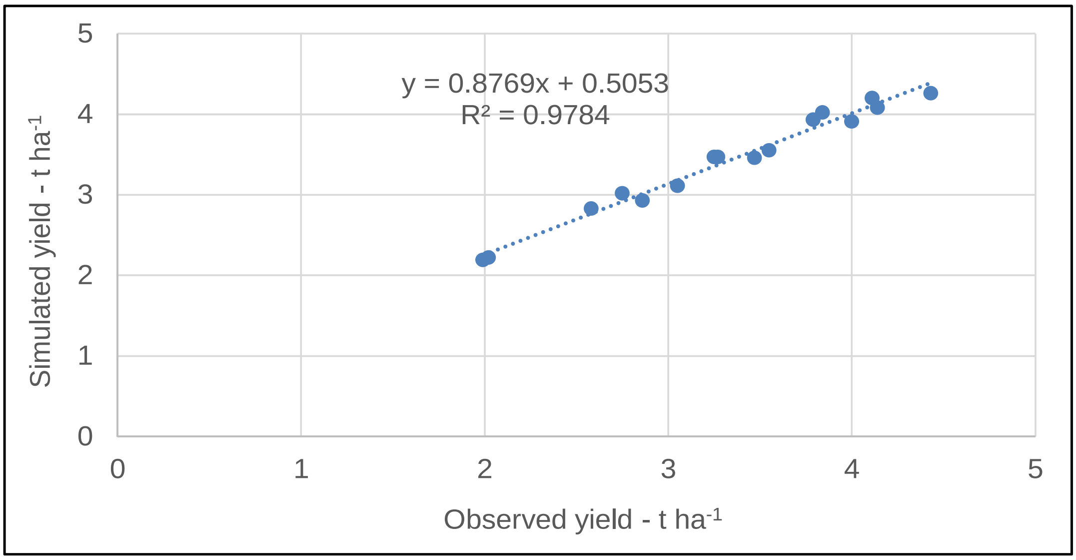


Figure 12. Observed versus simulated yield for all treatments for seasons 2014 and 2015

Water productivity

The water productivity was calculated as the amount of grain yield produced in kg per cubic meter of irrigation water applied. Total water volume (Irrigation and Rainfall) was 3990 m^3 for 2014 and 3500 m^3 for 2015. Although the yield of 2014 was greater than that of 2015, the water productivity of 2015 was higher than that of 2014. This is mainly due to the larger total irrigation water volume in 2014 than 2015 (Figure 13).

The correlation analysis between the observed and the simulated water productivity showed a good agreement with R^2 of 0.96 for all treatments during the two seasons (Figure 14).

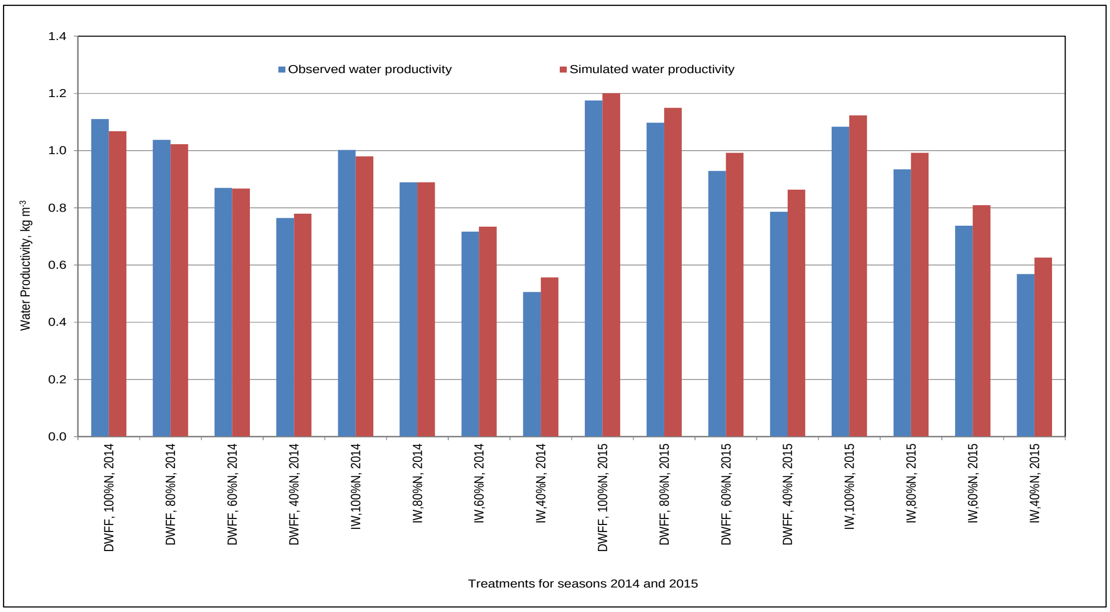


Figure 13. Observed and simulated water productivity for all treatments for seasons 2014 and 2015

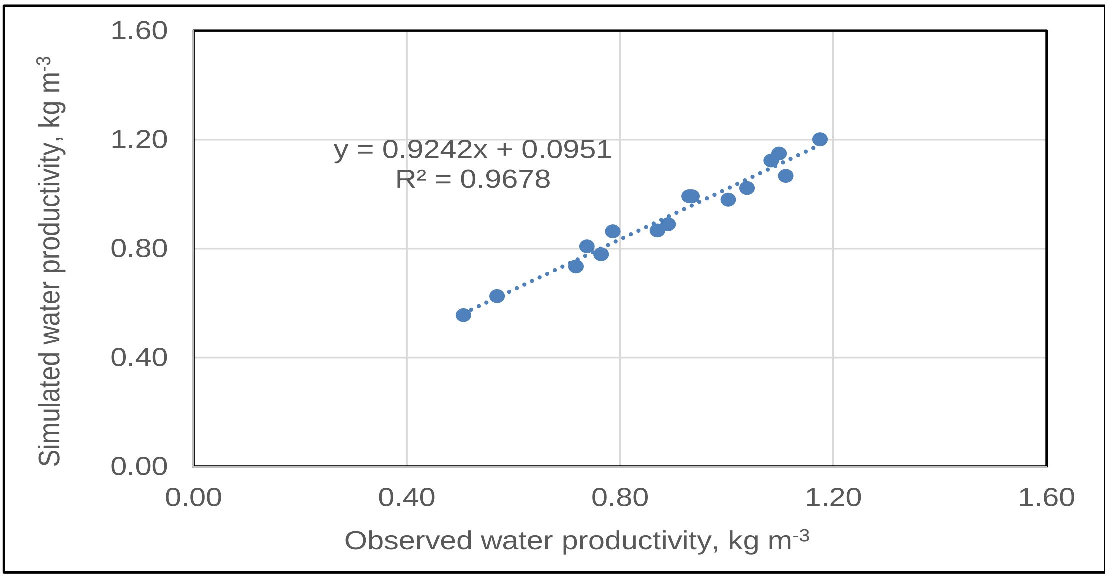


Figure 14. Observed versus simulated water productivity for all treatments for seasons 2014 and 2015

Table VII. Impact of water quality and fertigation rate of nitrogen on Harvest Index, yield and water productivity of wheat during 2014 and 2015

Season	Irrigation treatment	N-Application	HI	Observed yield, t ha^{-1}	Simulated yield, t ha^{-1}	% Relative error	Irrigation + rainfall, m^3	Observed water productivity, kg m^{-3}	Simulated water productivity, kg m^{-3}	%Observed yield Difference (DWFF-IW)/IW
2014	DWFF	100% N	0.48	4.43 a	4.26	3.84	3990	1.11	1.07	10.8
		80% N	0.46	4.14 b	4.08	1.45	3990	1.04	1.02	16.6
		60% N	0.39	3.47 e	3.46	0.29	3990	0.87	0.87	21.3
		40% N	0.35	3.05 f	3.11	-1.97	3990	0.76	0.78	51.0
	IW	100% N	0.44	4.00 c	3.91	2.25	3990	1.00	0.98	
		80% N	0.40	3.55 d	3.55	0.00	3990	0.89	0.89	
		60% N	0.33	2.86 g	2.93	-2.45	3990	0.72	0.73	
		40% N	0.25	2.02 h	2.22	-9.9	3990	0.51	0.56	
		LSD at 5%		0.02						
2015	DWFF	100% N	0.46	4.11a	4.2	-2.199	3500	1.18	1.20	8.4
		80% N	0.44	3.84 b	4.02	-4.69	3500	1.10	1.15	17.4
		60% N	0.38	3.25 d	3.47	-6.77	3500	0.93	0.99	26.0
		40% N	0.33	2.75 e	3.02	-9.82	3500	0.79	0.86	38.2
	IW	100% N	0.43	3.79 c	3.93	-3.69	3500	1.08	1.12	
		80% N	0.38	3.27 d	3.47	-6.12	3500	0.94	0.99	
		60% N	0.31	2.58 f	2.83	-9.69	3500	0.74	0.81	
		40% N	0.24	1.99 g	2.19	-10.05	3500	0.57	0.63	
		LSD at 5%		0.03						

N-Application: Fertigation Rates for Nitrogen, HI: Harvest Index, DWFF: Drainage water of fish farms, IW: Fresh water Irrigation. Means followed by the same letter in a column are not statistically different, means with different letters under the columns yield are statistically different at 5% level of significance

CONCLUSION

This study investigated the suitability and benefit of using drainage water of fish farms (DWFF) in contrast to the commonly used fresh irrigation water (IW) for wheat production through a field and modelling study using SALTMED model.

Although, there were no significant differences between dry matter values under all treatments during both the 2014 and 2015 seasons, there were significant differences between harvest index values under all treatments during the two seasons and that led to the differences in yields.

The experimental results indicated that there was a positive impact from increasing the N-fertigation rate on the yield using both DWFF and IW in both seasons. However, the yield under DWFF was (between 11% and 51% in 2014 and between 8% and 38% in 2015) higher than the yield under the IW treatment. The biggest difference was associated with the lowest Nitrogen treatment.

The modelling results indicated that the total N-Uptake improved under DWFF when compared with IW. Similarly, the yield under DWFF treatments was higher than the yield under IW treatments. This is possibly due to the additional inherent amount of biological nitrogen that was present in DWFF (15 kg N ha^{-1} in 2014 and 13 kg N ha^{-1} in 2015) as well other nutrients when compared with IW.

The model simulated quite well the soil moisture, nitrogen dynamics, wheat dry matter, yield and water productivity for all treatments for two seasons, 2014 and 2015. Although the yield of 2014 was greater than that of 2015, the water productivity of the 2015 season was higher than that of 2014. This is mainly due to larger total irrigation water volume applied in 2014 compared with 2015.

In summary, the field and modelling results, indicated that the use of drainage water of fish farms has some benefits that include a higher yield as well as reduced use of chemical fertilizers. These additional benefits mean more income to farmers, less pollution to the environment and a reduction in drainage water volume that needs to be disposed of to the local drainage networks. Therefore, this study recommends the use of the drainage water of fish farming for irrigation as a good alternative or a supplement to the limited fresh water resource.

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