EVALUATION OF WATER-ENERGY-FOOD LINKAGES BASED ON THE GREENHOUSE TEMPERATURE MODEL AND ANN

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ABSTRACT

To feed 9 billion people in 2050 (DESA, 2017), the most crucial task in agriculture is achieving higher crop productivity. WEF (Water-Energy-Food) Nexus was first introduced in World Forum 2011 to interpret inter-linkages among the resources and stakeholders. The objective of this study was to evaluate the linkages of three resources, which are water, energy, and food. Of the various kinds of farming methods, this study analysed protected greenhouse farming, as it is one of the most resource-intensive farming practices. For the analysis, reference evapotranspiration and heating energy load were simulated as 1-2 Win a four-span greenhouse. The inside temperature was simulated based on the equation suggested by van Henten (1994). This study acquired climate data in 2011 and 2012 from the KMA (Korea Meteorological Administration) for calculation. Furthermore, ANN (Artificial Neural Network) with multi-layer perceptron was applied to match the productivity with statistics reported by RDA (Rural Development Administration) annually. The input data for the model were crop productivity simulated from Aqua Crop model, and census data from the RDA reports. Data from 2013 to 2016 were used for the validation of this study. Among the various agricultural products, this study chose tomato for the analysis. The results of this study will help construct the WEF Nexus platform for protected greenhouse complex in Korea.

Keywords: Water-Energy-Food Nexus, Greenhouse, Temperature simulation, Evapotranspiration, Heating energy load, Republic of Korea.

1. INTRODUCTION

Water-food-energy nexus is a concept that emerged to use resources more efficiently by analysing the trade-off and synergy between resources (Choi, 2017). It was presented at the World Economic Forum in 2011, and since the Sustainable Development Goals (SDGs) were proposed in 2015, a number of studies have been conducted to analyse the relationship between resources. By far, research on water-energy-food nexus can be divided into 4 categories, which are scenario-based evaluation, integrated assessment modeling, decision support, and data-based model (Namany et al., 2019). Daher and Mohtar (2015) analysed the interdependence of water, energy and food through a scenario-based platform and evaluated its applicability through Qatar's case. In addition, water-energy-food analyses were conducted based on conflicts between resources in MENA (Middle East and North

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Africa), Gediz in Turkey, and Texas, and measures to cope with changing natural and social conditions (Daher et al., 2019; Lee et al., 2019; Degirmencioglu et al., 2019).

The previous studies assessed sustainability based on the relationship between resources derived from the constructed statistical data and the scenarios entered by the user. However, this approach has some disadvantages in that it cannot be applied when it is out of the local scope of the constructed statistical data, and it cannot flexibly simulate external conditions such as climate change. In particular, Irabien and Darton (2016) applied the water-energy-food nexus analysis to the cultivation agriculture with the virtual water and carbon footprint, but constraints remained as the statistics of the target area wereonly used. For simulation-based water-energy-food nexus analysis, it is necessary to be able to simulate the conflicts and ascendant relationships of each resource within the greenhouse, not by using statistics alone.

This study tried to estimate the reference evapotranspiration and the heating energy load in the greenhouse for the water - energy - food nexus analysis. For this purpose, inside temperature was simulated for the input value of nexus analysis.

2. METHODS

2.1 Water-Energy-Food Nexus Structure

Figure 1. is a structure of water-energy-food nexus constructed in this study. Nexus elements outside the triangle are resources calculated based on the national scale statistics. On the other hand, resources inside the triangle are resources simulated with the field scale value in greenhouse cultivation. The dotted line shows the input of resources, and the solid line shows the demand of one element on the other.

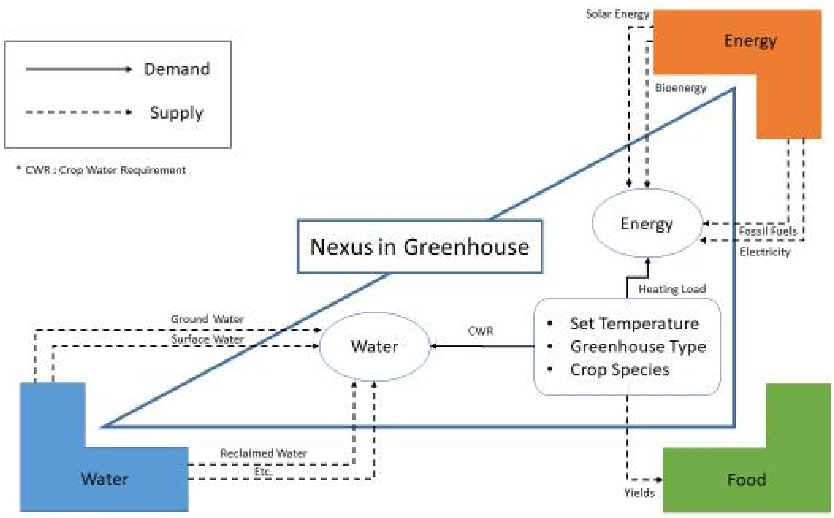

Figure 1. Structure of Water-Energy-Food Nexus in greenhouse

2.2 Inside Temperature Simulation

Inside temperature simulation model is as shown in the following Eq. 1, and consists of internal variables, external weather, and fixed conditions.

Eq. 1 $$\frac{dT_{in}(t)}{dt} = \frac{1}{C_a}(u_q(t) + C_{rad}S_r(t) - (T_{in}(t) - T_{out}(t))(c_{cap}u_v + c_{ai}))$$

T_{in} (t) is the room temperature, T_{out} (t) is the outdoor temperature, and C_g is the specific heat per unit area of the interior air, given by van Henten (1994). (W / m^2) is the solar radiation outside the greenhouse, C_{cap} is the specific unit heat of the air in the facility, u_v is the ventilation rate, And C_{ai} (W / m^{2}K) are the average flow heat losses of the facility, and the values are shown in Table 1. below.

Table 1. Comparison of parameter specifications between van Henten (1994) and this study

Parameter		C_g	C_{rad}	C_{cap}	C_{ai}	S_r	u_v	T(t)	u_q
Unit		J/m^{2}K	-	J/m^{3}K	W/m^{2}K	W/m^2	m/s	℃	W/m^2
Value	van Henten (1994)	30,000	0.2	1,290	6.1	Input data			
	this study	30,000	0.2 ~ 0.3	1,290	3.1	Input data			

2.3 Crop Productivity Estimation with Aqua crop Model

Aqua Crop model (FAO) simulates attainable yields of major herbaceous crops as a function of water consumption under rainfed, supplemental, deficit and full irrigation conditions (Steduto et al., 2008). Figure 2. shows the four steps calculation scheme of Aqua Crop (Raes, 2017). The dotted arrows indicate the water stress (a to e) and temperature stress (f to g). In this study, simulated air temperature and evapotranspiration were input variables for the Aqua Crop. CO2 and rainfall which was substituted for the irrigation requirement were fixed value for the Aqua Crop.

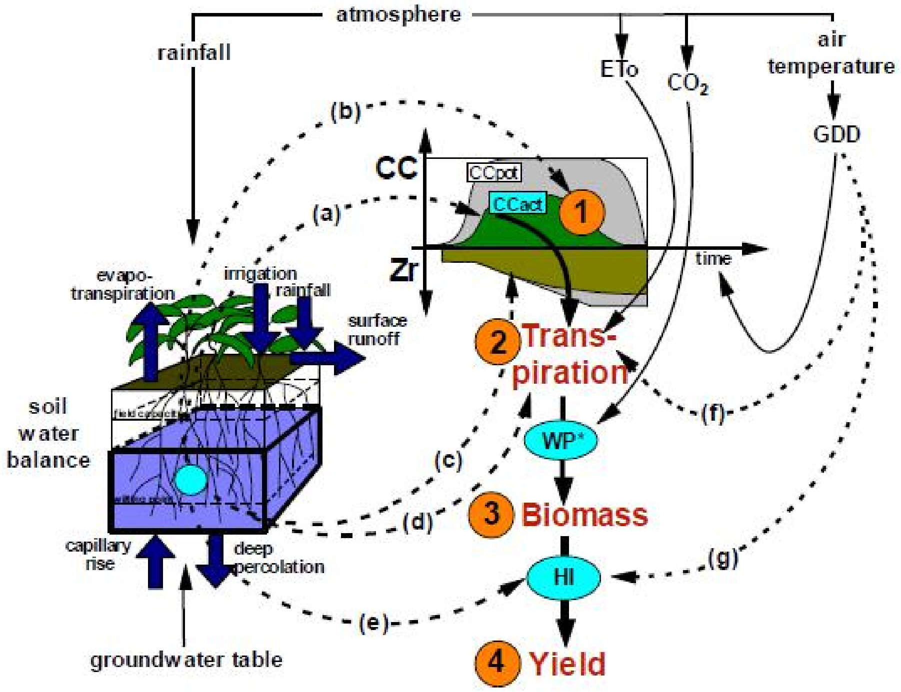

Figure 2. Calculation scheme of AquaCrop (Raes, 2017)

2.4 ANN Model

Figure 2. shows the structure of the ANN model used in this study. ANN model consists of an input layer, a hidden layer and an output layer. The nodes are connected with each other. The number of nodes in each layer can be adjusted based on the performances. In this study, sigmoid function was chosen for the activation function.

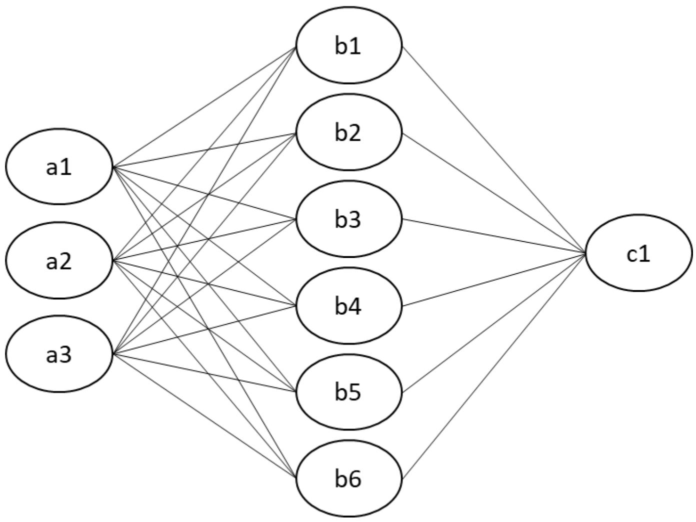

Figure 3. Structure of ANN in this study

3. RESULTS AND DISCUSSION

3.1 Inside Temperature Simulation

Figure3. and Figure 4. show the inside temperature of the experimental greenhouse. Blue and orange dotted lines show the simulated and observed inside temperature. And gray line show observed outside temperature. Figure3. is the result of the calibration in February 2011, and Figure 4. in March 2011. As shown in the figures, the results of this study show that the simulated inside temperature properly matches the observed temperature

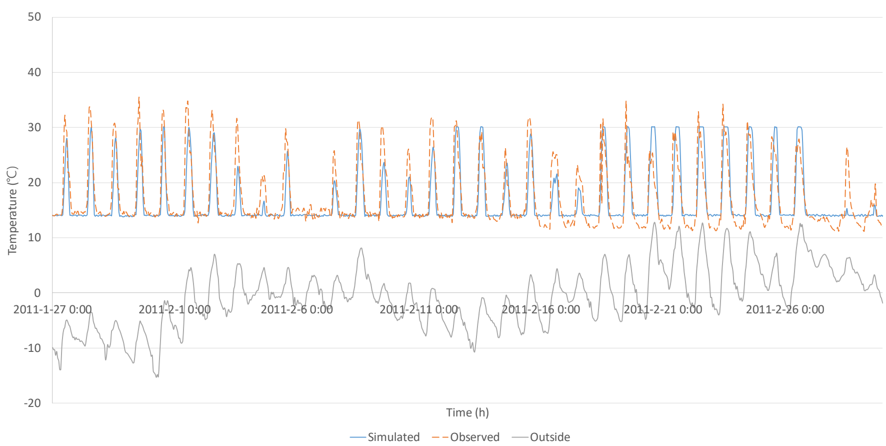

Figure 4. Observed and simulated inside temperature in February 2011 (calibration)

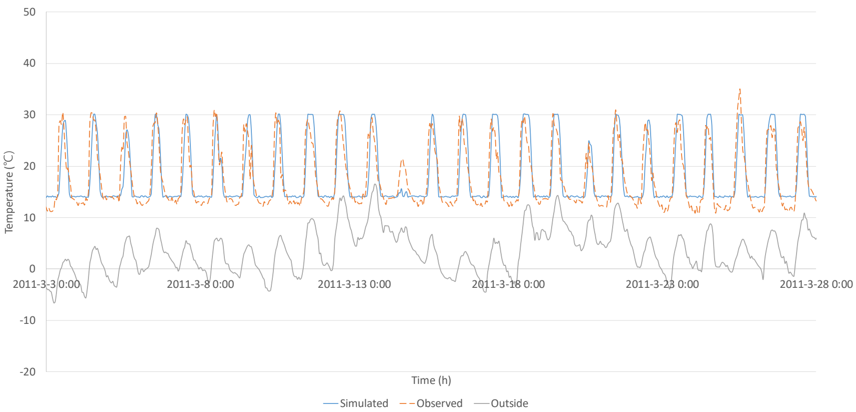

Figure 5. Observed and simulated inside temperature in March 2011 (calibration)

3.2 Crop Productivity Estimation with Aqua crop Model

Table 3. shows the crop productivity estimated from Aqua Crop. The input data were inside temperature and evapotranspiration values simulated in 2011 and 2012. Since both simulations in 2011 and 2012 were made at the same inside setting temperature, crop productivity did not show a significant difference.

Table 2. Results of crop productivity estimation with AquaCropin 2011 and 2012

Year	Biomass (ton/ha)	Dry Yield (ton/ha)	Cultivation Period (day)	Water Productivity (kg/ton)
2011	12.740	8.026	106	2.62
2012	12.892	8.122	106	2.67

4. CONCLUSIONS

This study simulated crop yields for water-energy-food nexus analysis in greenhouse farming. For this purpose, the inside temperature of the greenhouse was simulated to estimate the reference evapotranspiration and the heating energy load. The crop yield was simulated using Aqua Crop model by inputting the reference evapotranspiration and the inside temperature. As shown in Figure 3. and Figure 4., inside temperature was simulated well enough to estimate the crop productivity. With ANN model using yields from Aqua Crop and RDA (Rural Development Administration) reports, more statistically fitted results can be acquired in terms of Water-Energy-Food Nexus.

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