Water and Food Relationship Evaluation on WEF Nexus in greenhouse with water stress and soil condition

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***Abstract*—Due to the population growth, food production demands and water use increase, there is a wide variety of global discussions on resource management in terms of securing resources such as water and food considering sustainability. The concept of "Water-Food-Energy Nexus" has emerged to interpret the linkage of water, energy and food resources and to suggest an integrated management plan. There is a trade-off relationship among input resources such as energy, water and cost, for increasing food productivity, therefore, it is necessary to analyze the relationships comprehensively rather than single resource analysis. This study was conducted to evaluate the relationship between water and food among the water-food-energy nexus of upland crops in greenhouse. Because the growing the upland crops in greenhouse could control the environmental condition such as the temperature, humidity, and wind speed, the analysis based on the scenarios according to the environmental conditions could be conducted. Also, the upland crops are more vulnerable to water stress than paddy rice which cultivated by flooding method. And water stress has a significant influence on the upland crop growth and production. Thus, this study included simulating the response of the upland crops in greenhouse to water and to evaluate the relationship between water and food resources, using AquaCrop model which estimate water productivity of the upland crop. The AquaCrop model developed by FAO analyzes the effects of water environment, fertilizer and irrigation method on the production of various crops. Input data includes weather, crop, soil data and farm management data including irrigation and fertilizer. Then, the upland crop yield and water productivity based on the irrigation method, fertilizer, weather condition are simulated in terms of water stress. From the results, it was demonstrated that the water and food relationships for Nexus water-food bridge could be quantified using AquaCrop model.**

Keywords—Water-Food-Energy Nexus; Upland crop; Water stress; Soil condition; AquaCrop

I. INTRODUCTION

Four of the 10 most likely and influential global risk factors presented by Global Risks 2015 are related to climate change, water security and food security. In order to cope with such changes in the future environment, it is necessary to secure and utilize limited resources sustainably. Water-Energy-Food Nexus interprets water-energy-food interrelations to achieve efficient use of resources and ultimately to sustainability of agriculture. Sustainable water resource management using WEF Nexus can increase the sustainability of available water resources by using balanced water resources between water, food and energy. There is a trade-off relationship among input resources such as energy, water and cost, for increasing food productivity, therefore, it is necessary to analyze the relationships comprehensively rather than single resource analysis.

The purpose of this study is to evaluate the relationship between water and food among the water-food-energy nexus of the upland crops in greenhouse. Because the water stress and soil fertility have a significant influence on the upland crop growth and production, estimating the crop growth and production need to be analyzed considering the irrigation method. Thus, this study included simulating the response of the crops in greenhouse to water, soil fertility and evaluating the relationship between water and food resources, using AquaCrop model which estimate water productivity.

II. MATERIALS & METHODOLOGY

A. Protected cultivation (Greenhouse)

One of the best examples of water-energy-food nexus is protected cultivation. Protected cultivation is to cut off outdoor environmental conditions such as temperature, precipitation, and wind speed, and resources such as water and energy are put in order to provide an appropriate growth environment for crops. Therefore, water-food-energy nexus was applied to the protected cultivation area as a test bed for analyzing the trade-off between water, energy and food resources according to the environmental conditions in the greenhouse.

B. *Crop water requirement and production simulation using AquaCrop model*

In this study, using AquaCrop model, crop yield, evapotranspiration and the amount of the irrigation water use are estimated. AquaCrop model is designed to simulate the crop growth, biomass production, yield and evapotranspiration of herbaceous crop types (FAO, 2017). AquaCrop model concept represents yield response to water as a linear, crop-specific function of the ratio of actual to potential evapotranspiration over a growing season. AquaCrop model accounts for the dynamic effects of water and temperature stress on crop growth, and the impact of evaluated atmospheric CO2 concentrations on crop water productivity.

III. RESULTS & DISCUSSION

A. *Total yield, total irrigation water and water productivity simulation results*

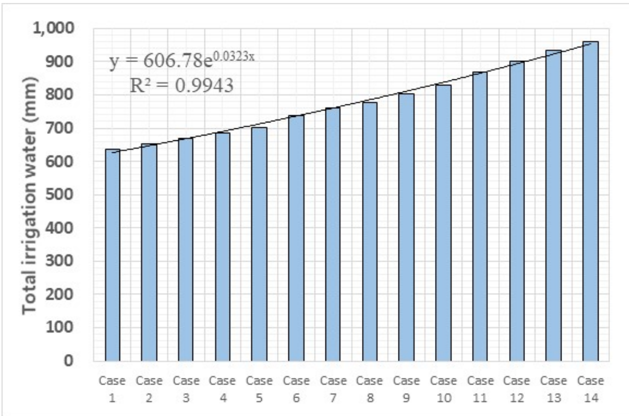
Total crop yield, the amount of the irrigation water and water productivity simulation results by the temperature conditions were estimated using the AquaCrop model. Simulation scenarios were set according to the crop environmental temperature conditions from 14℃ to 30℃ to evaluate the crop response to the cold and heat stresses. 1-year total yield and irrigation water were calculated by multiplying the unit yield and irrigation water per day by the growing period to consider that the growing period varies depending on the temperature conditions. In addition, water productivity is a concept that links crop yield and agricultural water use, and is an indicator of agricultural water use efficiency. Water productivity was estimated by dividing crop yield (ton/ha) by the amount of irrigation water (mm).

TABLE I. TOTAL YIELD OF 1-YEAR AND WATER PRODUCTIVITY RESULTS BY THE TEMPERATURE SCENARIOS

Case	Minimum Temperature (℃)	Maximum Temperature (℃)	Total yield (ton/ha/year)
Case 1	13	17	80.2
Case 2	14	18	82.9
Case 3	15	19	88.3
Case 4	16	20	92.0
Case 5	17	21	96.2
Case 6	18	22	100.9
Case 7	19	23	106.5
Case 8	20	24	109.0
Case 9	21	25	111.0
Case 10	22	26	118.4
Case 11	23	27	115.6
Case 12	24	28	123.9
Case 13	25	29	126.7
Case 14	26	30	123.6

TABLE II. IRRIGATION WATER REQUIREMENT AND WATER PRODUCTIVITY OF 1-YEAR AND WATER PRODUCTIVITY RESULTS BY THE TEMPERATURE SCENARIOS

Case	Minimum Temperature (℃)	Maximum Temperature (℃)	Total irrigation water requirement (mm)	Water productivity (ton/ha/mm)
Case 1	13	17	636.9	0.126
Case 2	14	18	654.1	0.127
Case 3	15	19	669.4	0.132
Case 4	16	20	686.3	0.134
Case 5	17	21	700.5	0.137
Case 6	18	22	737.1	0.137
Case 7	19	23	759.7	0.140
Case 8	20	24	775.8	0.140
Case 9	21	25	803.1	0.138
Case 10	22	26	829.6	0.143
Case 11	23	27	868.4	0.133
Case 12	24	28	900.8	0.138
Case 13	25	29	934.5	0.136
Case 14	26	30	959.3	0.129



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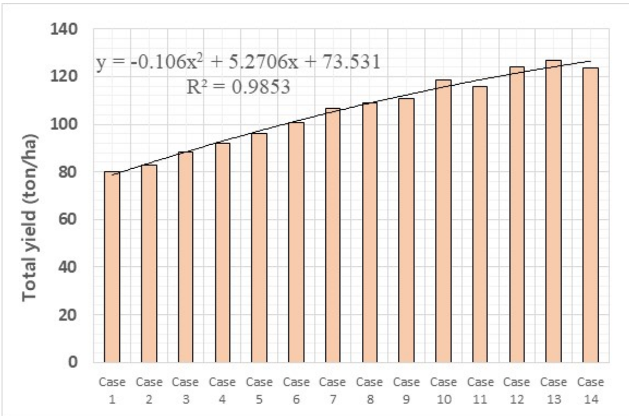

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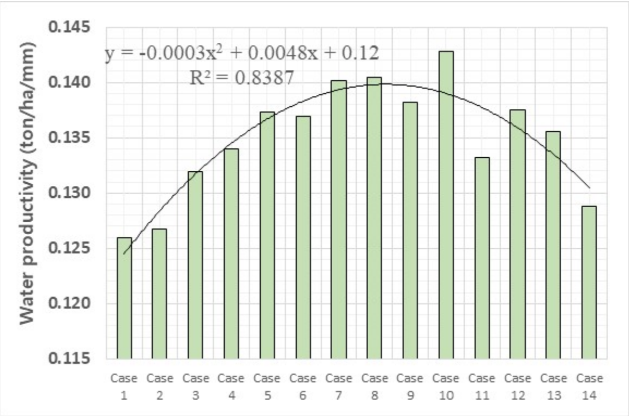

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Figure 1. Total yield, irrigation water requirement of 1-year and water productivity results by the temperature scenarios
((a): Total irrigation water requirement (mm), (b): Total yield (ton/ha), (c): Water productivity (ton/ha/mm))

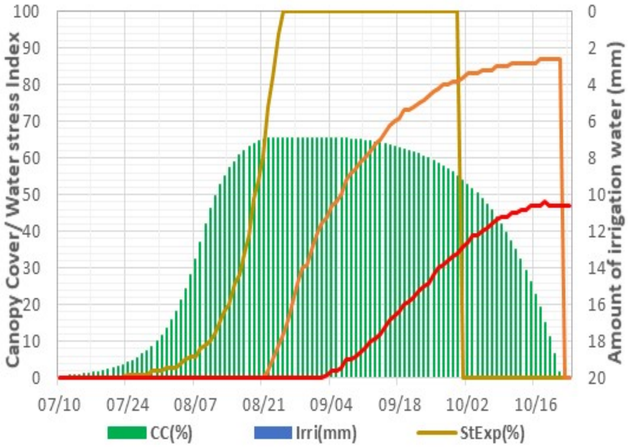
The total annual crop yield, irrigation water requirement and water productivity results for each temperature scenarios are as above. As the temperature increased, both crop yield and irrigation water requirement tended to increase. However, in the case of crop yield, the increasing slope gradually decreased, and it is considered that the high temperature stress acts as the temperature continuously increases. On the other hand, in the case of irrigation water requirement, it continuously increased to show the form of exponential function. Water productivity, which is the ratio of crop yield (ton/ha) to irrigation water requirement (mm), can be used as an indicator of water use efficiency and can be used to select the most efficient scenarios and the environmental conditions in policy or decision making.

B. Crop growth simulation results by water stress

For the simulating the crop growth response to water stress and, the biomass, crop yield and the amount of the irrigation water were estimated under the water stress conditions by the irrigation method. The study crop was tomato and the growing period was from January/10 to August/7 which is the 1 growing cycle of tomato. The irrigation method was adjusted to evaluate the crop growth response to water stress, and the conditions were four (Not irrigated, irrigated at the point of 10% RAW remained (Readily available soil water), irrigated at the point of the 50% RAW remained, irrigated at the point of 10% RAW remained (potentially irrigated)).

TABLE III. BOIMASS, YIELD, AMOUNT OF THE IRRIGATION WATER RESULTS BY THE IRRIGATION METHOD

Irrigation method scenario	Biomass (ton/ha)	Yield (ton/ha)	Irrigation water requirement (mm)
Not irrigated	6.04	3.41	0
Irrigated at 10% RAW remained	12.97	8.17	135.8
Irrigated at 50% RAW remained	13.42	8.47	191.4
Irrigated at 100% RAW remained (potential)	13.48	8.50	307.7



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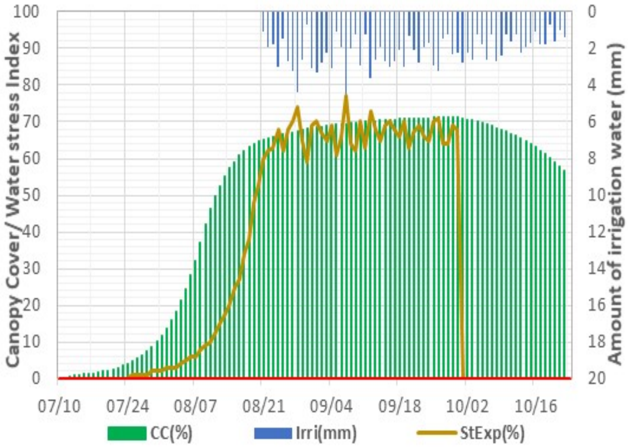

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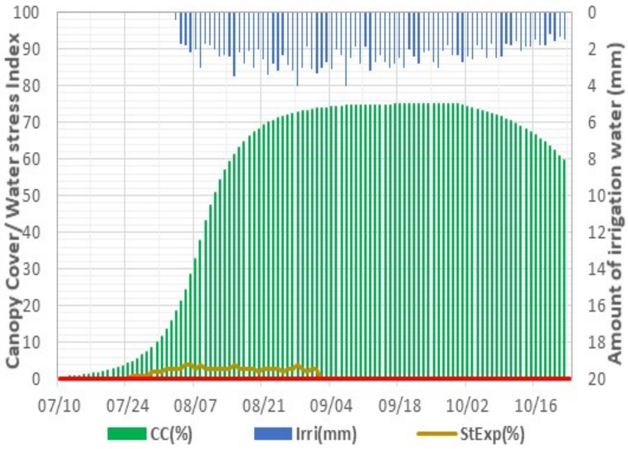

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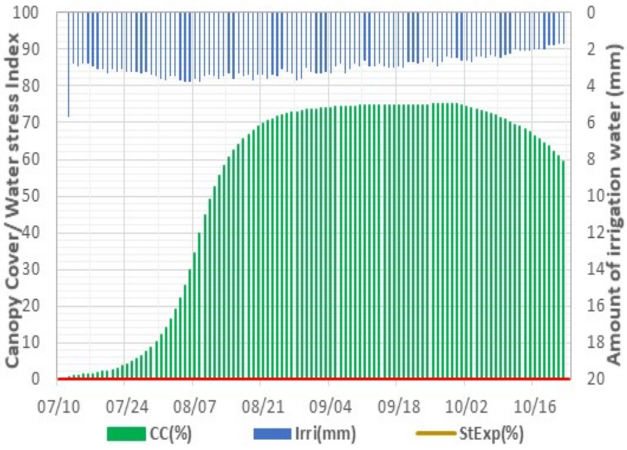

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Figure 2. Canopy cover, the amount of the irrigation water, water stress by the irrigation method
((a): Not irrigated, (b): Irrigated at 10% RAW remained (Readily available soil water), (c): Irrigated at 50% RAW remained, (d): Irrigated at 100% RAW remained (potentially irrigated))

(※ CC: Canopy cover (%), Irri: The amount of the irrigation water (mm), StExp: Percent water stress reducing leaf expansion (%), StSto: Percent water stress inducing stomatal closure (%), StSen: Percent water stress triggering early canopy senescence (%))

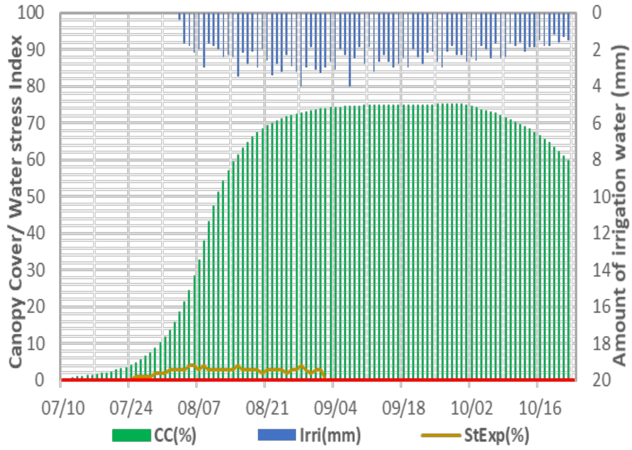
The crop yield, irrigation water requirement and water stress results of the one crop growing cycle according to the irrigation method are as above. Yellow, orange, and red lines indicate growth inhibition water stress, stomatal closure water stress and early canopy senescence water stress, respectively. First, without irrigation, yields were significantly lower and all three water stresses were found to occur. In the case of irrigation when the soil moisture content remained 10%, growth inhibition water stress only occurred and the yield was estimated to be 8 tons per one crop growing cycle. Secondly, when irrigation is carried out when the soil moisture content is 50%, there is a slight growth inhibition water stress, but there is no significant difference in the total yield compared to the case of irrigated potentially (Irrigated at 100% RAW remained), and the amount of irrigation water requirement is about 1.5 times.

C. *Crop growth simulation results by soil fertility*

For the simulating the crop growth response to soil fertility condition, the biomass, crop yield, the amount of the irrigation water and water productivity were estimated under the soil fertility stress condition. The soil fertility stress conditions were six (Potential (soil fertility stress 0%), Optimal (23%), Moderate (42%), Half (51%), Poor (59%), Very poor (69%)).

TABLE IV. BOIMASS, YIELD, AMOUNT OF THE IRRIGATION WATER, WATER PRODUCTIVITY RESULTS BY THE SOIL FERTILITY CONDITION

Soil condition (Soil fertility stress)	Biomass (ton/ha)	Yield (ton/ha)	Irrigation water (mm)	Water productivity
Potential (0%)	13.42	8.45	191.4	4.42
Optimal (23%)	10.77	6.79	174.1	3.90
Moderate (42%)	8.09	5.10	150.8	3.38
Half (51%)	6.70	4.22	136.9	3.08
Poor (59%)	5.43	3.42	122.3	2.80
Very poor (69%)	3.90	2.45	101.5	2.42



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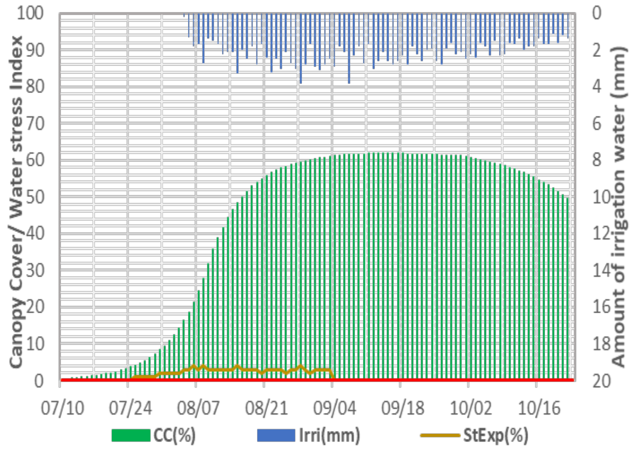

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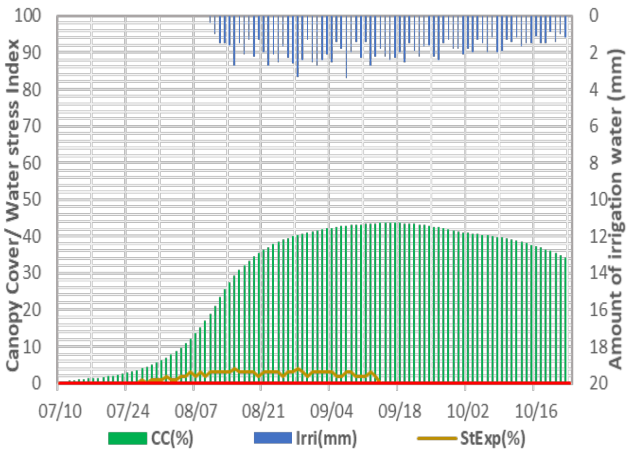

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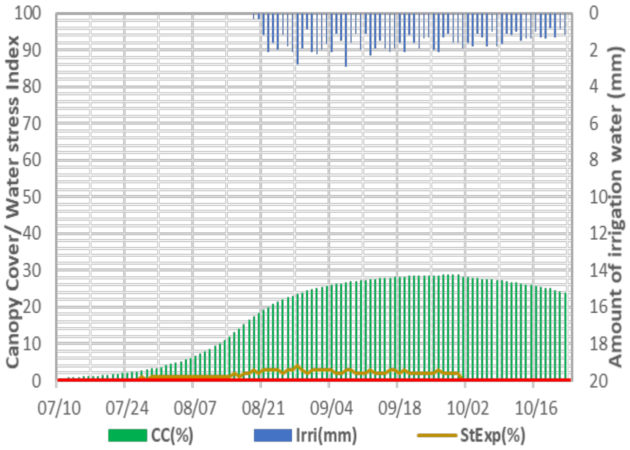

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Figure 3. Canopy cover, the amount of the irrigation water, water stress by the soil fertility stress condition
((a): Potential (soil fertility stress 0%), (b): Optimal (soil fertility stress 23%), (c): Half (soil fertility stress 51%), (d): Very poor (soil fertility stress 69%))

(※ CC: Canopy cover (%), Irri: The amount of the irrigation water (mm), StExp: Percent water stress reducing leaf expansion (%), StSto: Percent water stress inducing stomatal closure (%), StSen: Percent water stress triggering early canopy senescence (%))

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