Report on Crop Productivity Sub-Group Activity

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1. Research Plan for the Sub-Group

1) Research objectives

a: Clarification of the combined effect of CO_2, temperature and soil moisture and/or salinity using open fields, growth chambers and greenhouses

b: Improvement of evapotranspiration measurement with micro-meteorological approach

c: Separation of evapotranspiration into transpiration and soil evaporations with the sap flow measurement

d: Prediction of the future change of the water balance and crop productivity following climate change through computer simulation

2) Methodology and materials

a: Experimental studies are carried out to clarify the combined effect of CO_2, temperature and soil moisture and/or salinity in a set of growth chambers in Japan. The effects of temperature and soil moisture and/or salinity on crop production for wheat and maize are clarified experimentally in an open field and a greenhouse in Japan and Turkey.

b: Evapotranspiration with the Bowen ratio method as a standard approach is improved by introducing the energy balance flux ratio method.

c: Evapotranspiration is separated into transpiration and soil evaporation using the sap flow method and micro-lysimeters.

d: Crop productivity change and irrigation water demand change following climate change through computer simulation are predicted. The SWAP model and/or substitute models for it are used for simulation

3) Expected Outcomes at the End of the Project

a: The combined effect of CO_2, temperature and soil moisture and/or salinity on crop production is experimentally evaluated.

b: Evapotranspiration, transpiration and soil evaporation are accurately estimated as a function of weather and crop growth.

c: The future change of water balance and crop productivity is predicted using the climate change data.

4) Goal Until the End of March, 2004

a: The combined effect of CO_2 and soil moisture and/or salinity is experimentally clarified for wheat.

b: Evapotranspiration measured with the Bowen ratio method is accurately evaluated with the energy balance flux ratio method. Evapotranspiration is accurately separated into transpiration and soil evaporation with the sap flow method and micro-lysimeters.

c: Change in irrigation water demand following climate change for maize as one of main crops in the Mediterranean climate regions of Turkey is predicted using the three climate models data (the NCAR-PCM, ECHAM4/OPYC and MRI-CGCM2 models) and the original SWAP model.

2. Summary of Individual Research

1) Future change of water demand following global warming in arid area by T. Yano and Y. Liu, Tottori University

In order to predict future change of water demand in the Mediterranean climate regions of Turkey by using the predicted climate change data, monthly water balance was first calculated for the periods for 10 years from 2001 and 2090 in Siverek located at 37.75°N and 39.32°E, Turkey using the SWAP model developed in the Netherlands. Siverek was selected because it is located nearest to one of the grid points of the both models among the weather stations of southern Turkey. The B2 and A2 scenarios of the Emission Scenarios of

the Special Report on Emission Scenarios (SRES) of the ECHAM4/OPYC3 model of Maxplanck Institute for Meteorology, Germany and the NCAR-PCM model of the National Center for Atmospheric Research, USA were used as climate change data among the various scenarios. The temperature prediction with the NCAR model seems to underestimate the future temperature. Further, since there are obvious discrepancies between the present climate and the prediction, we created the climate scenario using the present observed data.

Next, monthly water balance was calculated for Adana. The predicted data with the MRI-CGCM2.2 model of Meteorological Research Institute, Japan was used in addition to the ECHAM and NCAR models. The value of a climate variable for Adana was computed with the predicted values at the four nearest neighboring grid points using the inverse distance wighted method. The climate scenarios were created in the same way as in the Siverek case. As the result of climate scenario creation for three models, we could not get much different prediction of the future water balance. The similar trial should be done using the latest climate data in Adana for investigating the validity of the used approach.

2) Impact evaluation of crop yield with simulated occurrence of rainfall by A. Tanaka and M. Koo riyama, Saga University

The impact of rainfall pattern in Saga on crop yield was investigated numerically using the SWAP model. The annual mean temperature in Saga increased for 1961-1999. On the other hand, though annual rainfall changed greatly at each year, it did not tend to increase as a whole. Day number of daily rainfall greater than 20 mm and 50 mm increased gradually since 1980. Therefore, it was considered that rainfall property of Saga in the recent year was characterized by an increase in rainfall intensity. From the probabilistic approach, daily rainfall occurrences were represented by a Markov process, and daily rainfall was simulated by the Monte Carlo method. Then change of crop yield with simulated daily rainfall was investigated numerically using the SWAP model. As a result, rainfall during crop development stage had a significant effect on crop yield.

In predicting the change of crop yield accompanying the global warming using the SWAP model, it is necessary to obtain the meteorological data from probabilistic approach and investigate the existence of serious decrease in crop yield by repeating simulation using the obtained meteorological data.

3) Estimation of evapotranspiration from a maize field with the energy balance flux ratio method by H. Odani, University of Shiga Prefecture

The impact of climate change on crop productivity will be predicted with the SWAP model. Evapo-transpiration (ET) is one of the basic input data in this model. One of targets in our investigations is to determine ET accurately for the whole growing season of maize.

We have proposed the energy balance flux ratio method (the EBFR method) as one of reliable micrometeorological methods to estimate ET, and have shown that there is much possibility that ET is estimated accurately using the EBFR method in a paddy field. ET from a maize field was measured using the EBFR method in Adana, Turkey during August 15-27, 2003. Measured results of ET were compared with transpiration obtained from the sap flow system. From the above results and considerations, it was considered that estimated ET values by the energy balance flux ratio method are reasonable.

4) Measurement of transpiration on maize with surface irrigation in Adana region by S. Takeuchi, Kyushu Kyouritsu University

The field observation was conducted to investigate the efficiency of furrow irrigation with maize field near Adana from 14 to 28 August 2003. ET was measured with the Bowen ratio method while transpiration was measured with the heat pulse method and the stem heat balance method. Soil evaporation was measured with micro-lysimeters. These values are classified for estimating detailed crop water requirements.

Practical furrow irrigation has been applied every 13-15 days. During our observation period, one cycle irrigation period was obtained. Root depth and profile were surveyed for evaluating application efficiency and consumptive use efficiency.

As an example of obtained data, 16 August was clear sky day. Air temperature above the canopy showed

constant value from 11:00 to 17:00. In the afternoon, prevailing wind blew from the south seacoast constantly. Sap flow rate measured with the stem heat balance method showed higher value than 100g h^{-1} at mid-noon, so combined approach with the heat pulse and the heat balance methods was applied to compute accurate sap flow rate. Daily sap flow rate was 741, 679, 784, 903, 770, 919 g d^{-1} among 6 plants, while average value was 800 g d^{-1}. These values are corresponding to 85 to 115% of average value.

Daily sap flow rate on cloudy day (26 August) was 661, 631, 752, 969, 673, 849 g d^{-1} among 6 plants, while average value was 755 g d^{-1}. These values are corresponding to 84 to 128% of average value. On cloudy day, sap flow rate was fluctuated among plants. Transpiration rate was computed by normalizing the sap flow data on a population basis, 5.33 and 5.04 mm d^{-1} for 16 and 26 August respectively.

Soil evaporation rate was reduced from 1.3 to 1.0 mm d^{-1} during first 3 days after irrigation, and then indicated 0.9 to 1.0 mm d^{-1} constantly. The ratio between transpiration and evaporation was changed from 16.9% to 24%. 54 % of plant root was concentrated from 10 to 20 cm from soil surface within 40 cm furrow. Between furrow, root did not exist significantly.

5) Effect of soil desiccation on transpiration in two Mediterranean wheat cultivars under the elevated temperature and CO_2 conditions by T. Kobata, Shimane University

It has been reported that high temperature and enriched CO_2 concentration increase biomass production in soybean but clear effects are not observed in rice. Also, it was reported that soil water deficit inhibited the biomass production and result in yield reduction in most crops. However, the effect of soil desiccation on the crop production under elevated temperature and CO_2 conditions is clearly unknown. To estimate the effects on Mediterranean wheat cultivars, seedlings of two cultivars were grown under the ambient and elevated temperature and CO_2 conditions and the response of transpiration rate to soil desiccation was observed.

Soil water content (% of field capacity) decreased by stopping of irrigation from 100 to 50 or 60% in both cultivars under the ambient and the elevated temperature and CO_2 concentration conditions. In Seri M82 ratio of transpiration rate slightly decreased although in Bezostaya1 it was maintained till 60% of field capacity regardless of the elevated treatments. There was not a clear difference in the response of the ratio of transpiration to soil water contents between the ambient and elevated treatment plots. During the soil desiccated treatment water use efficiency (WUE) increased in both cultivars under the elevated treatments although soil desiccation did not clearly affected the WUE. Because vapor water deficit in the elevated treatment chamber was similar to that in ambient chamber, the increase of WUE did not seem to be caused by differences of air humidity.

When transpiration rate clearly reduces with decrease in soil water content, the experiment data were not gathered by limitation of experimental period. The longer experimental period or use of pots having small soil volume should be expected to gather data under diverse soil water deficit.

6) Modeling the wheat growth under drought-prone environments by H. Nakagawa, Ishikawa Agricultural College

Crop simulation models are indispensable for the impact assessment of climate change on crop production. We will develop a simplified process model for simulating wheat growth under drought-prone environments and will compare several wheat growth models, including the crop sub-model of SWAP, SUCROS and our original model. This year, a phenology sub-model was created for winter cereal crops and was parameterized for a barley cultivar grown under well-watered conditions.

Parameters of the phenology model were estimated from heading dates of 'Amagi-Nijo' with meteorological data (18 data sets) with the related statistics. The present model could well explain the heading dates of 'Amagi-Nijo' grown under a wide range of environmental conditions with high accuracy (se = 1.43 days, r = 0.999).

The response of DVR to temperature and daylength was given with parameters and shows the curvilinearity of the temperature response and that long day conditions promote phenological development towards heading in 'Amagi-Nijo'.

The model with parameters was tested by using independent data sets of 'Amagi-Nijo' grown in 13

prefectures in Japan, which were documented in annual reports of agricultural research institutes in those prefectures. The present model could well explain the site-to-site difference and yearly variations of heading date without any adjustment of parameters.

These results suggest that the present model can be applied for simulating the phenological development of winter cereal crops grown under a wide range of temperature and daylength conditions, if the vernalization effect can be omitted as in the case of 'Amagi-Nijo'.

3. Research Plan for the Coming Years

1) Final goal of research

a: To clarify the combined effect of CO_2, temperature and soil dryness and/or salinity for main crops

b: To estimate the possible crop pattern in the future climate and to present the desirable on-farm water and soil management as a countermeasure against climate change

2) Plan for FY2004-2006

a: Measurement of the effect of temperature on crop growth in Adana (Kobata and Nakagawa)

In order to clarify the effect of high temperature on wheat and maize production, a series of field experiments by changing sowing date will be done in cooperation with Turkish researchers in an experimental field of Cukurova University.

c: Measurement of the combined effect of CO_2, temperature and soil moisture and/or salinity on wheat growth in Japan (Kobata and Nakagawa)

A series of experiments will be continued in a greenhouse and growth chambers in Shimane University and Tottori University, respectively.

d: Measurement of the combined effect of CO_2 and temperature on maize growth in Japan (Haraguchi and Yano)

A series of experiments will be conducted in growth chambers of Kyushu University under elevated CO_2 concentration and temperature. Evapotranspiration, transpiration and soil evaporation under maize cultivation together with phenology will be measured from germination and harvest.

d: Measurement of evapotranspiration and transpiration with the energy balance flux ratio method and the stem energy balance method (Odani, Takeuchi and Haraguchi)

A series of experiments will be conducted for a whole growth period of maize in an experimental field of Cukurova University.

e: Simulation of the future change of the water balance and crop productivity following climate change (Yano, Haraguchi and Kooriyama)

A series of computer simulations will be done to predict water balance and crop production of wheat and maize as main crops using the SWAP model and the created climate scenarios based on the various climate models.

3) Problems in conducting research and countermeasures against them

a: Salinity study

There has not been any progress of individual research on salinity, because we have not reached agreement on it with the Turkish side researchers. The necessary parameters of input data related to the salinity effect on crop productivity in the SWAP model should be decided by measuring evapotranspiration and phenology of maize in a salt-accumulated field. Further, we need a new member in charge of the topic to replace K. Inosako who wants to withdraw from the group.

b: Measurement of the combined effect of CO_2 and temperature on maize growth

The similar experiment with that of wheat is planned to be done by using a set of growth chambers of the Biotron Institute of Kyushu University. Since such experiments need long time occupation of facility and considerable amounts of budget, we have not yet finalized the detailed experimental plan for the coming years. Dependent upon the facility availability and budget distribution in the next fiscal year, the final plan will be fixed.