Report

IMPACT OF GLOBAL CLIMATE CHANGE ON TAIWAN'S AGRICULTURAL PRODUCTIVITY AND EVAPOTRANSPIRATION: CROP EVAPOTRANSPIRATION ESTIMATION

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INTRODUCTION

Econon.ic development, which is necessary and is occurred in most part of the world, has a profound effect on environment. The continuing increase of trace gases in atmosphere has disturbed the natural equilibrium of global physical, chemical, hydrological and biological systems on earth. The resulting impact on environment, particularly on climatic systems, is not merely a problem of a location or a region; it is a problem of global scale (Clark, 1989; Graedel and Crutzen, 1989; Charlson and Wigley, 1994; Schneider, 1994). The implication of climatic change would have on sustainability of life and life support systems is profound (ASA Special Publication No. 53, 1990, No.55, 1993, and No. 59, 1995; UNEP report No. 10, 1993; Bongaarts, 1994; Pimm and Sugden, 1994.) One of the possible direct effects of increasing trace gases is to increase temperature, which in turn will increase the rate of transpiration of plants, and evaporation from the land and ocean. Innevitably, this will increase global precipitation. However the effect will not be even geographically (UNEP report 10, 1993.) Though environmental problem is global in nature but its impact can only be quantitatively evaluated locally. Thus it is important to conduct specific and local studies to determine the regional or global effects.

Evapotranspiration (ET) is a composite index which conceptually describes the processes of water loss to the atmosphere from soil by evaporation and from vegetation by transpiration (Penman, 1948; Monteith, 1964; Campbell, 1977; Loomis And Connor, 1992.) Thus ET is a function of plant, weather and soil conditions. An assessment of ET in response to a changed climate will, therefore, provide impact information of climate change on natural and crop production systems (Baker et al., 1990; Jenson, 1990; Nie et al., 1992.) This impact information can help us to design appropriate cropping systems, which may adapt to the changes and to develop strategies to use natural resources wisely and effectively.

Many studies showed that ET will be affected by climate change and provides an important feedback for climate change (Nie at el., 1992; Baker et al., 1990; Liang et al 1997.) Hsiao (1993) theoretically derived results on ways that elavated CO_2

concentration may impact on plant growth processes of assimilation and transpiration. He showed that elevated CO_2 concentration reduces stomatal aperture, accelerates assimilation and leaf area development, and lowers transpiration per unit effective leaf area. The percentage increase in photosynthetic WUE due to elevated CO_2 is almost proportional of the new to the original concentration of CO_2 . It is anticipated that ET response to as leaf area expansion and stomatal resistance to the direct effect of rising CO_2 concentration are similar in magnitude but opposite in direction. Because of the obvious impact of ET on water balance, Dickinson et al. (1991) suggested that evapotranspiration submodel be incorporated into climate models, along with other parameterizations of land surfaces, to improve the realism of calculated surface energy fluxes and hence the representation of surface climate as needed for studies of future climate change.

The purpose of this study is to determine the potential impact of climate change on ET in Taiwan through an understanding of the demand of crop evapotranspiration in Taiwan. This information is important not only for Taiwan's resource management but also necessary for the database development, which are essential for regional and global studies of impacts of global climate change.

EVAPOTRANSPIRATION ESTIMATION

The factors affect crop applied water rates include (1) climate; (2) soil; (3) crop; (4) water economy; (5) irrigation system; (6) farming practices. The importance of each of these factors depends on conditions that are specific within every location. As a result the actual determination of an appropriate crop applied water rate is a complex issue.

Evaporative demand (ED) is the collective influence of all climatic factors, such as solar radiation, wind, air temperature, and humidity, on the rate of evaporation of water. ED is commonly measured with Class evaporation pans. The pans usually are located in a field of healthy full-cover grass, never short of soil moisture and kept clipped to a 3- to 6- inch height within the station enclosure. Research has demonstrated that evaporative demand serves as a good index to ET and, therefore, applied water requirements. For instance, the distribution of the monthly Pan-ET for Hualian and Ilan are shown in Figures 1 and 2. The highest monthly total occurs in July, which averages about 135 mm for Hualian and 123 mm for Ilan. The lowest ET occurs in December or January, which averages 55 mm for Hualian and 35 mm for Ilan. The yearly total ranges between 877 to 1166 for Hualian and 681 to 900 for Ilan between 1974 and 1993.

Methods of determining evapotranspiration. Broadly speaking, there are three approaches to determine ET, these are (1) Instrumental; (2) Empirical; (3) Mathematical. The instrumental approach uses lysimeters and is a relatively expansive procedure. Weighing lysimeters are adequate for most research. Some are designed to use strain gages for obtaining weight measurements. Another type is mounted on a rubber pillow filled with water, which produces a reading on a side tube. Still another type has air

chambers and is capable of floating within a closed water system; a variable water stage recorder may be used to produce a continuous record of weight loss due to ET.Weighing and floating lysimeters are generally more accurate than inflow-outflow lysineters. In addition to lysimeters, there are other newer portable instruments that can measure CO2 or water vapor exchanges on leaves and in canopy. These electronic devices are very efficient and accurate in collecting ET and other photosynthetically related parameters. The other technique is to directly monitor soil moisture depletion, e.g., the use of neutron probes. The second category is to use empirical methods. Empirical methods that use evaporimeters are much cheaper than lysimeters or portable electronic instruments and usually provide good estimates of daily ETs. Evaporation from evaporimeters, such as a Class "A" pan or Livingston black and white atmometers belong to this category. California Water Resources Department (Bulletine 113-3, 113-4) has compared the Class "A" pan ET and the directly measured crop ETs, and used its ratios to adjust Pan-ET. The ratio is called Kp, which is,
Measured Crop Evapotranspiration (ETc) / Measured Pan Evapotranspiration (ETp).

Thus, ETc = ETp * Kp.

California Water Resources Department has developed Kp for a number of the crops grown in Central Valley of California. Usually Kp is less than 1, because ETp tends to be larger than actual ETc. The ETp values for California rice planted in middle April range from 0.8 between April 15 to May 15, 0.9 to June 15, 1.0 to August 31, and 0.85 thereafter. The third category is to use functional equations. Mathematical equations to estimate ET are functions of weather variables. The commonly used equations will be discussed in the next section. The accuracy of these equations is good to excellent. They were also tested under Taiwan's conditions (Liang et al., 1997). The weather variables most often used are air temperature, humidity, wind, and solar radiation. The estimated crop ET is useful for crop management and irrigation scheduling. California' experience indicated that estimated daily ETc tend to have relatively poor accuracy when computed on the basis of weekly Kp's and daily ETp. However by the end of a week, crop ET totals have reasonably good accuracy, certainly good enough for irrigation scheduling. This is because variations in calculated daily crop ET tend to cancel out over a seven-day, or longer period. The potential for applying this type of approaches to schedule Taiwan's irrigation is an important area of research, which is worthy for further evaluation.

Ratio of eqaution estimated ET and measured A-Pan ET. AS we mentioned before, many equations were developed to estimate ET. Three basic formulas (Penman, 1948; Monteith, 1964; Priestly and Taylor, 1972) are shown below.

Penman (1948) $ETo = [\, s(R_n - G) + \gamma f(u)(e^* - e_a)] / (s + \gamma)$

Monteith (1964) $ETo = [\, s(R_n - G) + \rho_a C_p (e^* - e_a) / r_a] / [(s + \gamma)(1 + r_c / r_a)]$

Priestly and Taylor (1972) $ETo = \alpha\, s(R_n - G) / (s + \gamma)$

where r_a, aerodynamic resistance; r_c canopy resistance; f(u), function of windspeed; ρ_a, the density of moist air; and C_p, specific heat of air at constant pressure. α is a equilibrium evaporation parameter. ETo is the refered ET.

R_n = net radiation
G = sensible heat fluxes related to plants or water
e^* = saturation vapor pressure = $6.11 \exp[(17.27T) / (T + 237.3)]$ (mbar)
e_a = actural ambient vapor pressure which can be calculated when wet bulb temperature T_w is measured
$= e^*_w - \gamma (T_a - T_w)$ (bar)

where e^*_w is the saturated vapor pressure at T_w, T_a is the actual temperature and γ is the slope from e_a to e^*_w or the psychrometric constant. Both T_w and e^*_w are obtained by psychrometers. "s" is the slope of the saturation vapor pressure curve at T_l, the leaf temperature.

Many other simpler and weather driven methods are developed to compute potential ET with different requirements on weather data inputs (Allen et al., 1989; Allen and Pruitt, 1991; Hargreaves, 1994; Snyder and Pruitt, 1994.) The estimation procedures commomly used today are based on the correlation of measured ET with one or more climate factors, e.g. temperature, sunshine duration, irradiance, evaporation, relative humidity, vapor pressure deficit, and wind velocity. Snyder and Pruitt (1994) developed a program in which 10 different commonly used equations were included to calculate monthly reference evapotranspiration rates. They included the following equations in their program: original Penman (PEN), Penman-Monteith (PENM), Priestley-Taylor (PT), Jensen-Haise (JH), Hargreaves (Harg), SCS Blaney-Criddle (SBC) and another 4 corrected FAO equations. The corrected FAO equations are: the FAO Penman, FAO Blaney-Criddle (FAOSBC), FAO Radiation (FAO-RAD), and FAO Pan methods.

We have tested these equations by comparing these estimates with the measured A-Pan estimates (ETp) for Hualian and Ilan environments. Of these methods, except FAOSBC, JH and FAO-RAD, the ET values estimated from the other equations are all within 20% deviation from the measured ETp. This is true accross all months and for both Hualian and Ilan stations (Figures 3 and 4). These results imply that the equations shown above can be accurately applied to estimate ET in areas where only weather data are available but "A" pan data are not. Or ETp is estimable at all meteorological stations in Taiwan, which is a much larger number than that of agricultural meteorological stations. In order to further convert the estimated ETs to specific crop ETs, experimental data must be collected to establish the relationships between ETp and ETc. Section below describes the experiments have conducted and the data have collected up to this time.

EXPERIMENTS AND PRELIMINARY ANALYSIS

The experiments and crop data collection were done in Hualian Crop Improvement Station and its branch station at Ilan. Three crops we studied: rice, onion and cabbage. A randomized complete block with 3 blocks design was used to study the rice phenology of Tainung 67 in Hualian. Rice was transplanted on August 13, 1997, and plant measurements were taken biweekly until rice was harvested on December 15, 1997.

Plant fresh and dry weights and leave area were measured at each sampling time and yields were taken from adjacent plots at the end due to luck of plant material in the experimental plots. Cabbage was study in the Ilan branch station and onion was studied at both Ilan and Hualian stations. In Ilan, cabbage data were collected from 3 blocks and 3 samples were taken from each block. Cabbage data were taken biweekly from Oct. 13 to December 8, 1997. Cabbage data collected include leave number, leave area, plant fresh and dry weights of root, leave, stem and cover leaves. Onion data were collected from 3 samples of 3 blocks each. The measurements include shoot number, leave number, plant height, stem length, fresh and dry weights of root, stem, and leave. Data were taken biweekly from November 3, 1997 to January 12, 1998. In Hualian station, Rice data were collected by Jiunn-dwu Wang and his associates in the rice research group, and onion data were taken by Poon Huang. In Ilan station, data were taken by Jian-Shen Chang. Crop evapotranspiration data will also be taken by Mr. Chang in Ilan in 1998. In addition, weather data were received from Jen-Yu Liang of CWB and Mr. Wang of Hualian station. The process of data collection will be extended through out 1998.

Based on the weather data and the crop sampling dates, cumulative sun shing hours (CSH), cumulative radiation (CR), and heat units (HU) are calculated. The crop and weather indexes are presented in Table 1 for Rice, Table 2 for Onion, and table 3 for Cabbage. The heat unit that is also known as degree-days (DD), is calculated based on a method described by UCD IPM program. The maximum and minimum air temperature thresholds were set respectively at 10°C and 40°C and double triangle method, horizontal cutoff were used to calculate the area under temperature curve. Figure 5 illustrates the method graphically.

The relationships of the plant growth and the weather units are shown in Figures 6-8, respectively for rice, onion and cabbage. There relationships provide preliminary ideas on modeling the plant growth and estimating the ETc. It is clear that DD, CSH, and CR are strongly linearly related. Thus only one of these variables would be needed to modeling the plant developments. A curveatural relationship between the weather and leave growth parameters was observed for rice and cabbage but not for onion. We are still in the process of collecting additional pant growth data in 1998. We anticipate a simple degree day model can be developed for cabbage and onion. These models can easily be related to weather conditions for water management and irrigation recommendations. For purpose of illustration, we have run an existing rice model, DSSAT, to demonstrate the possible information that may be obtained from the model output. Figure 9 shows the simulated evapotranspiration of rice plant and the components of water loss due to plant and soil. The water evaporated from soil and plant can be calculated on daily basis for the entire growing season.

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Figure 1. Measured "A" Pan ET values in Hualian

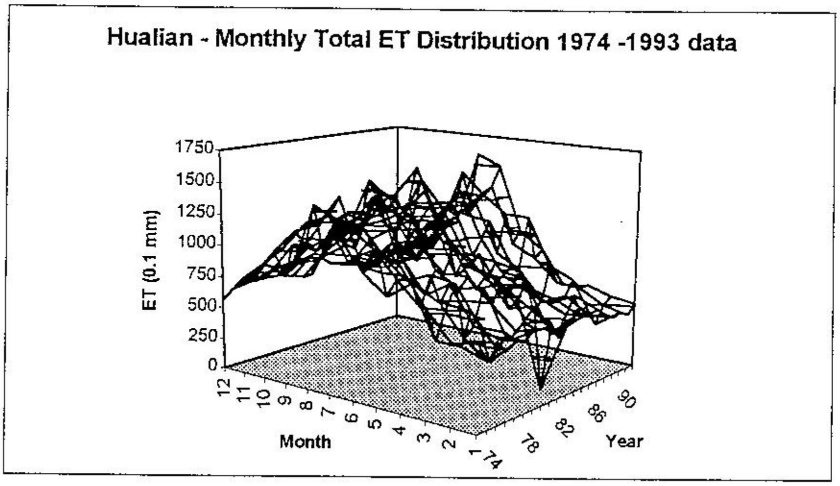

Figure 2. Measured "A" Pan ET values in Ilan

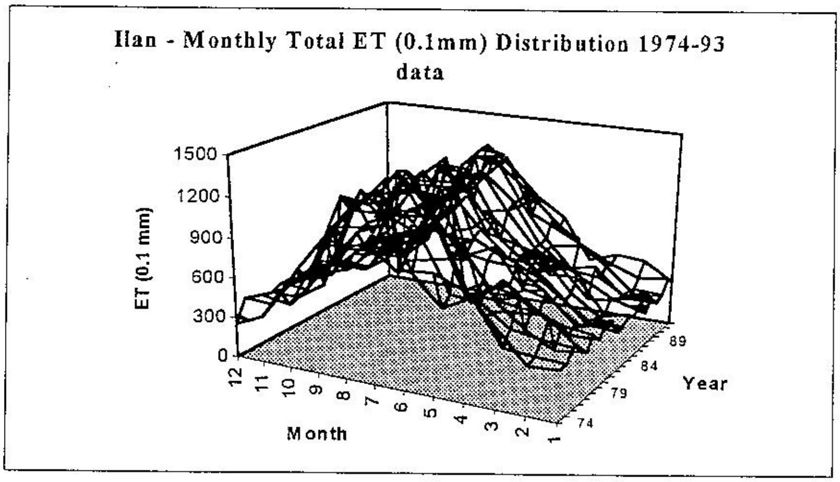

Figure 3. Ratios of Equation estimates and A-Pan measurements in Hualian

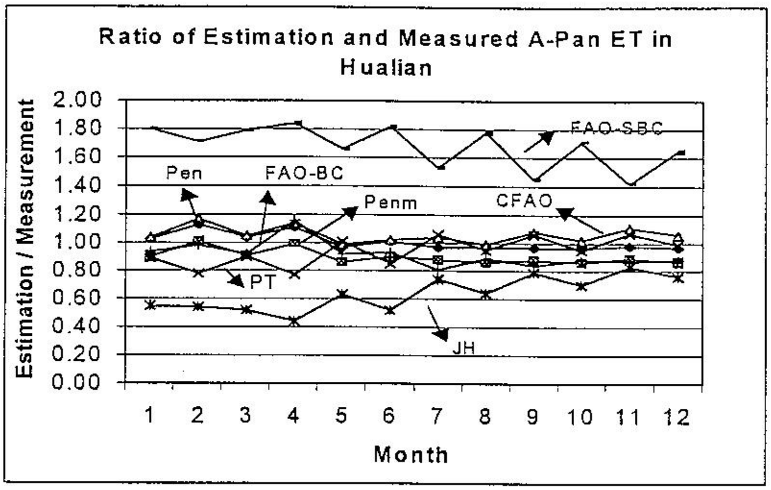

Figure 4. Ratios of Equation estimates and A-Pan measurements in Ilan

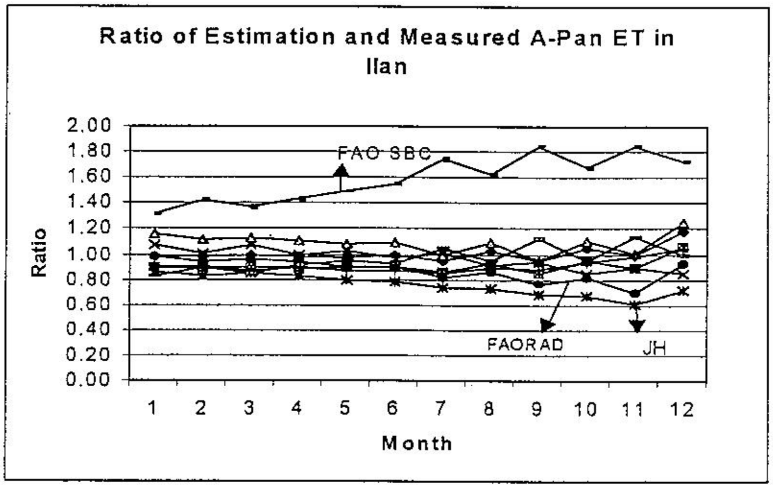

Figure 5. Degree Day Calculation Rules (Taken from UCD-IPM program)

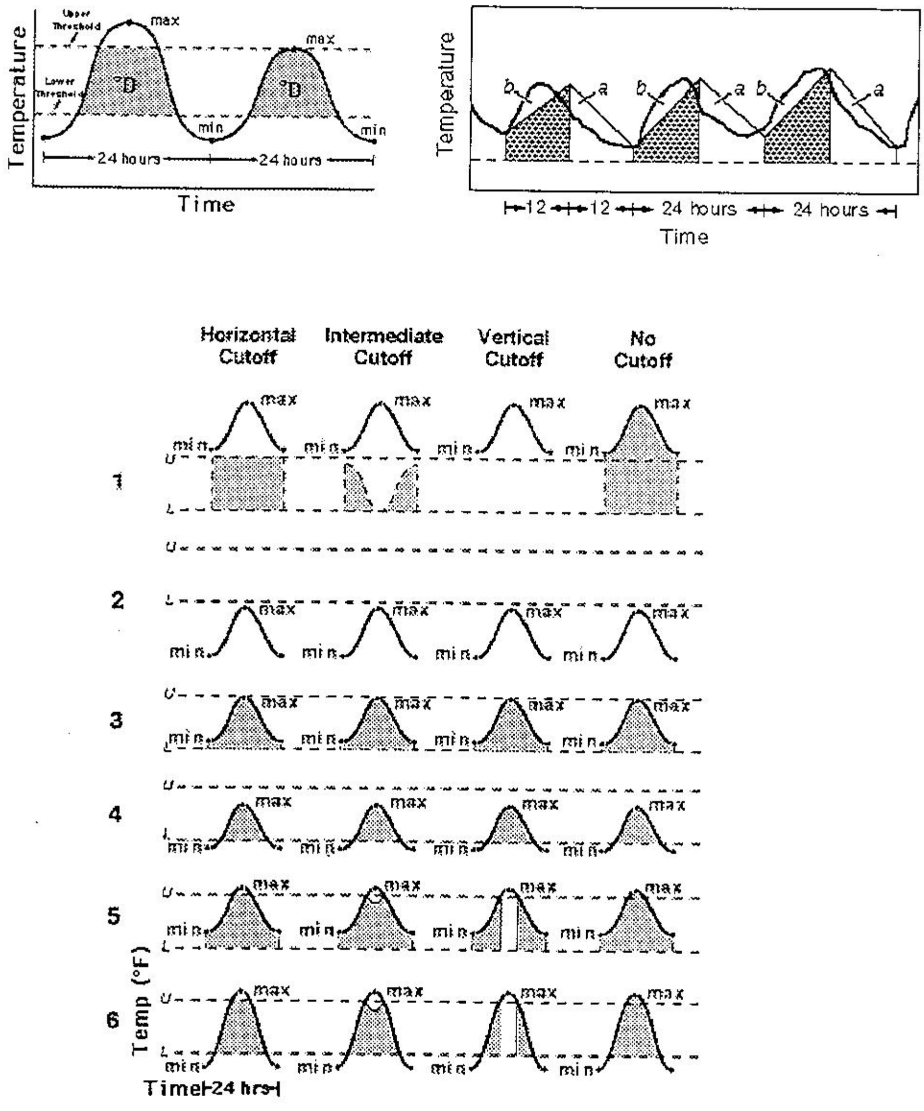

Figure 6. Relationships of Rice Phenology and Weather Parameters

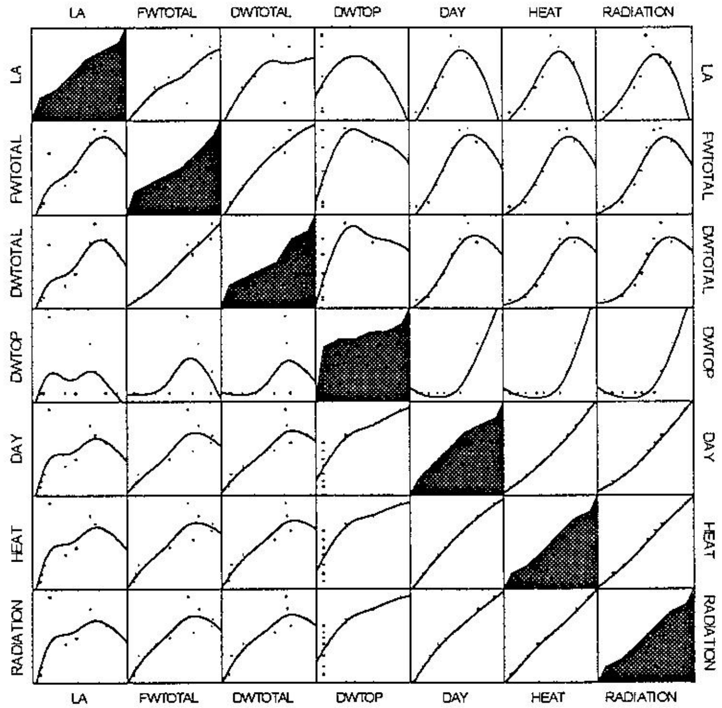

Figure 7. Relationships of Onion Growth and Weather Parameters

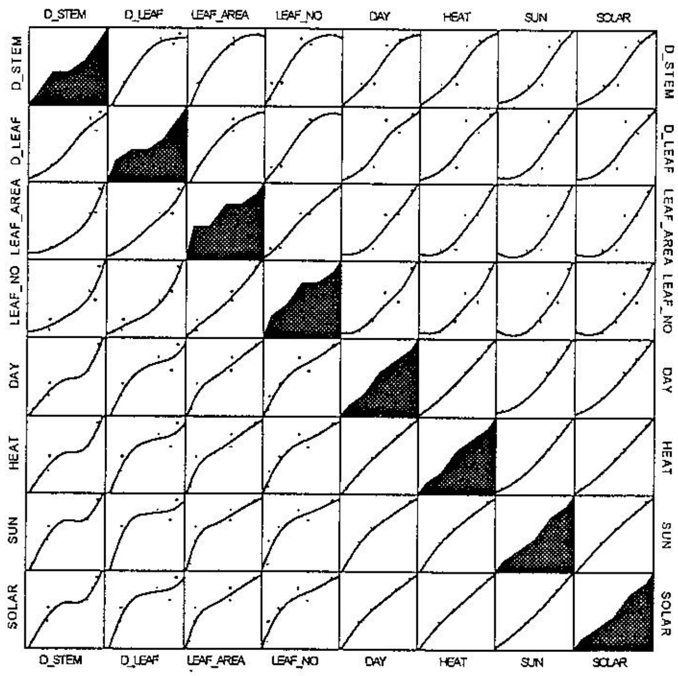

Figure 8. Relationships of Cabbage growth and Weather parameters

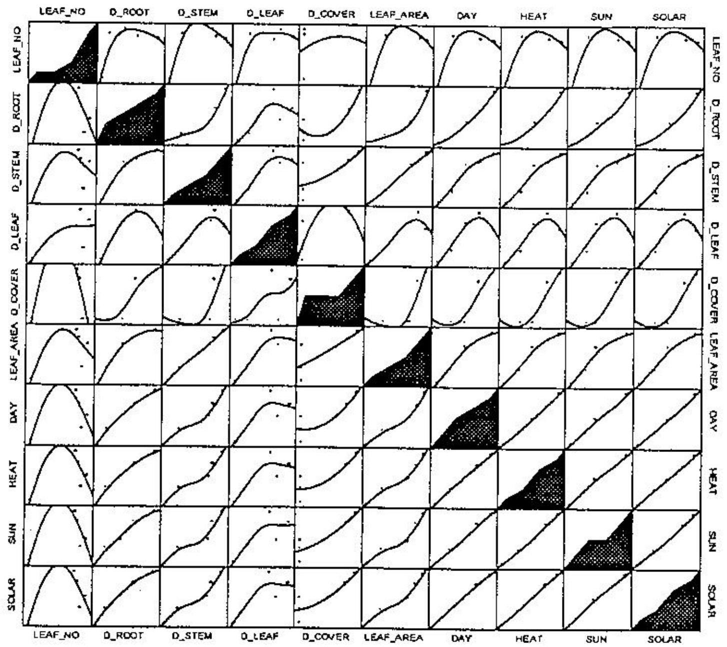

Figure 9. Simulated Evapotranspiration from Rice Model

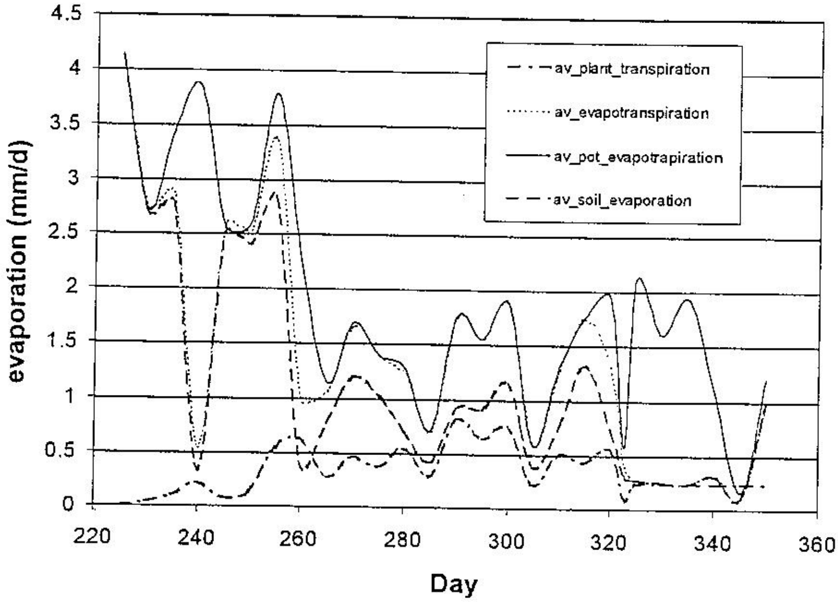

Table 1. Rice Growth and Weather Data in Hualian Station (all weights are in kg/ha)

Date	Leaf Area (cm^2/hill)	Fresh Weight	Fresh Weight of Tops	Dry Weight	Dry Weight of Tops	Days After Transplant	Heat Unit (degree-day)	Cum. Sun Unit (hour)	Cum. Radiation (MJ/m2)
8/13/97	5.2	30	0	7	0	1	18.5	3.4	11.1
8/22/97	18.2	141	0	22	0	10	183.1	23.0	82.0
9/2/97	42.7	615	0	89	0	21	372.0	67.8	183.7
9/15/97	231.7	2993	0	452	0	34	593.1	109.7	299.3
9/26/97	321.7	4904	0	852	0	45	747.7	123.6	356.8
10/9/97	701.4	8133	. 0	1430	0	58	929.2	135.5	411.3
10/22/97	593.8	10600	0	1919	0	71	1120.7	157.3	474.0
11/4/97	493.1	10807	1104	2422	444	84	1280.5	185.3	538.6
11/19/97	452.7	8978	1978	1815	1015	99	1447.9	263.2	638.2
12/15/97	90.3	7430	2363	1763	1570	125	1723.6	340.5	754.5

Table 2. Means Green Onion Growth (of 3 stocks) in Lan-Young Branch Station of Hualian Crop Improvement Station.

Date	*Bran-ches*	*Ht (cm)*	*WL (cm)*	*FRW (g)*	*FSW (g)*	*FLW (g)*	*DRW (g)*	*DSW (g)*	*DLW (g)*	*LA (cm^2)*	*LN*
11/3/97	8.7	54.3	14.3	4	29.8	40.9	0.56	1.9	2.7	708.7	21.3
11/11/97	11	55.3	14.7	3.7	43.8	65.7	0.56	4.4	5.4	1212.7	25.3
12/1/979	12	61	16	5.8	62.5	92.1	0.63	4.5	5.7	1296	31
12/15/97	17.3	66.3	15	16.3	164.9	344.8	1.63	10.6	20.1	3554	56
12/29/97	15.7	71.3	15.3	14.8	152.0	332.8	0.66	11.6	16.4	5116.3	48.3
1/12/98	15.3	71.3	15.3	22.6	199.7	414.3	1.1	12.2	22.0	7780	78

Table 3. Mean Cabbage Growth Data from Ilan Station

Time	leaf No. (N/plant)	D root (g/plant)	D stem (g/plant)	D leaf (g/plant)	D cover (g/plant)	Leaf area (cm2/plant)	day	degree-day	sun (hour)	solar (MJ/m2)
10/13/97	11.8	0.10	0.13	1.7	0.0	582	28	382.6	60.8	227.7
10/27/97	18.4	0.87	1.50	18.3	0.0	4086	42	575.3	118.9	362.3
11/10/97	19.2	2.53	4.87	59.8	0.0	10533	56	719.0	153.8	474.4
11/24/97	18.1	3.90	5.30	75.4	46.4	12568	70	889.6	229.4	613.4
12/8/97	17.7	6.13	6.40	50.4	56.4	14436	84	1037.4	269.5	711.4