DETERMINATION OF CROP COEFFICIENT USING GROUND BASED CLIMATOLOGICALLY DATA AND VEGETATION INDEX DERIVED FROM NOAA/AVHRR SATELLITE

PENENTUAN KOEFISIEN TANAMAN MENGGUNAKAN DATA PENGAMATAN IKLIM DAN INDEX VEGETASI DARI SETELIT NOAA/ AVHRR

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ABSTRACT

One of the most important parameter of climatic water balance computation is crop coefficient (Kc). Unfortunately, the Kc is one of the most difficult parameter to measure in the field. This paper attempts to determine the crop coefficient by using climate observation data and the NDVI (Normalized Difference Vegetation Index) derived from NOAA (National Oceanic and Atmospheric Administration). Calculation using Morton's Complementary Relationship Areal Evapotranspiration (CRAE) method that used elevation (m), annual precipitation (mm), monthly air temperature (°C), sunshine duration (%), as minimum requirement data, has been applied for more than 900 climatic stations over the Asian region that well documented by FAO-CLIM agroclimatic database to obtain the Kc value. The result was then related to NDVI derived from spectral reflectance of NOAA/AVHRR data. The relation results of NDVI and crop coefficient gave significant linear equation as Kc = 0.08 + 1.83 NDVI, with average correlation coefficient 0.72. It was high over humid area such as in Java island of Indonesia; on the other hand, it was low in semi arid area, such as west part of India. Even the results above were fit only for a specified area; this study has demonstrated a potential use of NOAA image for supplying the crop coefficient value that would be particularly necessary to determine actual evapotranspiration.

Key words: crop coefficient, NDVI, and evapotranspiration

ABSTRAK

Salah satu komponen penting di dalam perhitungan analisis neraca air adalah koefisien tanaman (Kc). Masalahnya, Kc merupakan parameter yang sangat sulit diukur di lapang. Paper ini bertujuan untuk menentukan koefisien tanaman dengan menggunakan data observasi iklim dan citra satelit dari NOAA *(National Oceanic and Atmospheric Administration)*. Metode perhitungan untuk menghitung Kc adalah *Morton's Complementary Relationship Areal Evapotranspiration (CRAE)*, yang menggunakan input data: ketinggian (m), curah hujan tahunan (mm), suhu bulanan (°C), dan lama penyinaran. Metode ini diaplikasikan pada lebih dari 900 stasiun iklim di Asia yang didokumentasikan oleh FAO-CLIM. Hasil perhitungan Kc kemudian dikorelasikan dengan NDVI *(Normalized Difference Vegetation Index)* yang diperoleh dari satelit NOAA. Persamaan yang diperoleh adalah Kc = 0.08 + 1.83 NDVI, dengan koefisien korelasi rata-rata 0.72. Koefisien korelasi tersebut tinggi untuk daerah basah, seperti Pulau Jawa di Indonesia, tetapi rendah untuk daerah semi arid seperti di bagian barat India. Walaupun nilai korelasi tersebut signifikan untuk daerah tertentu, tetapi hasil penelitian ini menunjukkan bahwa citra satelit dapat digunakan sebagai salah satu alternative untuk menentukan koefisien tanaman, yang sangat dibutuhkan dalam perhitungan evapotranspirasi aktual.

κata kunci: koefisien tanaman, NDVI, dan evapotranspirasi

INTRODUCTION

A lot of research has been carried out to estimate the Kc for several types of vegetation (Testi, *et al*. 2004; Williamsa and Ayarsb, 2005). The most frequently used in this sense is the table of Kc value has been prepared by Doorenbos and Pruit (1977) for various crops depending on their growth stages, soil, and climate characteristics. Other experimental Kc also have been determined for a number of different crops, and are usually expressed as a function of growth parameter such as leaf area index, percent cover, and growth stage.

The Kc used to quantify the actual evapotranspiration (AET) as water requirement by irrigated crops as introduced by Doorenbos and Pruit (1977) and Allen *et al.* (1998). The actual evapotranspiration (AET), in mm/day as:

$$AET = Kc \times PET \quad (1)$$

where, PET is potential evapotranspiration (mm/day) and the Kc as defined before. The PET is estimated by using observations of pan evaporation or calculations based on Penman-Monteith algorithm or other methods such as were publicized in Jensen (1990), Kondoh (1994), as well Salazar and Poveda (2006).

Uses of these kinds of experimental data for a large area are difficult since they are usually consisting of so many kinds of crop species and seldom at the same stage of development. Remotely sensed data for spectral reflectance may provide an indirect estimate of Kc over the wide area (Choudhury, 1997). The feasibility of estimating Kc from spectral measurements occurs because both Kc and NDVI are affected by leaf area index and fractional ground cover. However, inconsistency in any relation between Kc and NDVI can arise from changes in both soil and atmospheric characteristics and also due to interactions between soil and vegetation in determining evapotranspiration rates.

This paper attempts to determine the crop coefficient by using the Morton method and the image satellite from NOAA. This simple relationship between ground based climatic data and satellite remote sensing products is important to estimate the actual evapotranspiration from potential evapotranspiration.

METHODOLOGY

Datasets

The meteorological data that derived from agroclimatic database created by FAO-CLIM in 1995 was used in the present study. The database contains monthly averages of eleven climatic data such as, precipitation, mean/maximum/minimum air temperature, water vapor pressure, wind speed, relative sunshine fraction, global incoming radiation, etc. The locations of the stations in the FAO database could be easily correlated with the pixels of the monthly NDVI image using latitude and longitude coordinates to get the NDVI value of each climatic station.

This study also used the twelve monthly NDVI data that compiled from thirteen years (April 1985-December 1997) monthly NDVI datasets in Time Series of 0.144º Global Monthly Vegetation Cover from NOAA/AVHRR CD-ROM ver. 1.0. These dataset was calculated from data collected by the onboard the NOAA-9 (April 1985-November 1988), NOAA-11 (November 1988-September 1994), and NOAA-14 satellites (February 1995-December 1997). The NDVI was generated from red and near-infrared (NIR) bands by (NIR-red)/(NIR+red). Theoretically, NDVI values range from –1 to 1. In general, high values of this index are obtained for areas covered by green vegetation and low values for unvegetated areas and cloud covered.

The datasets used here was resulted from several important processing required in land resources information system. They are accessible in digital files of the same coverage and resolution, which is flexible regarding aggregation towards coarser resolutions. Each independent satellite NOAA/AVHRR image and climatic data has been fine documented that allow the data to be implemented in other research subjects.

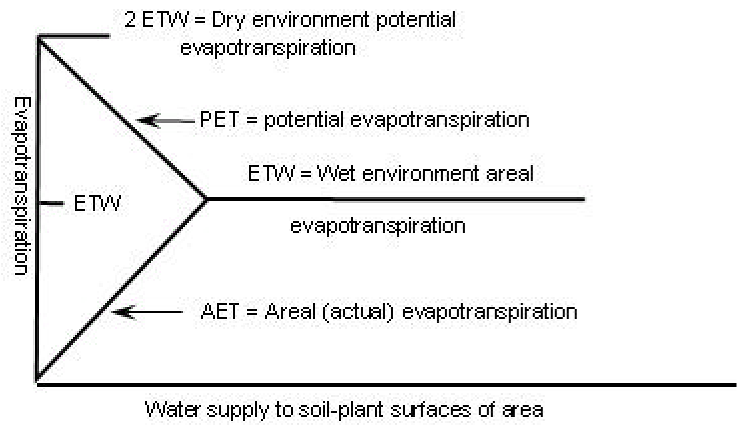

Figure 1. The complementary relationship between AET and PET (After Morton, 1983)

Morton Method

Figure 1 explains the Morton's complementary relationship between AET and PET (Morton, 1983). Under completely arid condition or zero supply, the PET would be at its maximum rate (2 ETW, the dry environment potential evapotranspiration), and the AET would be zero. As the water supply to the soil plant surfaces of the area increases, the AET would increase, equal to the supply, and the PET would decrease. Finally, when the supply of water to the soil-plant surfaces of the area has increased enough, the potential and areal evapotranspiration would be equal as ETW, wet environment areal evapotranspiration.

The PET computation is accomplished through estimation of potential evapotranspiration equilibrium temperature, T_p (°C), which is done by an iteration process. T_p is the temperature at which the energy balance and the vapor transfer for a moist surface give the same value of PET:

$$PET = R_T - [\gamma p f_T + 4\varepsilon\delta(T_p + 273)^3](T_p - T) \quad (2)$$

$$PET = f_T (v_p - v_D) \quad (3)$$

Where T is the air temperature (°C), R_T is the net radiation for soil-plant surfaces at air temperature (W/m^2). The term f_T is the vapor transfer coefficient (dimensionless); δ is the Stephan-Boltzmann constant ($W\,m^{-2}\,K^{-4}$); ε is the surface emissivity (dimensionless); v_D is the saturation vapor pressure at the dew point temperature (mbar); v_p is the saturation vapor pressure at T_p, (mbar); γ is the psychometric constant (dimensionless); ρ is the atmospheric pressure (mbar). ETW ($W\,m^{-2}$), is evaluated as given in equation:

$$ETW = b_1 + b_2\,[1+\gamma\rho/\Delta p]^{-1} R_{TP} \quad (4)$$

Where b_1 and b_2 are constants; R_{TP} is the net radiation for soil-plant surfaces at the potential evapotranspiration equilibrium temperature ($W\,m^{-2}$); Δp is the slope of the saturation vapor pressure curve at T_p, (mbar $°C^{-1}$). The γ and ρ terms are as defined previously. Upon estimation of PET and ETW, the value of AET, can be explicitly determined using the following equation:

$$AET = 2\,ETW - PET \quad (5)$$

The required station characteristics and climatologically inputs are the latitude (°), and altitude (m), average precipitation (mm $year^{-1}$), dew-point temperature (°C), air temperature (°C), and the ratio of observed to maximum possible sunshine duration (%).

The monthly Kc (as AET/PET) result was then related to monthly NDVI data by using the Curve Expert ver. 1.3, which is a comprehensive curve fitting system for Windows. It employs a large number of regression models (both linear and nonlinear) as well as various interpolation schemes to represent a data in the most precise and convenient way. In addition, it sifts through every possible curve fit, ranks the fits from best to worst, and presents with the best one.

RESULT AND DISCUSSION

Distribution of annual PET, AET, and Kc values

Figure 2(a) shows the distribution of potential evapotranspiration (PET) using Morton method. The range of PET is 0 till around more than 1000 mm year^{-1}, and we divided into 6 classes. The lowest value by < 1200 mm year^{-1} is distributed in sub tropical region such as China, Japan, Mongolia, etc. The medium value by 1200-2700 mm year^{-1} is distributed mainly in tropical region, such as in Indonesia, Philippines, Thailand, Malaysia, etc. The higher PET by more than 2700 mm/year is distributed in tropical region also such as India.

Figure 2(b) shows the distribution of annual actual evapotranspiration (AET) using Morton method. The range of AET is 0 till around more than 1800 mm/year, and we divided into 6 classes, and no doubt its distribution almost the same with the PET. The low value year is distributed in sub tropics region, while the high PET value is distributed in tropics region. The distribution of crop coefficient (Kc) using Morton method (Figure 2c). As expected, the distribution of Kc value is similar with the distribution of the greenness of vegetation. The highest Kc value (more than 0.8) is distributed in tropical rain forest such as Indonesia and Malaysia. The Kc value by 0.6-0.8 is mostly distributed in subtropics region such as the south part of China and Japan. The less value is covered in the conifer forest, grassland, and desert such as the central of China, and India.

Relationship between Kc and NDVI

Distribution of correlation coefficients with ranging from 0.0980 to 0.9824 (Figure 3). From this figure, the relation results of monthly NDVI and Kc gave significant correlation (more than 0.60) over Asian region such as, some stations in India, China, the west part of Burma and Thailand, as well as in Japan. The lower correlations (less than 0.60) are distributed in west part of India, West Asia, Philippine, and some stations in the middle of China.

Figure 4 illustrates a number of selected profiles of monthly NDVI and Kc over a one-year period for several correlation coefficients (r). Plot A, B and C represent the r less then 0.60, while Plot D and E represent the coefficient more than 0.60. Figure 5 shows the scatter diagram of the Kc versus NDVI data. This figure shows that, as expected, there was an acceptable positive relationship between annual Kc and NDVI data. The relationship is linear, with the correlation coefficient 0.72 for 957 stations. In view of this result, scatter diagram for all 957 individual stations were examined by applying either linear or nonlinear regression models.

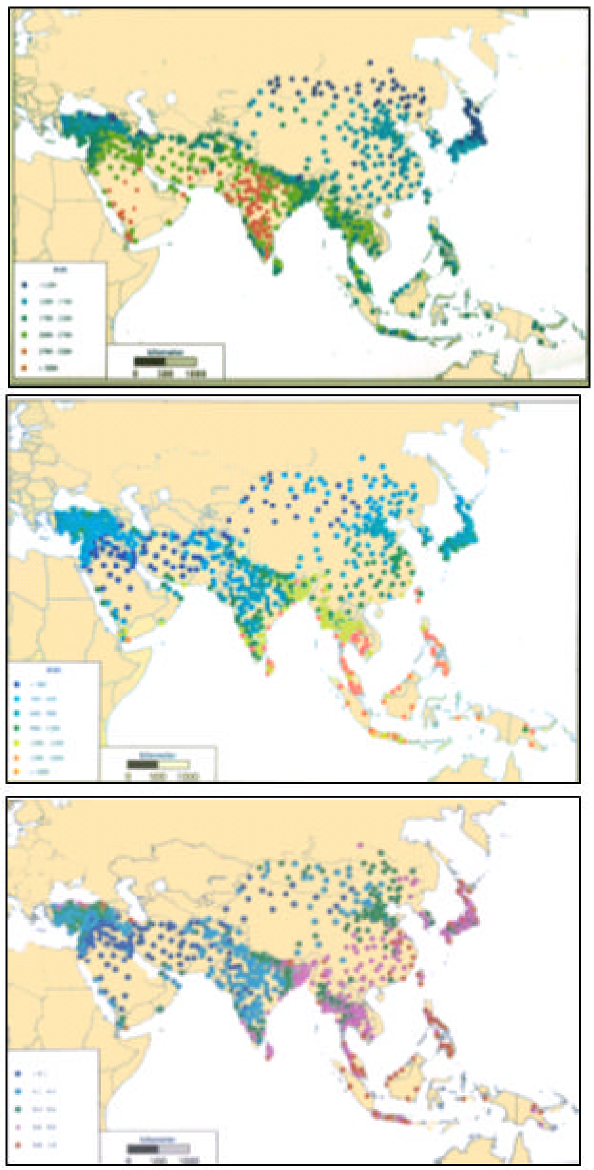

Figure 2. Distribution of (a) PET, (b) AET, and (c) Kc (AET/PET)

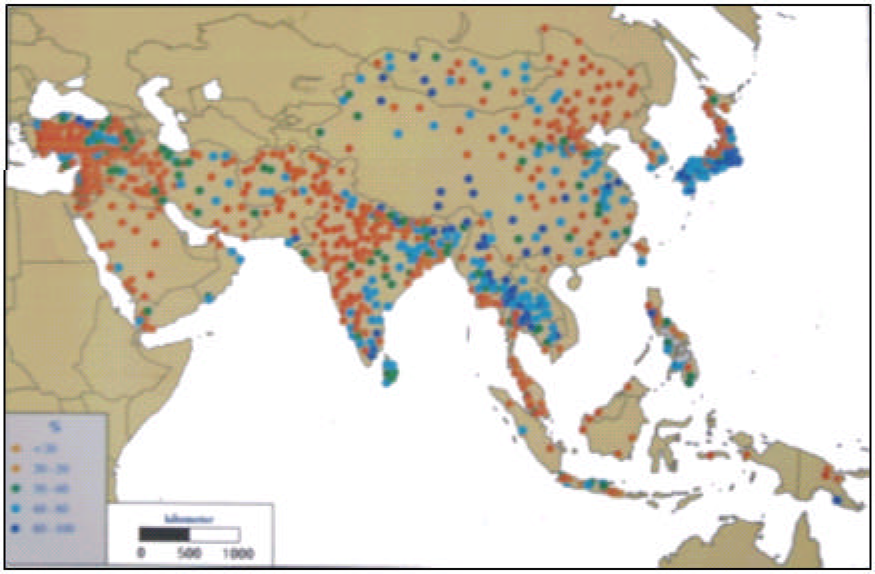

Figure 3. Distribution of correlation coefficients between Kc and NDVI over Asian region for 957 stations.

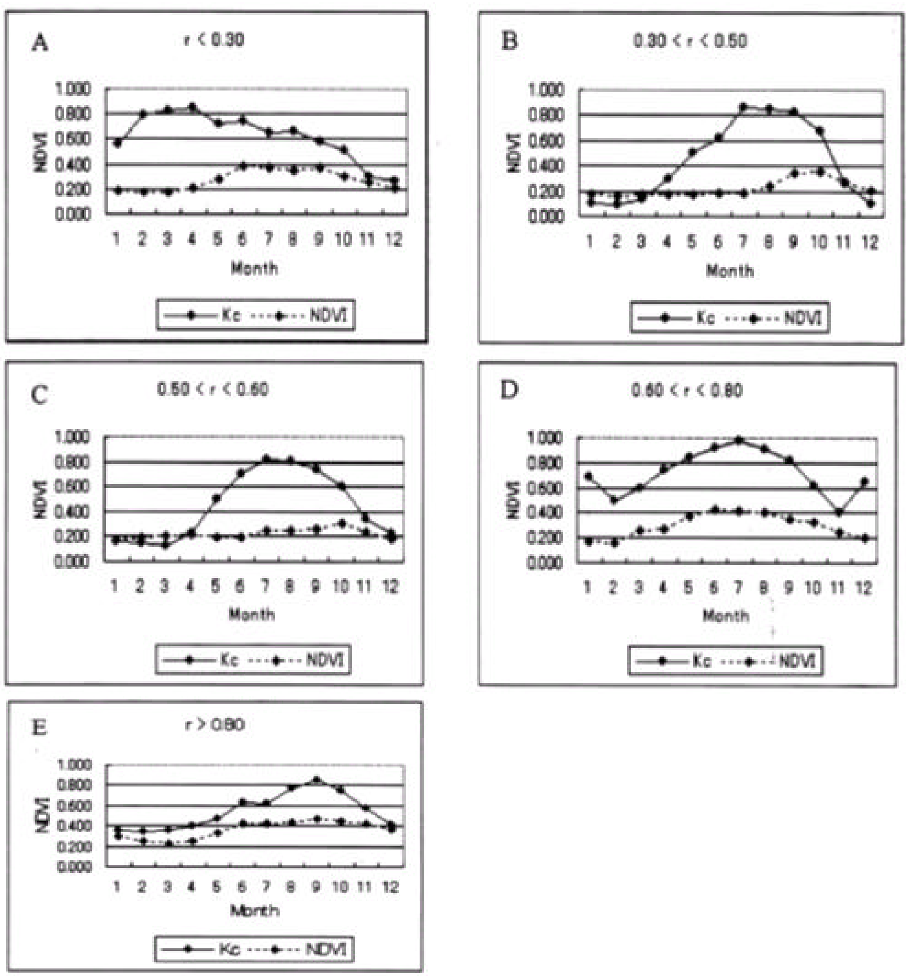

Figure 4. Temporal NDVI series for several correlation coefficients.

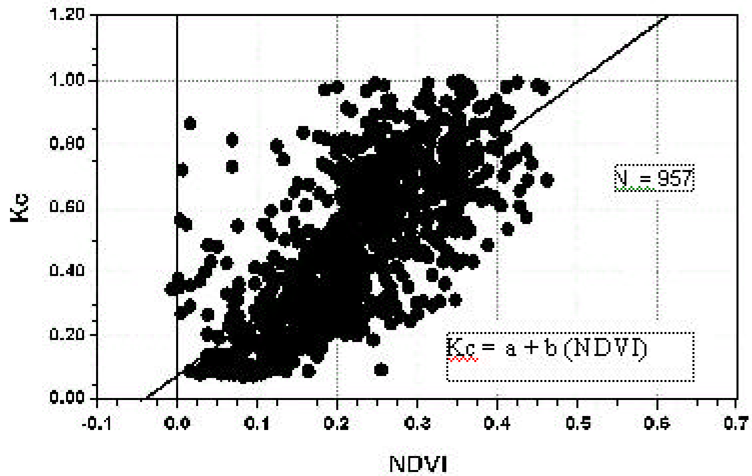

Figure 5. Scatter plot of annual NDVI versus estimated Kc. The parameters of linear regression are a = 0.08, and b=1.83.

I realized that this boundary corresponds well to that of distribution of rainfall and also the greenness of vegetation. As Heilman *et al*. (1982) noted that Kc will almost one when the soil surface is wet, regardless of crop stage of development or in other words, Kc can be increased by advection, or decreased when soil moisture becomes limiting. In addition, The Kc increases from a low value at the beginning of plant growth to a maximum at full cover.

CONCLUSION

This study has demonstrated several characteristics between NDVI and crop coefficient relationships over Asia. The relation result of NDVI and crop coefficient gave significant linear equation as Kc = 0.08 + 1.83 NDVI, with correlation coefficient 0.72. It was high (more than 0.60) over humid area such as in Java island of Indonesia; conversely, it was low in semi arid area, such as west part of India.

Even the results above were fit only for a specified area; this study has demonstrated a potential use of spectra reflectance for supplying the crop coefficient value that would be particularly necessary to determine actual evapotranspiration.

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REFERENCES

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome

Choudhury, B.J. 1997. Global pattern of potential evaporation calculated from the Penman Monteith equation using satellite and assimilated data, Remote Sens. Environ., 61: 64-81.

Doorenbos, J., and Pruitt, W. O. 1977. Guidelines for predicting crop water requirement, FAO Irrigation and Drainage Paper 24. FAO Rome, Italy.

Heilman, J.L., Heilman, W.E. and Moore, D.G. 1982. Evaluating the crop coefficient using spectral reflectance. Agron. 74: 967-871.

Jensen, M. E., Burman, R. D., and Allen, R. G. 1990. Evaporation and Irrigation Water Requirement, ASCE Manual No. 70, American Society of Civil Engineers, New York

Kondoh A., 1994. The comparison of evapotranspiration in Monsoon Asia by different methods.J. Japan Assoc. Hydro logical Sciences, 24, 11-30. (in Japanese with English Abstract)

Morton, F.I. 1983. Operational estimates of areal evapotranspiration and the significance to the science and practice of hydrology, J. Hydrology, 66: 1-76.

Salazar, L. F and G. Poveda. 2006. Validation of Diverse Evapotranspiration Estimation Methods using the Long-term Water Balance in the Amazon River Basin. *p*. 815-820. Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE,

Testi, L., Villalobosa F. J., and Orgaza F. 2004. Evapotranspiration of a young irrigated olive orchard in southern Spain. Agricultural and Forest Meteorology, Issues 1-2, 121: 1-18.

Williamsa, L.E, and Ayarsb J.E. 2005. Water use of Thompson Seedless grapevines as affected by the application of gibberellic acid (GA3) and trunk girdling – practices to increase berry size. Agricultural and Forest Meteorology, Issues 1-2, 129: 85-94.