1. Summaries of Doctor Theses

A New Method for Estimation of Evapotranspiration

Guo Yu Qiu

Subdivision of Water Resources, Division of Arid Land Environment

(Doctor's degree received in September, 1996)

Evapotranspiration (ET) and crop water stress index (CWSI) are two key variables for efficient agricultural water management. The process of ET is not only a function of meteorological parameters but also a function of soil and plant parameters. Because of these complex processes, it has been quite difficult to accurately estimate ET. The extensive use of the weighing lysimeter method is restricted due to its high cost and limited location. Other water balance methods are not accurate enough over short periods and the errors in the measurement of various terms in water balance equations are passed on to ET. Though micrometeorological methods have provided voluminous formulae to calculate ET, such as the Penman-Monteith method, Bowen Ratio method et al., their applicabilities are limited to large, flat areas with a uniform vegetation cover. Due to large instrument requirements, micrometeorological methods may be costly. Moreover, crop correction factors, empirical coefficients, or estimations of aerodynamic and canopy resistances are required to estimate actual ET. In natural environments, micrometeorological methods rely heavily on empirical formula to define the resistance to water vapor movement. There are many factors and assumptions that can make the extrapolation of these formula to new situations unreliable. Accurate estimations of canopy resistance and aerodynamic resistance are the major difficulty to determining ET. Plant physiological methods are designed to estimate transpiration. Though the techniques, such as porometer and heat pulse, are suited to large plants, hilly terrain, small plots, and isolated trees, these methods are applicable only over short periods, or usually, correlation coefficients are required to estimate the actual transpiration. Thus, there has been a long search for theoretically sound and simple method, which would overcome these shortcomings.

CWSI is another key factor for agricultural water management. Two forms of CWSI based on canopy temperature have been proposed, an empirical approach reported by Idso, and a theoretical approach reported by Jackson. The Idso's method estimates CWSI by determining "non-water-stressed baselines" for crops, and estimation of the upper limit of temperature that a non-transpirating crop will attain is necessary. However, the non-water-stressed baselines change not only with the crop variety but also with seasons. The Jackson's CWSI is estimated by meteorological parameters and an aerodynamic resistance factor. Because these variables are site-specific, it is a delicate operation to get the representative meteorological data for a field practice in a small and heterogeneous crop area. Requirements of large uniform fields and local meteorological data are the main problems facing application of Jackson's CWSI.

This study was conducted to develop, test and apply a new method to estimate soil evaporation and plant transpiration. In this method, ET can be estimated by using three different temperatures. Therefore, this method is named as the "three temperatures method". Sensitivity analysis shows that though three temperatures are the most sensitive input parameters to estimate soil evaporation, changes in the three temperatures together would not cause a significant error in evaporation. Errors of 5% in each of the three individual temperatures would result in changes from -0.17% to +0.17% in ET. Errors of 90% in the three temperatures would only result in changes from -2.81% to +3.15% in ET. The suggested method has a strong error resistance to simultaneous changes (for example, system errors et al.) in the three temperatures.

In the case of estimation of soil evaporation, the three temperatures are soil surface temperature, dry soil surface temperature, and air temperature. The test experiment was conducted in a sand soil field. A weighing lysimeter, four dry soil columns, and a variety of other equipment were installed in this field. Soil evaporation, soil and dry soil surface temperatures, soil and dry soil temperature profiles, air temperatures, wind speed, air humidity, solar radiation, net radiation, reflection of soil and dry soil, and heat fluxes in soil and dry soil were measured and all these data were recorded with four dataloggers at an interval of 30 minutes. The verification was done over a period of one month and over a wide range of soil wetness and temperatures. Experimental results showed that daily evaporation computed with the three temperatures method was in good agreement with lysimeter measured values. Furthermore, soil evaporation calculated by use of infrared thermometer measured temperatures was also consistent with measured evaporation. Therefore, it is concluded that soil evaporation can be accurately estimated by the three temperatures method.

In the case of estimation of plant transpiration, the three temperatures are sunlit leaf temperature, imitation leaf temperature, and air temperature. The imitation leaf is defined as a leaf without transpiration. The major advantage of the proposed method is that plant correction factors, empirical coefficients, and canopy and aerodynamic resistances are not required for calculating the plant transpiration. An experiment was conducted in a one hectare sorghum (*Sorghum bicolor* (L.) Moench.) field. Results were compared with the transpiration obtained by the lysimeters and porometer. The hourly transpiration measured by porometer is consistent with the calculated transpiration. Furthermore, the calculated daily and longer-period plant transpiration by the proposed method are also consistent with the results estimated by a weighing lysimeter and microlysimeters. Therefore, plant transpiration levels for hourly, daily, and longer periods can be accurately estimated by this method.

There are a number of methods to estimate ET. A few of these commonly used methods were selected for comparison with the three temperatures method. The selected methods were Penman-Monteith, Bowen ratio, and Temperature difference. A comparison experiment was conducted. Extensive measurements of microclimate variables, soil water variables, and soil heat variables were made. Results show that both the estimated transpiration by Penman-Monteith and three temperatures method agree with the lysimeter measured values. The mean absolute error (MAE) between the measured and Penman-Monteith methods and the MAE between the measured and three temperatures methods are 0.42 mm day^{-1} and 0.45 mm day^{-1}, respectively. The MAE values between the measured and Bowen ratio methods is 0.63 mm day^{-1} and between the measured and Temperature difference methods is 0.69 mm day^{-1}. From above, it is found that the MAE values of all these methods are less than 1 mm day^{-1}. The performance of the three temperatures method can be as good as or better than the other commonly used methods.

The three temperatures method was extended for detecting of CWSI. Aerodynamic resistance is avoided by introducing the imitation leaf temperature. The reported method has the advantages of being theoretically sound and practically simple. The method was applied to a field experiment and the results were compared with Jackson's CWSI. Values of CWSI calculated by the three temperatures method are in agreement with the Jackson's CWSI. These results suggest that the three temperatures method is a reasonable method to detect crop water stress.

Effects of Low Root Temperature on Growth, Transpiration, Nutrient Composition and Root-born Phytohormones in Tomato, Sesame and Rapeseed Plants

Imad-eldin Ahmed Ali

Subdivision of Plant Ecophysiology, Division of Biological Production

(Doctor's degree received in March, 1997)

In the arid desert areas, root-zone temperatures fluctuate both diurnal and during the growing season with cold or frost nights followed by clear sunny days. Under these arid conditions plant desiccation often occurs after a cold night. This might be attributed to the low soil temperature effects on uptake and transport of water and nutrients as well as its effect on root-born phytohormones.

The objectives of this study were 1) Clarification of the role of roots under low soil temperature stresses in the regulations of growth and development of shoots and 2) Understanding of mechanisms related to the differential responses of plant species, adapted to different climatic environments, to low root temperatures. A minor objective was also to examine the responses of the different plant species to different forms of nitrogen at low root temperature. This work focused on the response of seedlings three different crop species: tomato (*Lycopersicon esculentum* Mill.), sesame (*Sesamum indicum* L.), and rapeseed (*Brassica napus* L.), to low, constant or variable (day/night) root temperatures under different $NO_3^-:NH_4^+$ ratios, as sources of N, in the irrigation solution. Plant species were selected to represent different climatic environments. Root temperature treatments were identical for tomato and rapeseed, being 12/12, 16/8 and 20/20°C (day/night), and 15/15, 20/10 and 25/25°C (day/night) for sesame. The lower two temperatures in each experiment remained constant or varied for day and night periods, so that their average resembles that of the constant low root temperature. The ambient conditions for the shoots were kept constant for each individual plant species. The plant species were studied in separate experiments, using growth cabinets in which shoot and root temperatures were independently controlled.

Low root temperature reduced the shoot growth of the three plant species. Lowering the root temperature from 20/20°C to 12/12°C reduced shoot growth by about 25% in rapeseed and nearly 50% in tomato. In sesame lowering the root temperature to 15/15°C resulted in a 50% reduction in shoot growth as compared to the 25/25°C. The variable low root temperature, having the same average as that of the low constant one, did not affect the shoot growth of sesame or rapeseed, as it did in tomato, in comparison with the constant low root temperatures. The influence of low root temperatures on sesame and tomato roots growth was similar to that on their shoots. For rapeseed, however, the effect on root growth was negligible. The soluble carbohydrates concentration, expressed as mg g^{-1} DM, increased at low root temperatures in the shoots and roots of tomato and sesame, while in rapeseed the increase was only in the roots. The relative partitioning of the carbohydrates between the shoots and roots, in the three plant species, increased in the roots, but decreased in the shoots at low root temperatures.

The three plant species showed a conspicuous reduction in the transpiration at lower day time root temperatures. The root xylem exudation of the detopped plants decreased drastically at the low root temperatures. The measurements of sap flow rate in the stems, and of leaf temperatures in tomato, at different root temperature regimes showed clearly the decrease in water transport through the plant with the fall in day root temperature.

The nutrient composition in the shoots and roots of the three plant species were affected differently by low root temperatures. Both tomato and sesame showed a very similar trend for the cations and anions content. At low root temperatures, the concentrations of NO_3^-, $H_2PO_4^-$ and K^+ in the shoot tissues of the two species decreased, while their concentration in the roots increased. In the rapeseed plants the concentrations of $H_2PO_4^-$ and K^+ were not affected by the root temperature while that of NO_3^- in the roots increased at high root temperature. The concentration of Na^+ was increased in the shoots of tomato and sesame plants at low root temperatures, but was not affected in rapeseed. In the three plant species, Na^+ concentration in the roots was much greater than in the shoots. The partitioning of the accumulated total nitrogen, between the shoots and roots, was significantly affected by the root temperature treatments in the three plant species. It was apparent that the shoot-N decreased at low root temperatures, while the root-N increased. The concentration of NO_3^- in the xylem exudate of tomato and rapeseed plants increased at the lower root temperatures, while in sesame plants it was not affected. When this NO_3^- concentration was related to the volume of the xylem exudate, an increase in the total NO_3^- at the high root temperatures was apparent for sesame and tomato only.

Low root temperatures had indisputable effect on the root production of cytokinins and gibberellins, and their upward transport to the shoot. In tomato and sesame plants, the transport rate of cytokinins was more affected than its production at low root temperature. The production and upward transport of gibberellins were similarly affected by the low root temperatures in all three plant species.

In conclusion, low root temperature reduces water transport through the plant as a result of its effect on the hydraulic conductivity of the root membranes. This reduction causes a decrease in the upward transport of the root-born phytohormones and nutrients from the root to the shoot. The reduction in the upward transport of the phytohormones, cytokinins and gibberellins, might have a role as root-signals and regulate shoot development to match the uptake of water and nutrients. This regulation of shoot may be influenced by shoot/root ratio and water flux. Root temperature also may affect the production of phytohormones in the roots. Plant species, adapted to different climatic environments, respond differently to low root temperature, due to their specific nutrient uptake capacity and their different partitioning of the dry matter between shoot and roots. Increasing NH_4^+ in the nutrient solution has no effect on plant growth under different soil temperature, but only affected the uptake of calcium, magnesium and chloride, thus influenced the ionic balance in the plant tissue.