Changes in Evapotranspiration of Summer and Winter Crops of Netted Melon Grown under Glass in Relation to Meteorological and Plant-related Factors

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Summary

Measurements of evapotranspiration taken in the summer and winter on netted melon crops grown under glass were taken to characterize seasonal and daily changes. The data were compared to meteorological and plant-related factors to seek some relationships.

Evapotranspiration followed a sigmoid curve until one week after pollination, and then decreased gradually during fruit growth. Cumulative evapotranspirations after transplanting were about 116 kg and 60 kg, respectively, for the summer and winter crops, whereas the peak evapotranspirations were $3.0 \text{ kg plant}^{-1} \text{ day}^{-1}$ and $1.3 \text{ kg plant}^{-1} \text{ day}^{-1}$. The rapid increase in the evapotranspiration during the early stage was associated with the increase in leaf area; its gradual decrease during fruit growth was associated with a decrease in the transpiration potential of leaves. Therefore, irrigation amounts should be increased with leaf development and decreased with fruit growth.

The curve of solar radiation in sunny summer days peaked at noon, whereas vapor pressure deficit usually peaked in early or mid afternoon; evapotranspirations in the afternoon had higher values than had those in the morning. In winter, vapor pressure deficit was relatively high during late afternoon and early morning because of heating, whereas it was low during the remainder of the day on account of low ventilation. These fluctuations led to a weak correlation between evapotranspiration and vapor pressure deficit.

Regression analyses indicated that solar radiation was a main meteorological factor affecting evapotranspiration.

Key Words: netted melon, evapotranspiration, solar radiation, vapor pressure deficit, leaf area.

Introduction

Evapotranspiration, the combined amounts of transpiration from plants plus evaporation from soil, influences not only water balance and air humidity in a greenhouse (Joliet, 1994), but also the irrigation requirement of plants (Naito, 1969).

Netted melons which are grown year round under glass, are exposed to a wide range of solar radiation, temperature, and humidity. Accurate estimation of evapotranspiration under various environmental conditions provides useful information for an intensive management of irrigation and humidity control to produce high quality fruits. However, there are few studies on evapotranspiration on netted melon culture and none on the winter crop.

According to Kamiya (1992), irrigation requirements for netted melon plants varied slightly from season to season. However, other researchers have reported

transpiration or evapotranspiration from greenhouse grown *Helxine solierolii* (Lake et al., 1966), cucumber (Kozai et al., 1982) and tomato (Okuya and Okuya, 1988) with respect to solar radiation and vapor pressure deficit. These results show that evapotranspiration and irrigation requirements vary with seasonal changes in solar radiation and vapor pressure deficit.

The objective of this work is to measure the amount of evapotranspiration from developing netted melons grown under glass during the summer and winter and to characterize it in relation to meteorological and plant-related factors.

Materials and Methods

Plant materials and greenhouse management

In two experiments which were conducted in a greenhouse, netted melon (*Cucumis melo* L.) 'Earl's knight natsu No. 2' (Sakata seed Co. Ltd.) seeds were sown on 22 June. Seedlings were transplanted on 10 July for the summer experiment, whereas 'Crest syutou' (Yokohama nursery Co. Ltd.) seeds were sown on 26 Septem-

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ber and the seedlings were transplanted on 16 October for the winter experiment. The plants in containers (26 × 38 × 23 cm depth) were trained vertically and in the ground beds, and irrigated daily according to weather and plant conditions. The tops of the main stems were pinched on 29 July and 17 November, respectively, for the summer and winter experiments. The greenhouse which is north-south oriented has a floor area of 50 m² divided into two rows of ground beds, separated by a central aisle. The container-grown plants for the evapotranspiration measurement were placed in the ground bed and lined with additional bedded plants at the same height to form a continuous canopy. In the summer, the plants were grown in 4 rows (two rows per bed) and the containers were in the second row from the east. In the winter, the plants were grown in 2 rows (single row per bed) and the containers were in the east row. Average plant densities, based on the floor area, were 1.08 plant m⁻² in summer and 0.76 plant m⁻² in winter. From weekly measurements of leaf dimensions, leaf area was estimated as

$$A = 6.81 \times 10^{-5} D^2 + 0.769 D - 6.25$$

where A is the leaf area (cm²), and D is the product of leaf width and length (cm).

The greenhouse was naturally ventilated through the roof and side windows when air temperature exceeded 25 °C; it was heated by a heater set at 18 °C and the warm air was distributed via ducts.

Evapotranspiration measurement

The evapotranspiration measurement system consisted of two electronic balances that were interfaced to a personal computer. Placing one container-grown plant on each balance, weight changes were recorded every 5 seconds; average data over 1 min were stored on the personal computer at a 3-min interval. Evapotranspiration data from two plants were similar; therefore, subsequent data were collected from one plant.

Measurements of environmental factors

Solar radiation was measured with pyranometers situated outside and inside the greenhouse, above the crop canopy. Aspirated dry and wet bulb thermometers, which were set at a height of 1.7 m to calculate vapor pressure deficit, were recorded every 3 min by a data logger. Hourly changes in solar radiation on the inside were calculated from the outside solar radiation and seasonal average transmissivity of the greenhouse.

Results and Discussion

Summer and winter evapotranspirations

The changes in inside solar radiation, average vapor pressure deficit, evapotranspiration, and leaf area after transplanting for the summer and winter crops are shown in Figs. 1 and 2, respectively. The numbers of days from transplanting to fruit harvest were 72 days

Fig. 1. The changes in inside solar radiation, average vapor pressure deficit, evapotranspiration and leaf area for the summer netted melon crop.

Fig. 2. The changes in inside solar radiation, average vapor pressure deficit, evapotranspiration and leaf area for the winter netted melon crop.

and 94 days, respectively, for the summer and winter crops. The leaf area per plant for the summer crop followed a sigmoid curve until one week after pollination, then remained constant at about 1.2 m². The trend of evapotranspiration also had a sigmoid curve until one week after pollination when the maximum rate of 3.0 kg plant⁻¹ day⁻¹ occurred; it then decreased gradually during fruit growth. The rapid increase in evapotranspiration during the early stage was associated with the increase in leaf area. General patterns of seasonal leaf development and evapotranspiration for the two crops were similar.

The peak evapotranspiration rates were 3.0 kg plant⁻¹ day⁻¹ for the summer crop and 1.3 kg plant⁻¹ day⁻¹ for the winter crop, which coincided with the period of rapid fruit expansion. Maximum evapotranspiration rates for netted melon crops, grown hydroponically or in soil using an auto-irrigator system, varied from 1.0 kg plant⁻¹ day⁻¹ to 2.5 kg plant⁻¹ day⁻¹ during July to September (Tamai, 1956; Kondo, 1967; Honda and Amano, 1972; Konishi, 1974). A relatively low evapotranspiration of 1.0 kg plant⁻¹ day⁻¹ was observed by Kamota et al. (1972) for summer netted melons, grown in a large plastic house.

The changes in evapotranspiration demand, leaf area, and transpiration potential of leaves determine the pattern of evapotranspiration. High rates of evapotranspiration in summer probably resulted from high values of solar radiation and vapor pressure deficit.

Cumulative evapotranspirations after transplanting were about 116 kg and 60 kg for the summer and winter crops, respectively, comparable to total irrigation. Using data from Figs. 1 and 2, the evapotranspiration rates adjusted for leaf area and solar radiation, decreased during fruit growth (Fig. 3). A seasonal de-

Fig. 3. Evapotranspiration rates, normalized by leaf area and solar radiation, during fruit growth stage of summer and winter netted melon crops. Normalized evapotranspiration was calculated as daily evapotranspiration divided by leaf area and daily solar radiation.

crease in the ratio of evapotranspiration to pan evapotranspiration was observed by Konishi (1974). Leaf conductance (mainly stomatal) changes with leaf age; as the leaf expands, it increases and attains a maximum peak, and then declines to a low value with leaf senescence (Burrows and Milthorpe, 1976). The decreased rates of evapotranspiration probably indicate that the transpiration rate of leaves decreased with age on account of decreased leaf conductance.

High soil moisture during fruit maturation reduced fruit sugar concentration (Wells and Nugent, 1980); this reduction is attributed to increased sugar consumption by anaerobic roots of flooded plants (Kroen et al., 1991). In systems with isolated beds, irrigation water is required to supply the evapotranspiration for plant growth. When irrigation water exceeds largely evapotranspiration, soil moisture becomes excessive. Therefore, the amount of irrigation water should be reduced gradually as evapotranspiration decreases.

Diurnal courses in evapotranspiration

The curve of solar radiation in sunny summer days peaked at noon, whereas vapor pressure deficit usually peaked 2 to 5 hours afterward (Fig. 4). The evapotranspiration in the afternoon had higher values than those in the morning. On an hourly basis, evapotranspiration

Fig. 4. Typical daily courses of solar radiation (outside and inside), vapor pressure deficit and evapotranspiration in the greenhouse during the summer when netted melons were being grown.

versus solar radiation curve for sunny days is represented by a counterclockwise loop (Fig. 5), whereas the evapotranspiration versus vapor pressure deficit curve is represented by a clockwise loop (Fig. 6).

Diurnal patterns of transpiration have been classified into one-peaked and two-peaked courses; one-peaked courses were observed with well-watered plants and two-peaked courses were observed when soil water was limiting (Schulze and Hall, 1982). On cloudy days, evapotranspiration versus solar radiation curve is almost a straight line, whereas on a sunny day it would be curvilinear. Hence, Sato (1989) reported that the coefficient

Fig. 5. Relationship between solar radiation and evapotranspiration in the greenhouse during the summer when netted melons were being grown. Solar radiation and evapotranspiration were indicated as hourly integrals.

Fig. 6. Relationship between vapor pressure deficit and evapotranspiration in the greenhouse during the summer when netted melons were being grown. Vapor pressure deficit and evapotranspiration were indicated as hourly mean and hourly integral, respectively.

of correlation between evapotranspiration and solar radiation on an hourly basis was low, but improved from 0.6 to 0.86 when the data from 10:00 to 14:00 were excluded.

Before the greenhouse was heated in the winter, curves representing the relationship between evapotranspiration versus solar radiation and evapotranspiration versus vapor pressure deficit were similar to those of summer crops. As winter progressed, air temperature decreased below the set points of heating and ventilation, so that the vapor pressure deficit in winter differed greatly from that in summer (Fig. 7). During midday, an increase in evapotranspiration resulted in the increase in the water content of the air in the greenhouse with less ventilation, leading to a decrease in vapor pressure deficit.

Evapotranspiration versus solar radiation curve in winter represented neither a linear nor a loop (Fig. 8) because the midday evapotranspiration rate was high in spite of low vapor pressure deficit, whereas in the morning and late afternoon, evapotranspiration was low in spite of high vapor pressure deficit (Fig. 9).

Effect of environmental factors on evapotranspiration

Evapotranspiration is influenced mainly by leaf area for a growing plant with a partial canopy cover, but af-

Fig. 7. Typical daily courses of solar radiation (outside and inside), vapor pressure deficit and evapotranspiration in the greenhouse during the winter when netted melons were being grown.

Fig. 8. Relationship between solar radiation and evapotranspiration in the greenhouse during the winter when netted melons were being grown. Solar radiation and evapotranspiration were indicated as hourly integrals.

Fig. 9. Relationship between vapor pressure deficit and evapotranspiration in the greenhouse during the winter when netted melons were being grown. Vapor pressure deficit and evapotranspiration were indicated as hourly mean and hourly integral, respectively.

ter full leaf expansion, it is affected mainly by meteorological factors (Naito, 1969). Therefore, when vapor pressure deficit and temperature affecting mature plants from the day they reached 70% of final leaf area to fruit maturity (6 August to 18 September for summer and 26 November to 13 January for winter), vapor pressure deficit and temperature were included as variables in the regression equations, their effects were small but significant (Table 1). Analyses of the data reveal that the best one-variable equation for estimating evapotranspiration is solar radiation.

Table 1. Regression equations for the estimation of hourly evapotranspiration. The analyses were done on mature plants from the day reaching 70% of final leaf area to the day of fruit maturity (August 6 to September 18 for summer and November 26 to January 13 for winter). E : evapotranspiration ($\text{g plant}^{-1}\text{hr}^{-1}$), S : inside solar radiation ($\text{MJm}^{-2}\text{hr}^{-1}$), V : average vapor pressure deficit (kPa), T : average temperature ($^{\circ}\text{C}$)

season	regression equation	R ²
summer	$E = 148.38 S + 10.66$	0.891
	$E = 106.19 V - 31.35$	0.635
	$E = 17.48 T - 392.56$	0.554
	$E = 122.56 S + 29.75 V - 8.27$	0.914
	$E = 125.87 S + 5.10 T - 116.49$	0.918
	$E = 117.11 S + 17.67 V + 3.62 T - 90.7$	0.924
winter	$E = 85.67 S + 11.08$	0.779
	$E = -54.10 V + 86.64$	0.125
	$E = 12.71 T - 236.71$	0.511
	$E = 82.31 S - 20.51 V + 32.64$	0.796
	$E = 73.57 S + 3.11 T - 51.72$	0.794
	$E = 58.80 S - 34.81 V + 5.44 T - 62.22$	0.830

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施設栽培された夏作、冬作の温室メロンの蒸発散量の生育時期別変化、日変化の特徴と蒸発散量に対する気象要因および植物要因の影響

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摘 要

施設栽培された夏作、冬作の温室メロンの蒸発散量を比較測定し、気象要因、植物要因が蒸発散量の生育時期別変化および日変化に及ぼす影響を検討した。

生育時期別の蒸発散量は、定植から開花後1週間まではS字型曲線で示すことができ、その後は果実生長にともなって徐々に低下した。定植から収穫までの全蒸発散量は1株当たり夏作116 kg、冬作60 kgであり、日蒸発散量の最大値はそれぞれ3.0 kg、1.3 kgであった。蒸発散量は生育初期には葉面積の増加につれ急増し、着果以降は葉の蒸散能力の低下につれて低下した。そのため、かん水量は葉面積の増加につれ増やし、果実の生長につれ減らす必要がある。

日射量、飽差、蒸発散量の日変化をみると、夏季晴天日においては日射量は正午ころ最大となるが、飽差はそれより遅れて最大となった。そのため、午後の蒸発散量は午前の蒸発散量に比べて大きくなった。冬季においては、飽差について特徴的变化が認められた。すなわち、夕方から早朝にかけての飽差は暖房により高く、昼間の飽差は低換気率のため低くなった。これにより、蒸発散量と飽差との相関は低くなった。

回帰分析の結果、蒸発散量に影響する主要な気象要因は日射量であることが認められた。

*現在：果樹試験場