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Water Consumption of Cucumbers during Vegetative and Reproductive Stages of Growth[1]

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Abstract. **The best irrigation schedule for pickling cucumbers (*Cucumis sativus* L.) involved removal of between 48 and 64% of the available water in the upper 90 cm of the soil profile between irrigations. The ratio (Kc) of consumptive water use to evaporation pan loss reached a maximum of 1.5 during the early harvest season. Moderate moisture stress had no significant effect on the grade or number of poorly developed fruit.**

Transpiration rate (ml/cm^2), leaf area, water use pattern, and total water use were compared in greenhouse and growth chamber environments for fruiting and nonfruiting cucumbers. Transpiration rate was higher and leaf area smaller for fruiting plants. Fruit production did not significantly affect total water consumption or the seasonal water use pattern.

Little specific research has been done on the water requirement of cucumbers. Several workers have stated that a constant supply of moisture is necessary during the life of the planting, especially during flowering and fruiting (4, 10, 13). Seelig (12) found that growers generally apply 46–61 cm of water[4] per season. Whitaker and Davis (14) recommended at least 38 cm for maximum production. Hammett et. al (4) said that cucumbers should have 2.5 to 3.8 cm of water per week depending on soil type.

Water use curves for the common gherkin *Cucumis anguria* L. were described by Hall (3). He observed that water absorption reached its maximum value during flower development, fertilization, and the early stages of fruit growth. As fruit development progressed, water absorption declined.

Our objectives were to 1) relate seasonal water use to evaporation pan data, 2) determine the optimum irrigation schedule, and 3) measure the effect of fruit growth and development on water consumption.

Materials and Methods

Consumptive use and irrigation schedules. The field experimental area consists of a silt loam, moderately well-drained soil measuring 82 × 82 m. It was divided into 16, 9.1 m square plots separated on all sides by 9.1 m buffer strips. Plots were individually irrigated with part circle sprinklers. Hydraulic weighing lysimeters of the type described by Middleton and Jensen (8) were located in the center of each test plot.

'Pioneer' (gynoecious hybrid, pickling) cucumbers were planted over the entire area including the buffer strips in rows 1.2 m apart and spaced 10–15 cm in the rows. Fertilizer (10N–8.6P–16.6K) at 672 kg/ha was broadcast and incorporated before planting.

Irrigation schedules based on the amount of water used by the plants between applications were assigned to plots arranged in a 4 × 4 Latin square design. The 1971 schedule was 1.2, 2.5, 3.8, or 5.0 cm water used between irrigations; 1972 schedule was 2.5, 3.8, 5.0, or 6.2 cm; 1973 and 1974 schedule 2.5, 5.0, 7.5, or 10.0 cm. We found that the effective soil moisture extraction depth for cucumbers was 90 cm. Since this soil holds 15 cm of available water per 90 cm of soil depth, each 1.25 cm of water removed equaled about 8% of the available soil moisture. The above irrigation treatments, therefore, ranged from 8 to 64% available water removal between applications. Differential treatments were initiated 35 days after planting.

Daily consumptive use was measured with the lysimeters and comparable evaporation losses by a 1.2 m diam evaporation pan.

Yields of cucumbers were obtained from 7.6 m sections in each of 2 adjacent rows. The fruit were graded according to size and deformed cucumbers were weighed separately during 1973 and 1974. The harvest period was limited to 1 month each year and ranged from 7 to 9 pickings.

The soil moisture extraction pattern for cucumbers was determined in a well-drained soil using a gravimetric procedure similar to that used for strawberries (1). Soil samples were taken from an area 125 cm × 6 m between 2 adjacent rows. Eighteen locations on a 25 cm × 3 m grid were sampled to a depth of 1 m in increments of 15.2 cm using a soil tube. Samples were taken just before and 24 hr after each irrigation. The amount of water extracted by the roots between irrigations was calculated for each depth increment.

Water use, leaf area, and transpiration rate. Water consumption during harvest in the field trials proved to be exceptionally high. This led us to further investigation of the effect of fruiting on water use, leaf area, and transpiration rate under controlled environmental conditions.

The first trial was carried out during the summer of 1974 in a fiberglass greenhouse located in Vancouver, Washington. With the exception of an exhaust fan, which was thermostatically actuated at 27°C, there was no control of environmental factors in the greenhouse. Twelve plants of 'Pioneer' cucumber of equal size and vigor were grown in plastic pots having a volume of 7.6 liters. The growing medium consisted of equal parts of vermiculite and ground peat moss with a slow release 10N–2.6P–3.3K fertilizer added at a rate of 4.2 kg/m^3. At field capacity each pot contained 6900 g of medium.

Plants were trained to a single stake and all laterals removed. Half of the plants were hand pollinated and the remainder had all flower buds removed daily. They were arranged in a paired plot design replicated 6 times. Pots within replications were rotated every third day to minimize any position effect.

Tensiometers were inserted 15 cm into the medium and plants were irrigated when the average tension was 30 centibars. Water consumption was determined by measuring the amount of water necessary to bring the medium back to field capacity at each watering. Three pots containing growing medium but no plants were placed among the plots to determine the amount of

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[4]Water use in terms of cm refers to hectare centimeter, the amount of water needed to cover 1 ha of land 1 cm deep.

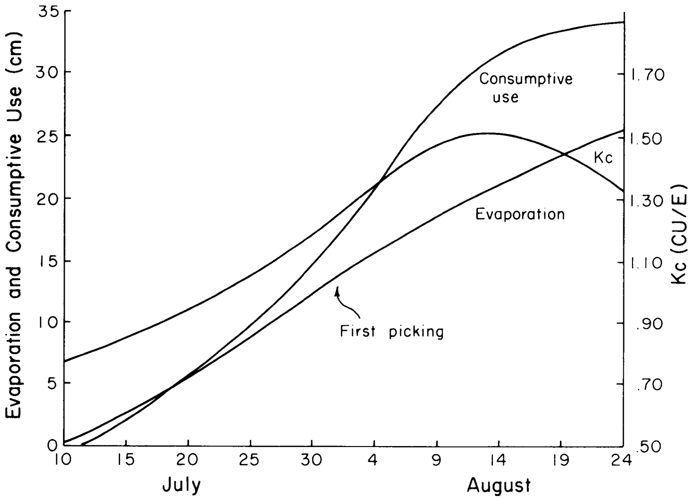

Fig. 1. Seasonal consumptive use (CU), evaporation (E) from a 1.2 m diam evaporation pan, and Kc (CU/E) for 'Pioneer' cucumbers growing in the field.

water lost by evaporation from the soil surface. This loss was subtracted from the water added to the pots to give total water consumption.

Transpiration loss from each of the plants for the 24 hr period just before termination of the experiment was determined gravimetrically. All leaves were then removed and blueprinted and the leaf area measured with a polar planimeter. Transpiration rate was calculated for each plant by dividing transpiration by leaf area.

Statistical analyses of total water use, leaf area, and transpiration rate were conducted using Student's method of paired comparisons.

A second trial was conducted during the spring of 1975 in a Hotpack Model 1970-1 controlled environment chamber measuring 2.8 × 3.0 × 1.9 m. Light during the 15-hr light period was supplied by a ceiling bank of 30 Westinghouse coolwhite and 30 Sylvania Grolux wide-spectrum fluorescent tubes, supplemented with twenty 40-watt incandescent lamps. The lights were separated from the growth chamber by mylar panels. Total light intensity as determined with an ISCO Mod. SR spectroradiometer between 380 nm and 760 nm was 16.2 klx. Temperatures were maintained at 25°C during the light period and at 19°C during the dark period.

Ten comparable plants of 'Pioneer' were grown in plastic pots having a volume of about 6.5 liters. At field capacity each pot contained 5900 g of vermiculite-peat moss medium. Five plants were trained to a single stake and allowed to fruit while 5 others had the flower buds removed daily. Two pots without plants were used to determine evaporation from the soil surface.

The total leaf area of each plant was determined every 3–5 days with a polar planimeter using tracings of the individual leaves. Transpiration losses were measured over 30 min periods that corresponded to the time of leaf area determination using gravimetric procedures. Transpiration rates were calculated from these determinations.

Data obtained during the growing season were averaged to develop graphical patterns of leaf area development and transpiration rate. Measurements made at the conclusion of the experiment were compared statistically using Student's method of paired comparisons.

Results

Consumptive use. Differential irrigation treatments were started in early July when the cucumber plants were growing rapidly. Average consumptive use (CU) from this time to the end of the season is shown in Fig. 1. The rate of use increased during flowering and early fruiting then leveled off during late harvest. The total amount of water used during the 2 month period ranged from 30 to 40 cm over each of the 4 years of the experiment.

Table 1. Yield, grade, and percentage of deformed cucumbers as influenced by irrigation frequency in field trials.

Water use between irrigations ha cm[z]	Yield[y] (ton/ha)	Grade (% by wt)[x]				
		No. 1	No. 2	No. 3	Culls	Crooks
		1971				
1.25	44.7	17.4	32.5	40.0	10.1	
2.50	41.0	17.3	34.0	38.9	9.8	
3.75	41.3	17.2	32.7	43.2	7.0	
5.00	39.8	20.1	31.2	39.1	9.6	
		1972				
2.50	33.9	22.5	28.8	40.6	8.2	
3.75	36.8	15.8	29.1	44.0	11.1	
5.00	36.3	20.3	29.6	39.3	10.8	
6.25	34.1	19.0	30.2	38.9	11.9	
		1973				
2.50	15.1	21.6	30.2	34.3	10.4	3.6
5.00	15.6	21.8	30.0	31.4	11.3	5.5
7.50	18.8	18.6	25.4	34.6	15.3	6.1
10.00	18.0	19.9	27.3	38.0	8.9	5.9
		1974				
2.50	30.1	20.6	30.2	32.1	10.0	7.0
5.00	32.1	20.6	29.3	34.8	6.3	9.0
7.50	32.1	17.5	29.1	36.0	8.7	8.7
10.00	28.4	20.5	29.3	31.7	9.1	9.4

[z]Ha cm = hectare centimeter. The amount of water needed to cover a hectare of ground 1 cm deep.

[y]Statistical analysis indicated no significant differences in yield, grade, or % crooks within years at the 5% level.

[x]Grade No. 1 = cucumbers under 2.5 cm diam; No. 2 = 2.5–3.8 cm diam; No. 3 = 3.8–5.1 cm diam; culls = cucumbers over 5.1 cm diam plus deformed fruits. Deformed fruits were weighed separately in 1973 and 1974.

The ratio (Kc) of CU to evaporation from an evaporation pan (E) increased to a maximum of 1.5, 10 days after first picking and then declined but still remained high when picking was terminated.

Irrigation schedules. Crop yields were not significantly affected at any of the depletion levels (Table 1). There did, however, appear to be a downward trend as the water use between irrigations was increased from 7.5 to 10.0 cm (48 to 64% of the available moisture). Cool weather during 1973 reduced yields below that of the other 3 years.

The percentage of cucumbers in the size grades was not influenced by irrigation frequency. The amount of deformed fruits is sometimes increased by moisture stress but in our trials there was no significant difference.

Soil moisture extraction pattern. Cucumbers extracted 50% of the total amount of water consumed from the upper 30 cm of the soil profile, 30% from the next 30 cm, and 10% from the next 30 cm. Since very little water was extracted from below 90 cm, the effective rooting depth for cucumbers is considered to be ca 90 cm.

Water use, leaf area, and transpiration rate. Total water consumption (table 2) and the pattern of seasonal water use (Fig. 2) were not significantly different for fruiting and nonfruiting plants, however, growth chamber results near the end of the trial showed a tendency for fruiting plants to have a greater total water consumption. Plants in the greenhouse used much more water than those in the growth chamber, probably because of the higher temperatures. Chamber temp was maintained at

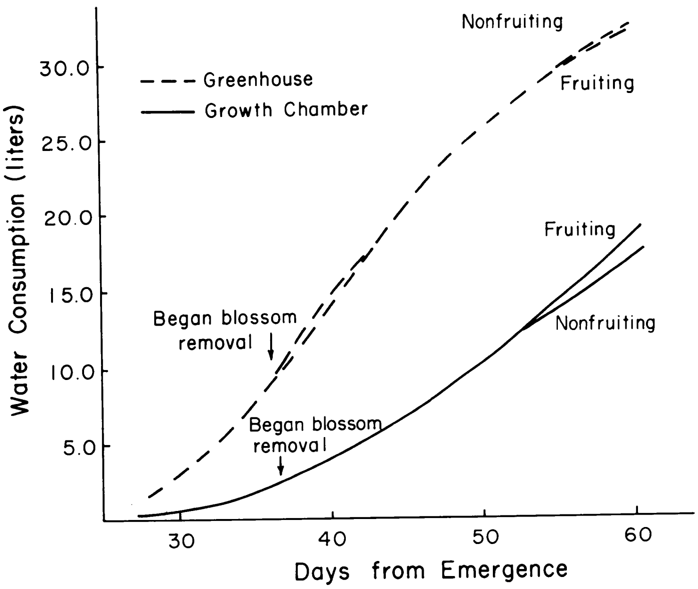

Fig. 2. Seasonal water consumption in liters per plant of fruiting and nonfruiting 'Pioneer' cucumbers.

25°C days and 19° nights, whereas, greenhouse temp ranged from about 32° to 23°.

The average leaf area of the fruiting plants in the greenhouse at the end of the season was significantly less than that of the nonfruiting cucumbers (Table 2). In the growth chamber where the leaf area was measured every 3 to 5 days during the course of the experiment, the rate of increase in leaf area for the fruiting cucumbers coincided with that of nonfruiting plants until early fruit development (Fig. 3). The rate of increase for the fruiting plants then tended to become less than that of the nonfruiting cucumbers.

Transpiration rate (water consumption per unit leaf area) reached a maximum shortly after the first flowers were fully developed (Fig. 4). This maximum was then followed by a decline in transpiration rate with a general leveling off for both fruiting and nonfruiting plants during the final five days. The transpiration rate for fruiting plants in both the greenhouse and growth chamber was significantly higher than for the nonfruiting plants at the end of the experiment (Table 2).

Discussion

Large differences among the irrigation schedules used for cucumbers in the field had a minimal effect on yield and quality. We believe that this lack of response was due to the rapid root growth and extensive root system of the cucumbers which made it possible for them to thrive under the wide range of soil moisture levels.

Table 2. Final transpiration rate, leaf area, and total water consumption of 'Pioneer' cucumber plants in the greenhouse and in the growth chamber.

Stage	Transpiration rate (ml/cm^2)	Leaf area (cm^2)	Total water consumption (ml)
		Greenhouse trial	
Fruiting	.06*	8816**	30600
Nonfruiting	.05	11188	30800
		Growth chamber trial	
Fruiting	.12**	6183	17720
Nonfruiting	.09	6477	16720

*Significant at 5% level.
**Significant at 1% level.

The high rate of water consumption during harvest was surprising. The ratio (Kc) of water use to evaporation pan loss was much higher than is found in other crops with the possible exception of rice (5). Even though cucumbers are able to utilize the available water quite efficiently, these results emphasize the need for large amounts of water during harvest.

We were interested in exploring further the reasons for this high water use and, therefore, initiated the controlled environment studies.

We found the transpiration rate per unit leaf area for fruiting cucumbers in the greenhouse and growth chamber to be greater than for nonfruiting plants. This increase, however, was counteracted by reduced leaf surface resulting in no significant difference in total water consumption. Hall (3) reported similar results with gherkin (*C. anguria*). He found that water absorption reached maximums during anthesis, fertilization, and early fruit development. As the fruits became larger, water absorption decreased. Other workers (2, 11, 15) found that metabolic activity and vegetative growth increased in tomatoes and cucumbers during the time of flowering and pollination. Following this time, seed development caused a rapid decrease in vegetative growth (7, 15). Few fruits developed per plant in our greenhouse and growth chamber trials and most of those that did were allowed to reach relatively large size. It is not surprising, therefore, that the transpiration increase was offset by leaf area reduction and resulted in a minimal effect on total water consumption.

In commercial fields of cucumbers grown for pickles the fruits are harvested while small. Few are allowed to reach large

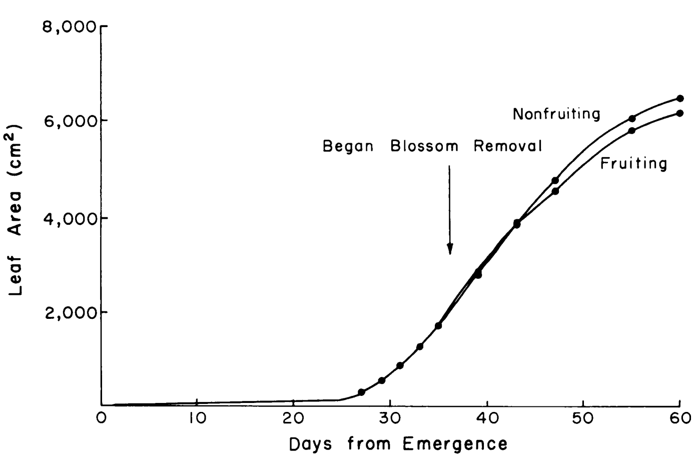

Fig. 3. Seasonal leaf area development for fruiting and nonfruiting 'Pioneer' cucumbers in the growth chamber.

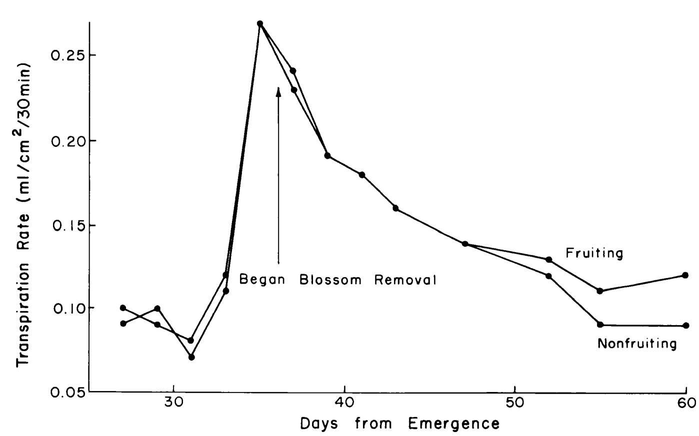

Fig. 4. Seasonal transpiration rate for fruiting and nonfruiting 'Pioneer' cucumbers in the growth chamber.

size. Each plant, therefore, has many blossoms and early developing fruits throughout the harvest period. Using the controlled environment studies as a model we would assume that these plants would have a high transpiration rate and good leaf development. The high water use measured during harvest in our lysimeter studies support this assumption.

We do not know what caused the increase in transpiration rate of cucumbers, however, recent research with excised barley leaves (6) and tobacco (9) showed increased transpiration associated with higher gibberellin and cytokinin levels. We feel that growh regulator levels in the rapidly dividing, highly metabolic cells of young cucumber fruits should be investigated as an underlying cause of the increased transpiration rate.

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Compositional Changes in Muskmelons during Development and in Response to Ethylene Treatment[1]

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Abstract. **Fruits of muskmelon (*Cucumis melo* L., cv. Honey Dew and Powdery Mildew Resistant No. 45) were harvested at weekly intervals after anthesis, and weight, shape, flesh firmness, flesh color, and the content of total solids, alcohol insoluble solids, total sugars, reducing sugars, glucose, fructose, and sucrose were measured. Total sugars (mainly sucrose) increased rapidly between the 28th and 42nd days; hence early harvest must inevitably lead to loss in quality. Ethylene treatments of fruits harvested less than fully mature did not alter sugar content since melons have no starch reserve.**

Muskmelons are among the sweetest of the fleshy fruits. For example, in this laboratory, we have found soluble solids contents (SSC) as high as 17% of the juice in fully ripened 'Honey Dews'. The sugar contents of ripe melon fruits have often been reported (frequently as SSC), but there have been few reports of sugar analyses in relation to stages of fruit development. Pratt (16) reviewed the biochemistry of melon fruits and made the following points: Sugar accumulation during the development of muskmelons is of special interest, since sugar content is used by many as the principal criterion of fruit quality, not only in research and in commerce but also in enforcement of marketing regulations. Many workers have shown a strong correlation between high SSC and other attributes of high quality. Sugar content and cultural practices have been related in many reports which can be readily located in the literature; in general it appears that the highest sugar contents will be found in melons on healthy vines with a high yield. In more recent work (1, 24) it has been pointed out that high SSC alone does not adequately define good melon quality. The best flavor depends on "sweetness," which is only partially correlated with SSC, and on ideal proportions of various volatile compounds whose nature is not yet fully defined. Nevertheless, while all melons with high SSC will not necessarily be of good quality, the absence of high SSC makes good quality very unlikely (24).

In this work we followed changes in various sugar-related components of 2 important muskmelon types from early stages in fruit development to maturity. We hoped to correlate changes in sugar content with other changes in the physical characteristics of the fruit, so as better to understand physiological criteria for the commercial harvesting of muskmelons. Because 'Honey Dews' are regularly treated with ethylene during commercial handling, the effect of ethylene treatment on melon composition was also examined.

Materials and Methods

Plant material. The muskmelon cultivars studied, 'Powdery Mildew Resistant Cantaloupe No. 45' ('PMR-45') and 'Honey

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