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Lysimeter-based Crop Coefficients for Young Highbush Blueberries

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Abstract. **Inexpensive weighing lysimeters ($1475/unit) were constructed for measuring evapotranspiration of young highbush blueberries (*Vaccinium corymbosum* L.). The use of a single load cell and other design characteristics decreased lysimeter measurement accuracy but minimized lysimeter construction costs. Measurement error was within ±3%. Crop coefficient (CC) curves for 5- and 6-year-old 'Bluecrop' highbush blueberry plants in their third and fourth year of production were generated using reference evapotranspiration and crop water use data from the 1991 and 1992 growing seasons. The CC increased during leaf expansion and flowering in the spring to its maximum value of about 0.19 in 1991 and 0.27 in 1992 and remained near these values until leaves began senescing in the fall. Water use on sunny days during June, July, and August ranged from (liters/bush each day) 3.5 to 4.0 in 1991 and 4.0 to 4.5 in 1992. During the second year of the study, plants had an average height of 0.9 m, an average diameter of 0.9 m, and covered 18% of the total cultivated area. The maximum calculated CC was equal to 1.5 times the measured canopy cover percentage.**

Lysimeters are used to provide an isolated soil environment for the study of water and nutrient uptake by plants and nutrient mobilization within soils. Lysimeters also are used to measure crop water use to determine crop coefficients (CCs), calibrate and validate evapotranspiration (ET) models, and evaluate other methods of measuring ET. Lysimeters are often plagued by inaccuracies arising from the influence of their physical characteristics on the environment and on the plants they contain. Large, undisturbed, monolithic lysimeters are generally less problematic than small lysimeters, but they are extremely expensive. Small lysimeters are much less expensive, and therefore can be economically replicated and easily installed, instrumented, and serviced. Small lysimeters generally lack the accuracy of large lysimeters.

Small lysimeters have been used by other researchers. Allen and Fisher (1990) described weighing lysimeters they built at a cost of $5500 per lysimeter. These devices used four surface-mounted cantilever load cells to weigh a disturbed, 1-m^2 area × 1.2-m depth soil tank. A battery-powered datalogger accurately recorded mass changes with a resolution of less than 0.05 mm of water, or 1% of daily crop water use. They concluded their design was sufficiently accurate for determining daily crop water use, but hourly measurements were limited by the resolution of the datalogger and thermal instability within the surface-mounted load cells. Thermal instability problems were eliminated by removing the surface-mounted load cells and mounting them beneath the lysimeter tank.

Yoder et al. (1993) designed small lysimeters intended to be used in watershed studies where many lysimeters were needed. Their devices had a surface area of 0.05 m^2, 0.07 m^2, or 0.11 m^2, and a depth of 0.7 m. To minimize costs, they constructed lysimeters out of PVC pipe and designed and built their own load cells. Accuracy was limited due to temperature effects on load cell excitation voltage, and because of the small lysimeter surface area, which resulted in small daily mass changes. The experiences of Allen and Fisher (1990) and Yoder et al. (1993) suggest that temperature changes in the lysimeter measurement system can cause unacceptable errors, but that these can be minimized by installing load cells below ground level. The problems associated with a small lysimeter surface area and its effect on evaporated and transpired water mass can be minimized by making water use measurements over periods of one or more days (vs. hourly).

Crop coefficients (CCs) generated by using lysimeters have been reported for many agronomic crops and, to a lesser degree, for some vegetable and fruit crops grown using sprinkler irrigation and bare-ground culture. A primary use of CCs has been in irrigation management schemes. Many of the CCs reported in the literature do not specify the cultural conditions under which the crops were grown, limiting their usefulness to other researchers (Stanley and Maynard, 1990). Limited scientific information exists concerning blueberry water requirements, although regional recommendations exist. In New Jersey, Kender and Brightwell (1966) reported that mature highbush blueberries required 14–27 liters/bush per day (based on 1.2 × 3.0 m plant spacing). In a northeastern U.S. extension publication, Ross et al. (1985) suggested that 3- and 4-year-old highbush blueberries require 5 liters/bush per day. In contrast to this estimate, Byers and Moore (1987) concluded that the current irrigation recommendation in Arkansas of 3.8 liters/bush per day for young highbush blueberries was nearly three times as great as the 1.3-liter/bush per day requirement that they measured. Others have established that young blueberries are drought-sensitive (Davies and Johnson, 1982; Moore, 1976), and that adequate water is essential for plant establishment (Spiers, 1983).

In New Jersey, blueberries are typically grown on coarse-textured soils of low available water-holding capacity (0.05–0.1 mm water/mm soil) and low organic matter content (≤0.5%). Irrigation and fertilization are critical for commercial blueberry production on these soils. The use of sprinkler irrigation is common but inefficient, especially when plants are young, due to the large amount of bare soil present between plants and rows. Progressive growers in New Jersey are adopting drip irrigation to conserve water and to optimize growing conditions for young plants. In this study, the water requirements of young highbush blueberries were determined.

Materials and Methods

Lysimeters were constructed and used for measuring blueberry water use at the Rutgers Cranberry/Blueberry Research Center in Chatsworth, N.J. Four matched lysimeters were constructed from 25-mm (outer tank) and 19-mm (inner tank) A/C exterior-grade plywood. Pressure-treated lumber was used to frame and strengthen the lysimeter outer chamber. Seams were glued, nailed, and caulked to prevent leakage, and all wooden surfaces were coated with a wood preservative. The inner tank was rectangular in shape, had a surface area of 0.21 m^2 (0.46 × 0.46 m), and a depth of 0.41 m (Fig. 1). The outer tank had surface dimensions of 0.60 × 0.97 m, was 0.55 m deep in the lysimeter chamber, and 0.81 m deep in the access chamber. The access chamber was used to collect drainage from an access port in the inner tank.

An Interface (Scottsdale, Ariz.) SSM-AJ-500 stainless steel tension/compression load cell with a 227-kg load capacity was used to measure the mass of the inner tank. This unit was hermetically sealed and designed to provide automatic temperature compensation. The

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safe load limit of the cell was 150% of rated load capacity, or 340 kg. Maximum nonlinearity of the cell was ±0.05% of rated output. Maximum hysteresis was ±0.03% of rated output.

The inner tank, its support plate, and the soil, water, and plant within it weighed about 180 kg when saturated, and was supported by the single load cell. The load cell was bolted in an upright orientation on top of and in the center of a 6.4 mm × 0.50 m × 0.50-m steel lower support plate. A 25-mm-diameter stainless steel ball bearing was placed on top of the load cell's upper, 13-mm, threaded mounting hole. Another 6.4 mm × 0.50 m × 0.50-m support plate with a centered, 13-mm hole rested on top of the ball bearing. The inner tank rested on top of this support plate. As a result of the configuration of the load cell and support structures, the lysimeter inner tank was balanced on a single point (the ball bearing) and was able to tip in any direction. Four (one per side) small, but stiff, springs (32 mm in length, 16 mm in diameter) were placed in the 19-mm gap between the inner and outer tanks, 20–40 mm below the upper lip of the tanks, to assure that the inner tank was not resting against an outer tank wall.

A Campbell Scientific (Logan, Utah) 21X datalogger and AM416 multiplexer were programmed to excite the load cell resistance bridge, measure the load cell output voltage, and record meteorological data used to calculate reference ET. Load cells and instruments were interrogated once each minute. Sixty consecutive values were averaged and logged each hour into permanent storage. Relative humidity, wind speed, and air temperature were measured at a height of 2 m in a mowed grass field (≈30 × 50 m) adjacent to the blueberry block. Solar radiation, rainfall, and Weather Bureau "Class A" evaporation pan data also were measured. Grass reference ET was calculated using the Penman–Monteith equation (Allen et al., 1989). The total cost of designing, building, installing, and testing four lysimeters was $5900, or $1475 per lysimeter, which included the cost of the datalogger, load cells, and lysimeters ($3600), nine technical support days ($1100), and 5 scientist days ($1200).

Lysimeters were installed in 1989 in a 0.1-ha block of 4-year-old 'Bluecrop' highbush blueberries. Plant spacing within rows was 1.2 m. Row spacing was 3.0 m. In each of four rows within the block, a randomly selected plant was carefully removed while lysimeters were installed. In each inner tank, a 50-mm depth of 2-mm-diameter stone was placed and covered with a piece of porous horticultural ground cloth. Plants were then placed in the inner tanks, and soil from the excavation was lightly packed around the rootball, filling the lysimeter tank. Inner tanks were then installed in the lysimeters, returning plants to their original location within the row.

In each year of the study, fertilizer was applied to the blueberry plants in four biweekly applications, beginning in mid-April. A dry-blend (10N–4.4P–8.3K) fertilizer was applied at 50 g/plant per application. Soil at the site was a Lakehurst sand (mesic, coated, Aquodic Quartzipsamments) and is typical of blueberry-producing soils in New Jersey. Plants were pruned each year during the winter when air temperature was above freezing.

A quantity of irrigation water about equal to the daily requirement of the blueberries was applied manually each day at midmorning and supplemented, if needed, at midafternoon. Irrigation water rapidly infiltrated the coarse-textured soil, resulting in a small wetted surface area which resembled that for other plants in the drip-irrigated block. Tensiometers were installed at a depth of 0.15 m and used to monitor soil matric potential to assure that plants were not stressed. Before each irrigation, the volume of lysimeter leachate, if present, was measured. Irrigation water and leachate measurements were used along with electronic mass measurements to calculate crop water use as the difference between the lysimeter mass at midnight on consecutive days. CCs were calculated as the ratio of plant water use (expressed as millimeters of water over the 1.2-m plant spacing × 3.0-m row spacing area) to reference ET (millimeters). Crop water use data included in this report were from the 1991 and 1992 seasons. The lysimeters were not protected from rainfall and data from days in which rains fell were excluded from the study.

Results and Discussion

Lysimeter accuracy was limited by lysimeter design and construction rather than load cell or datalogger resolution. Lysimeter accuracy was tested before and after the 1991 and 1992 growing seasons by placing known masses on the surface of the lysimeters and comparing the actual mass with the measured lysimeter output. The use of springs in the lysimeter resulted in a small portion of the lysimeter mass being supported by the lysimeter walls, and reduced lysimeter accuracy. In load tests, the lysimeters underestimated both positive and negative mass changes. The error in mass changes was within ±3%.

Lysimeter plants grew normally, despite the restricted rooting volume available to plants in lysimeters. Tensiometer readings indicated that soil matric potential was maintained between –10 to 0 kPa, indicating that the plants were not water stressed. During the second year of the study when measurements were made, plant volume was equal to that of other

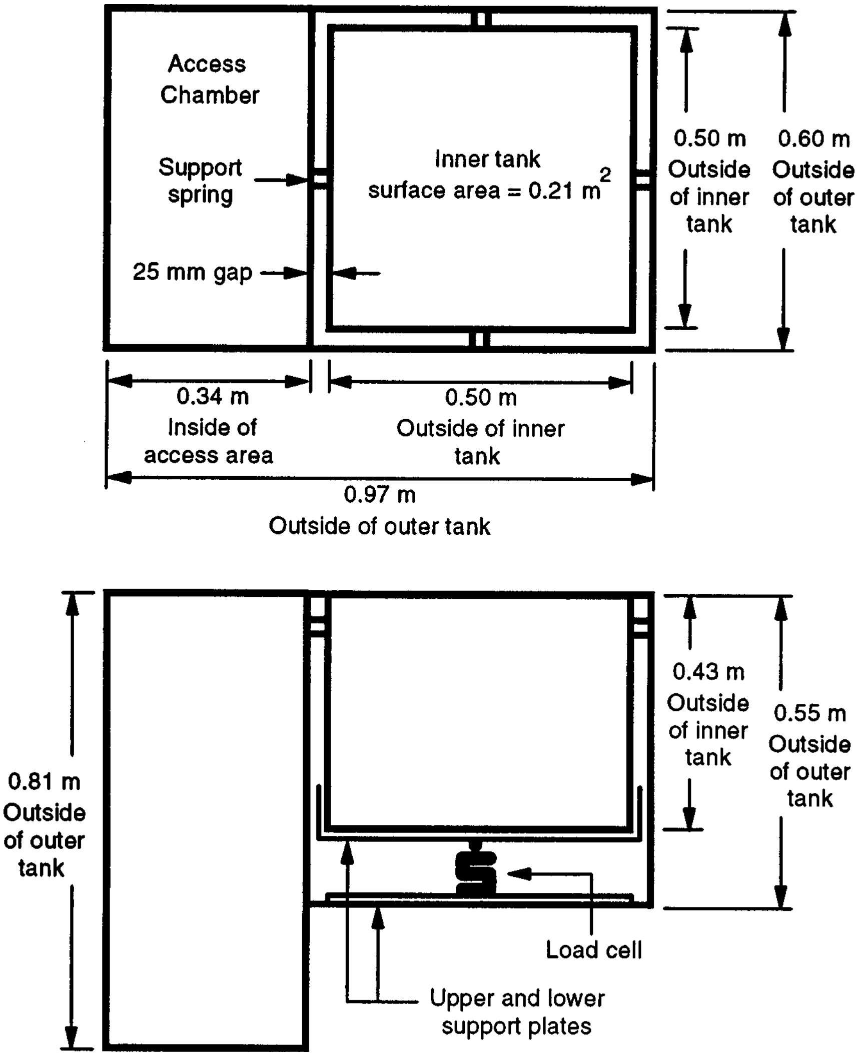

Fig. 1. Top and side views of the inner and outer lysimeter tanks.

plants in the block, and yields from the lysimeter plants were equal to or higher than those of plants not in lysimeters. Marketable yield from lysimeter plants averaged 1882 g/bush over the 2-year study.

Lysimeter data collection began during late flowering on 25 May in 1991 and before flowering on 3 Apr. in 1992. In both years, crop water use measurements were discontinued at the end of October, just before leaves began senescing. Water use data used in CC calculations were obtained by averaging water use from the four lysimeters. Reference ET (Fig. 2) in 1991 was: June, 109 mm; July, 105 mm; August, 105 mm; September, 75 mm; and October, 45 mm. Reference ET in 1992 was: April, 52 mm; May, 74 mm; June, 90 mm; July, 100 mm; August, 88 mm; September, 63 mm; and October, 42 mm. Daily reference ET data were used along with daily crop water use data to generate the CC curves (Fig. 3). In 1991, CCs remained constant throughout the period that measurements were made, averaging 0.19 (Fig. 3, lower horizontal line; SD = 0.03). In 1992, CCs increased steadily from 0.05 beginning in early April until the first week of July (Fig. 3, sloped line; R^2 = 0.84). The calculated CC remained constant from early July through the end of October, averaging 0.27 (Fig. 3, upper horizontal line; SD = 0.03). Water use on sunny days during the months of June, July, and August ranged from 3.5 to 4.0 liters/bush per day in 1991 and from 4.0 to 4.5 liters/bush per day in 1992.

Plant size was measured in 1992 during July and used to calculate canopy coverage and plant volume. At this time, plants in lysimeters had an average height of 0.9 m, average diameter of 0.9 m, and, assuming a cylindrical plant shape, an average plant volume of 0.6 m^3. The CC for many annual species that form a continuous canopy is closely correlated with plant canopy coverage (expressed as a percentage of the total cropped area) and approaches 1.0 as the plant reaches effective full groundcover (which occurs when canopy cover reaches ≈70% to 80%) (Doorenbos and Pruitt, 1977). However, this pattern does not always hold true for crops with open canopies, such as young trees. Fereres et al. (1982) found that water use by young, drip-irrigated almond [*Prunus dulcis* (Mill.) Webb.] trees with 50% canopy coverage was nearly equal to that of a mature orchard, suggesting that the CC of the young trees was about equal to twice the canopy cover percentage. Assuming a cylindrical plant shape, canopy coverage in our study was equal to 18% of the total cultivated area. The maximum CC reached in 1992 was 0.27. Therefore, the CC was equal to 1.5 times the canopy coverage. Upright plants that lack complete canopy coverage are exposed to more radiation and experience more advective water loss (Fereres and Goldhamer, 1990) than plants growing closely together with complete canopy coverage. The increase in maximum CC from 0.19 in 1991 to 0.27 in 1992 reflected the increase in plant size over this period.

Byers and Moore (1987) reported that 3-year-old highbush blueberries grown in Arkansas in 1985 required 1.3 liters/bush per day. In contrast, 5- and 6-year-old plants in our studies required 3.5–4.0 and 4.0–4.5 liters/bush per day, respectively. Plants in the Arkansas study were ≈1 m tall and consisted of three to four canes (P.L. Byers, personal communication). Our plants were of similar height but contained about twice as many canes. In our study, the marketable yield averaged 1882 g/bush over the two years. This level is average for 'Bluecrop' plants in their third and fourth year of production. Byers and Moore reported yields of 529.8 g/bush. Therefore, our bushes likely were significantly larger than those of Byers and Moore.

Byers and Moore (1987) calculated irrigation volumes by multiplying uncorrected pan evaporation by several trial CCs and by the surface area of the barrels in which plants grew. As a result of their studies, they suggested that a CC of 0.75 was appropriate for their young plants. This value is much larger than our calculated maximum CC of 0.27 and differs because of the land area used in the respective CC calculations.

One of the principal advantages of reporting crop water use with CCs is that comparisons can be made between locations, climates, or growing seasons in which reference ET

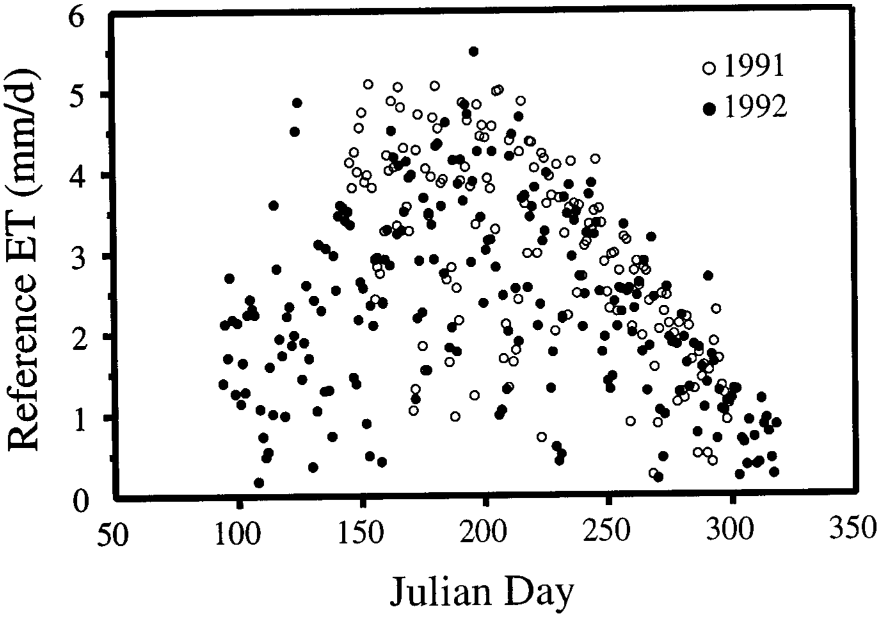

Fig. 2. Penman–Monteith grass reference evapotranspiration at Chatsworth, N.J., in 1991 and 1992.

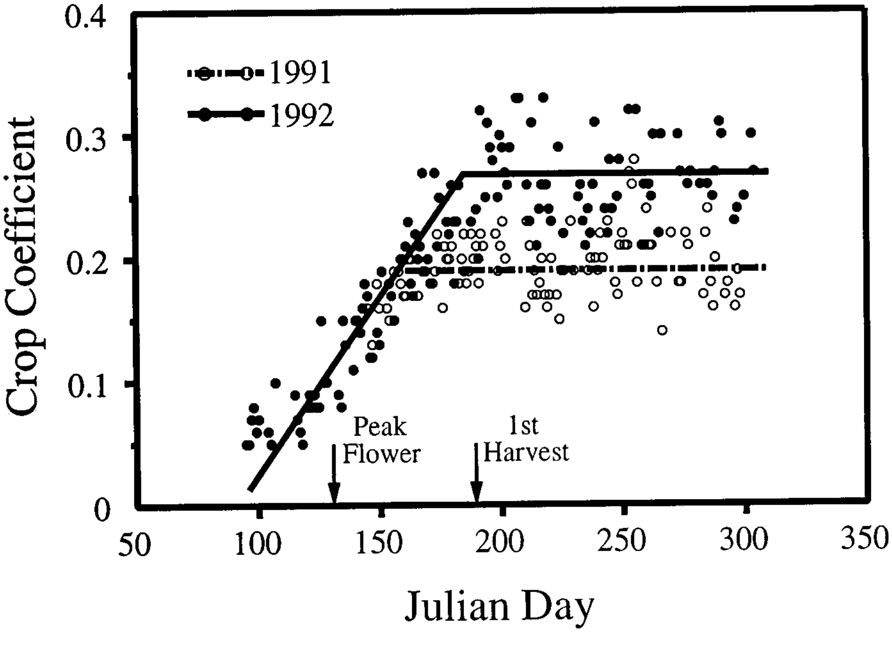

Fig. 3. Crop coefficient curves for 5-year-old (1991) and 6-year-old (1992) 'Bluecrop' highbush blueberries measured at Chatsworth, N.J., using weighing lysimeters. Open circles and dashed line are from 1991. Solid circles and solid line are from 1992.

varies. However, meaningful comparisons require that factors that directly influence the calculation of the CC be explicitly stated (Stanley and Maynard, 1990). It is essential that the model used to calculate reference ET or the type of evaporation pan (and pan coefficients) be described. The land area on which CCs are based and the plant and row spacing also should be described, along with other cultural factors that influence crop water use. For crops with incomplete canopies, an estimate of the canopy coverage can aid in water use comparisons. Irrigation characteristics, such as wetted area, irrigation frequency, and irrigation duration, also can improve the utility of reported CCs.

CCs have traditionally been calculated using the entire cultivated land area associated with the crop (Doorenbos and Pruitt, 1977; Wright, 1982). Following this convention, CCs of plants that do not completely cover the land area should be based on the amount of land "used" by the crop (calculated by multiplying the plant spacing by the row spacing). If the land area used to calculate the CC is different from the entire cultivated area, it is important for the researcher to specify this difference to allow other researchers to compare water use studies and to allow crop producers to use these data for management purposes. Where lysimeters are used to generate CCs, the CC also should be based on the amount of land "used" by the crop, which may or may not be equal to the surface area of the lysimeter.

Summary

Inexpensive weighing lysimeters were constructed for measuring evapotranspiration of young highbush blueberries. The error in daily measurements of plant evapotranspiration were within ±3%. CC curves for 5- and 6-year-old highbush blueberry plants were generated using reference evapotranspiration and crop water use data from the 1991 and 1992 growing seasons. The CCs increased during leaf expansion and flowering in the spring to their maximum values of ≈ 0.19 in 1991 and 0.27 in 1992 and remained near these values until leaves began senescing in the fall. Water use on sunny days during the months of June, July, and August ranged from 3.5 to 4.0 liters/bush per day in 1991 and from 4.0 to 4.5 liters/bush per day in 1992. During the second year of the study, plants had an average height of 0.9 m, an average diameter of 0.9 m, and covered 18% of the total cultivated area. The maximum calculated CC was equal to 1.5 times the measured canopy cover percentage.

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