THESIS

MEASURING EVAPOTRANSPIRATION OF TURFGRASS

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Charles M. Feldhake

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY CHARLES M. FELDHAKE ENTITLED MEASURING EVAPOTRANSPIRATION OF TURFGRASS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

Jackie D. Butler

William T. Franklin

Robert E. Danielson
Adviser

W F Keim
Head of Department

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ABSTRACT

MEASURING EVAPOTRANSPIRATION OF TURFGRASS

Evapotranspiration (ET) of Kentucky bluegrass (*Poa pratensis* L) was measured in urban lawns, in a growth chamber and as part of a study relating canopy temperature to water stress. Lysimeters, 30.5 cm in diameter, were used to measure ET. Lack of control over urban lawn sites restricted the reliability of relating ET to microclimate.

In the growth chamber study, ET was influenced by day temperature, night temperature, clipping height and soil texture. It was shown that soils high in clay are not desireable for use in lysimeters due to limited root growth.

Average midday canopy temperature was more reliable at identifying water stress than daily ET measurements using lysimeters. Canopy temperature measurements, using an infrared thermometer, were utilized without correcting for canopy quality differences since the thermal emissivity of lush, green turf and dead, brown turf was found to be the same. The Barnes 14-220 infrared thermometer was calibrated and it's scale was found to be 8% high for the 0-50°C range.

Charles M. Feldhake
Department of Agronomy
Colorado State University
Fort Collins, Colorado 80523
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INTRODUCTION

Lawns are not an occasional fancy in the United States. It has been estimated that more than 20 million acres of lawns exist which compose between one and two percent of the total land in the United States. Falk (1977) estimated that a well-kept lawn may require 1,856 Kcal/m^2 each year when maintenance is expressed terms of energy while a good corn crop may only require 715 Kcal/m^2 for a season. In terms of dollars, Nutter (1965) calculated that 13 years ago people in the United States were already spending over 4.3 billion dollars each year on turf maintenance.

In the more arid parts of the country, turf maintenance can put a significant demand on water resources. It was estimated by Barrelli et al. (1976) that turf occupies ten percent or more of the irrigated land in Colorado. Often fifty percent or more of a homeowner's yearly water bill is due to lawn applications. It is important that efficient lawn irrigation methods be developed and be communicated to the general public.

This thesis is an attempt to investigate the effectiveness of small lysimeters for measuring the water requirements of lawns. Even though the use of lysimeters has become a widely accepted method of measuring evapotranspiration (ET), large variations in the plant canopies grown on lysimeters exist due to the diversity of investigated ecosystems. It has generally been assumed that in most situations plant type, canopy height, growth rate and root environment have a neglibible effect

on ET, but the validity of this assumption has not been quantitatively demonstrated. As the size of the lysimeter decreases, and therefore the sample of the ecosystem under study, the need to understand factors affecting ET increases.

It is desirable to have a method to verify that the ET measured with a small lysimeter is the same as the region the lysimeter is intended to represent. Canopy temperature is a function of ET and can be utilized to determine relative ET for canopies within the same microclimate.

REVEIW OF LITERATURE

Kentucky bluegrass (*Poa pratensis* L.) is one of the most common grasses used for lawns in the northern half of the United States. Bluegrass can be found in a wide variety of climates. It grows best in a humid climate, however, it also grows well in a dry climate when adequate water is applied and it hardens to a very drought tolerant state when water is lacking.

Plant-Environment Interactions

It has been shown by Beach (1958) that Kentucky bluegrass can grow well under conditions of less than optimum water even though total dry matter production will decrease. In the case of lawns, we are not normally concerned with yield; therefore, lawn quality in dry regions is determined by individual preference. A wide range of water application rates may provide for healthy Kentucky Bluegrass turf.

Cultural practices such as frequency of irrigation, fertility management, and mowing height have an effect on how well turf thrives under any given moisture allotment. Consumptive use of water by turf is controlled by many environmental conditions in addition to the cultural practices.

The root environment is influenced by soil texture. Weaver et al. (1949) demonstrated that root growth is optimal in loose, well drained soils. Tight soils can restrict root penetration and the diffusion of

oxygen that is needed for root growth. The water holding capacity of soils is one of the factors which determines how long turf has adequate moisture. As soil water decreases, transpiration decreases until, at wilting, it nearly stops. If Kentucky bluegrass continues in a wilted state for any length of time, it will begin to go into dormancy. It can exist in this dormant, drought tolerant state for weeks and sometimes months. With the application of water it will become green and lush within one to two weeks.

Soil temperature was shown to have a large effect on ET by Tew et al. (1963). They concluded that lessened water uptake from soil by roots, due to decreased membrane permeability, may limit the transpiration rate at low soil temperatures. At high soil temperatures, the warm water taken up by the plant warmed the plant and resulted in increased conversion to vapor at the leaf surface. This resulted in higher ET rates at a constant air temperature than if the water had been cool.

Krogman (1967) showed that ET may also be a function of soil fertility. Very low fertility levels will decrease ET by decreasing root growth and canopy density. High nitrogen levels can promote growth of very succulent turf. While the effect of such growth on ET is not clearly understood, it will decrease drought hardiness.

Man has developed extensive technology to help improve the soil environment for plant growth. He is, however, basically helpless to make significant changes in the above-ground outdoor climate. Most climatic factors can, however, be studied to better understand their relationship to water use.

Radiation and convection are the means by which the energy needed for ET arrives at the turf canopy. Radiation comes from the sun directly or indirectly. Indirect solar radiation can be either light reflected from a light colored surface or heat re-radiated from a dark surface. Convection is a function of air temperature and movement. The potential for ET increases as air temperature and air velocity increase. It is ultimately determined by the effect of radiation and convection on the water potential gradients and resistance to flow in the system.

Most land plants are homiohydric; that is, they have evolved mechanisms that allow them to maintain a steady state water potential well above that of their foliar environment. Plants have a cuticle which restricts water movement from the tissue to the atmosphere. They also contain stomates that act as valves, regulating the diffusion of water out of the plant and carbon dioxide into the plant. The degree of stomatal opening is a function of light, heat, carbon dioxide concentration and the water status of the plant.

Determination of Evapotranspiration

There are several approaches to calculating ET. One has been to optimize the factors which man can control, such as; soil moisture, soil fertility and plant population densities, then monitor the atmospheric climate, measure ET and develop equations to relate ET to climatic data. These potential ET equations work quite well in some situations, but none of them are universally applicable.

Another method for calculating ET is to monitor soil water. Since nearly 100% of the water used by plants is taken up from the soil, keeping a balance of soil water, irrigation and precipitation can give a fairly reliable measure of ET. Some error is induced by measurement technique, deep percolation losses, or gains to the root zone from capillary rise. Soil moisture can be monitored by taking core samples and making a gravimetric analysis from different depths or by installing access tubes and monitoring soil water with neutron or gamma probes.

A third method for measuring ET is with the use of lysimeters. This method entails the weighing of a contained soil mass at predetermined time intervals. The net decrease in weight will be equal to the evapotranspiration from the lysimeter after correcting for vegetative growth.

Lysimeters

Lysimeters are considered by Chang(1968) to be the most direct and accurate instruments for the determination of ET. There are numerous lysimeters around the world used to measure ET in various environments. Each lysimeter that has been used was built and operated with the intention of obtaining a specific type of ET data. This diversity of needs resulted in lysimeters which varied greatly in size, texture of contained soil mass, frequency and amount of irrigation and crop type. Grasses constitute the most commonly used crop; however, a large number of species have been used with no conformity of mowing height and mowing frequency.

One of the longest studies was conducted at Coshocton, Ohio, using a lysimeter planted with deep rooted grasses and legumes. The purpose of the study was to measure ET of a hayfield. McGuinness and Bordne (1972) found that from 1948-1965 computation methods predicted higher ET during the middle and end of the summer, while the lysimeter measured the highest ET during late spring and early summer. Natural precipitation was the only water input into the lysimeter, so the data was adjusted for periods when soil moisture was limiting. At least 15 days of data was discarded after each hay cut while a canopy cover was regrown. There was no discussion of lysimeter size, soil texture, cutting frequency, canopy height at various times, or the amount of growth on the lysimeter relative to the surrounding area. This study obtained data on ET of hayfields and, therefore, some caution may be needed in drawing conclusions for other ecosystems.

At Reno, Nevada a system of lysimeters 1 meter in diameter and 1.5 or 2.8 m deep were used to measure ET of lawn grass by Tovey et al. (1969). The lysimeters contained either a loam or a sandy loam soil and were given irrigations twice a week, once a week, or once every 10 days at a rate that averaged 5 cm of water per week. The grass was either bermudagrass (*Cynodon dactylon* L.) or a mixture consisting of primarily Kentucky Bluegrass and several fescues (*Festuca* spp. L.) labeled "Nevada Blend". The grass in the lysimeters and surrounding area was clipped to a 5-cm height weekly. Computational methods utilizing meterological data were rated comparatively adequate in estimating lawn ET compared to lysimeter data. They found that irrigating less than twice a week on the sandy loam resulted in water stress

of the Nevada Blend but not the bermudagrass. The treatments which experienced no water stress throughout the entire growing season developed the most extensive root system. During the summers of 1966 and 1967 the Nevada Blend averaged 5.1 mm/day and the bermudagrass 4.6 mm/day of evapotranspiration.

The frequency distribution pattern of daily ET at Davis, California was calculated and made available by Pruitt et al. (1972) for irrigation system design. They collected data for 10 years using a 6-m diameter, 1-m deep lysimeter planted with perennial ryegrass (*Lolium perenne* L). The lysimeter was located in an open grass field which was mowed to a 10-cm height weekly. The grass was sometimes as high as 25 cm before mowing. The lysimeter was filled with a loam soil which was maintained at about field capacity. Ceramic tubes in the bottom maintained a suction of 0.2 bars on the soil water to simulate a well drained profile. Applying suction to the bottom of the lysimeter helps eleviate problems which could be caused by unnaturally high water availability as discussed by Colman (1964). The lysimeter was able to measure ET to within ± 1% per day.

Evapotranspiration from lysimeters was compared with evaporation (E) from black Bellani plate evaporimeters by Wilcox and Sly (1974). Their lysimeters, 55 cm in diameter and 40-cm deep, were planted with bromegrass (*Bromus* sp. L) and were mowed weekly to 30 cm. Forty percent of the available water capacity was allowed to be depleted by the bromegrass before the silt loam soil was irrigated. It was determined that ET rates were not affected by soil moisture content unless the available water dropped below 50% of capacity. They concluded that there was a highly significant increase in the ET/E ratio with an increase in the

evaporating power of the air; therefore, to estimate ET from E, a greater ratio of ET should be used in hot weather than in cold weather. They showed that ET and E were mainly due to temperature and radiation effects with radiation affecting ET more, presumably because of its effects on stomatal opening.

Lynch et al. (1976) utilized lysimeters 47 cm in diameter and 60-cm deep to measure ET in a grazed pasture. The ET measurements, which were made at Armidale, Australia, were compared with values calculated with the use of a neutron moisture meter. The two methods, when used for determining seasonal water consumption, were found to be interchangeable. There was no information given on the soil-water environment of the lysimeter site, however.

Several types of lysimeters, whose surface areas ranged from 0.25 m^2 to 1.0 m^2, were used at Raleigh, North Carolina to measure ET of bermudagrass and corn (*Zea mays* L). Except for a few lysimeters being irrigated every sixth day during the early stages of the project, all lysimeters were irrigated daily with a complete nutrient solution. The bermudagrass was clipped once every 4 days to a 5-cm height. Potential evapotranspiration (PET) was calculated using the complete Penman formula by van Bavel and Harris (1962). They reported that PET consistantly exceeded measured ET, except for corn between silking and the soft dough stage, where the reverse was true. During 1957 and 1958, ET for bermudagrass was 4.00 and 3.65 mm per day respectively, and ET for corn was 5.65 and 4.45 mm per day. Some of the bermudagrass was grown on granite rock screenings and the rest, plus the corn, was grown on a fine sandy loam. It was demonstrated that the difference in character of these two soils had no perceptible influence upon the observed ET.

In recent years small lysimeters have been developed which are easily handled and are economical to build. Their use seems to have begun in Russia around 1950. Konstantinov (1966) maintained that they are less accurate than large lysimeters, but are still quite reliable and are used in a large network of weather stations across the USSR to monitor ET. The lysimeters in this network are 25 cm in diameter and range from 50 to 100-cm deep.

At the University of Nottingham School of Agriculture in England, Davenport (1967) discussed the use of lysimeters 9 cm in diameter in a study of the effect of antitranspirants on transpiration and growth of grass. These 50-cm deep lysimeters were planted with creeping red fescue (*Festuca rubra* L.) and were clipped once a month to an undisclosed height. He had questionable success in determining the effect of varying the antitranspirant application rate and concluded that lysimetry was too inaccurate a method for studying relatively small treatment effects. He may have needed a greater surface area/soil volume ratio for effective results.

"Microlysimeters" were used by Rogowski and Jacoby (1977) to assess water loss patterns of a 58-ha watershed in Pennsylvania. Each lysimeter (20 cm in diameter and 33-cm deep) was built around an undisturbed soil column to utilize the natural vegetation and soil profile at a variety of microclimates within that watershed. Each of the wooded understory, meadow and crop field sites studied had a silty loam soil. The object of the study was to obtain data on actual water losses rather than maximum ET rates possible at each microclimate. The lysimeter data correlated closely with values calculated from gamma probe measurements.

It may be concluded, therefore, that the small lysimeters were satisfactory for measuring ET under these type of conditions.

Infrared Thermometer

In recent years, the infrared thermometer has become an important tool in the field of thermal sampling. It is especially valuable in determining plant canopy temperatures for two reasons: 1. temperature is determined by measuring the amount of emitted radiation, and therefore, the system being measured is not physically disturbed. 2. By its very nature, the infrared thermometer integrates the temperature over an area which eliminates the need for the large number of sensors that were required when using thermistors or thermocouples.

Plants have evolved with the ability to absorb visible radiation efficiently since they require it for photosynthesis. Gates et al. (1965) showed that plants reflect the near infrared which helps keep them from becoming overheated and absorb the far infrared which makes them efficient radiators of heat acquired from the absorption of visible radiation. It is the efficient radiation of far infrared energy that makes the use of the infrared thermometer a practical means of measuring plant temperature. The efficiency with which an object radiates far infrared, or thermal, energy is called its emissivity (ε). Fuchs and Tanner (1966), Heilman et al. (1976) and Blad et al. (1976) have reported an emissivity of 0.94 to 0.98 for growing plants.

Efforts have been made to estimate ET of field crops with the use of an infrared thermometer. Heilman et al. (1976) found that when temperature readings were taken from aircraft, atmospheric attenuation

produced errors of 1 to 6°C in the scanner measurements. The magnitude and variation of this error makes it difficult to utilize aircraft data in determinations of absolute ET. It was determined by Bartholic et al. (1972) that aircraft measurements offer potential as a useful aid for delineating water stressed and nonstressed fields, evaluating uniformity of irrigation, and evaluating surface soil water conditions.

Measurements of canopy temperature using hand-held infrared thermometers have been found to be reliable. There is a need for better methods of utilizing these data in calculating ET. Two methods, the Bartholic-Namken-Wiegand (B-N-W) and Brown-Rosen (B-R), were evaluated at the South Dakota Agricultural Experiment Station. Stone and Horton (1974) found the B-N-W estimates to be approximately 17% smaller and the B-R estimates to be approximately 22% larger than typical estimates obtained by the Penman and energy budget-Bowen ratio methods.

RESEARCH

The discussion of research is in three sections. The first is concerned with problems which arose with using lysimeters in urban lawns. The second discusses a growth chamber study designed to measure ET under controlled conditions. The third section reports preliminary work done to determine how well canopy temperature measurements can indicate reductions in ET due to water stress.

Each section adds to an understanding of the others and they should be considered together. It is important to note that the response of roots to clay soil in lysimeters, as observed in the second section, was instrumental in developing the discussion of water stress in the first section.

Urban Lawn Project

Methods and Materials

The urban lawn project was funded by the United States Department of the Interior's Office of Water Research and Technology. The primary objective of this study was to obtain measured data concerning water use of urban lawns. This thesis is concerned with that aspect of the project which utilized lysimeters to determine the water requirements of lawns.

The lysimeters, which were constructed from 3.2-mm thick P.V.C. pipe, were 30.5 cm in diameter and 61.0-cm deep. A hole was dug in the

ground to contain each lysimeter and a 31.8-cm diameter shell was placed into the hole to maintain its shape. A 5-cm gravel layer was placed in the bottom of the lysimeters to facilitate drainage. Soil from the excavation was used to nearly fill the lysimeters and the original sod was placed on the surface. Each lysimeter was then lowered into the appropriate shell. Each lysimeter had a plug in the bottom which could be removed to facilitate draining excess water when necessary. Slots were cut near the top of the lysimeters to use in lifting them in and out of the ground. The sod was allowed at least two months to become well established in the lysimeter before ET measurements began. An installed lysimeter was difficult to detect visually in the lawns.

The weight of the lysimeters was obtained after thoroughly soaking the lysimeters and allowing them to drain for one day, then weighing them then the soil was at the maximum moisture level. This was done during cool cloudy weather so that a minimum amount of water was lost through ET. The lysimeters were always weighed to within 0.1 kg.

Residents of the lysimeter sites were provided with lids and asked to cover the lysimeters whenever they watered their lawns. The turf in the lysimeters was mowed and fertilized by the homeowner, with the rest of the lawn. The lysimeters were pulled out, weighed and watered twice a week in 1977 and three times a week in 1978. Enough water was added each time to bring the weight of the lysimeters up to the weight at the maximum moisture level. The weight before the addition of water was subtracted from the weight at the maximum moisture content to give the weight of water lost due to ET. The lysimeters had to be drained when the water content increased above the desired level. This happened

periodically due to rainfall or when homeowners failed to cover the lysimeter during lawn watering.

Fifteen lysimeters were placed in Fort Collins with five in each of three lawns. The lysimeters were placed with the intent of obtaining a representative measurement of ET with due consideration given to microclimate, soil and vegetation. Placement of the lysimeters was determined by the following criteria: (1) one lysimeter was located on each side of the house and placed approximately in the center of the grassed areas, (2) if a house did not have grass on all side, two or more lysimeters were placed in the lawn so they were as representative as possible of the lawn, and (3) one lysimeter was located as close as possible to a potential heat source such as a driveway, sidewalk or sidewalk-driveway intersection.

Results and Discussion

An analysis of the entire Urban Lawn Project can be found in the M.S. thesis of Peter Haw, 1978.

The average ET measured with each of 15 lysimeters in Fort Collins for 1977 and 1978 is listed in Table 1. The difference in ET measured with individual lysimeters was largely a function of microclimate. Some lysimeters were located in open areas, some in shaded areas and some in hot spots such as along driveways. Site differences resulted from the location of sites within the urban environment. Site 1 had open fields to the east and west which may have resulted in increased air movement. The average ET for site 1 was higher than ET for site 2 and 3 for 1977 and 1978.

Table 1. Average water use rate of lysimeters in Fort Collins.

Site No.	Lysimeter ET, mm/day					Average
	A	B	C	D	E	
1977*						
1	6.3	6.2	5.9	6.6	7.4	6.5
2	5.1	4.6	5.5	3.6	6.4	5.0
3	4.3	3.9	4.8	4.9	4.4	4.5
1978**						
1	6.7	6.6	6.1	5.1	6.1	6.1
2	4.5	4.7	5.6	3.5	5.1	4.6
3	5.1	4.5	6.3	4.3	4.5	5.0

*May 19-Aug. 29

**May 11-Aug. 23

When daily ET from each lysimeter was compared on a relative basis, the result sometimes differed from the seasonal trend. The variety of errors which influenced lysimeter data merit discussion.

Random Procedural Errors

Random errors were a significant problem in determining ET of urban lawns. Listed below are the most common ones.

1. Home owners forgetting to cover lysimeters when watering their lawn.
2. Home owners forgetting to uncover lysimeters after watering their lawn.
3. Error in weighing, or in adding, water to lysimeters by Personnel.

In cases where a large error was introduced from one of these sources, it was obvious by inspection, and that data point was deleted. When a small error resulted from one of these sources, it was often difficult to distinguish from normal data variability. It was assumed that small errors occurred infrequently and, therefore, had little effect on the overall average data values. For example, if two of the fifteen lysimeters in Fort Collins gave a data value for ET which contained 10% error, on any given day, this would result in only a 1.3% error in the average lawn ET value for that day.

Systematic Procedural Error

During the summer of 1977, the lysimeters were normally weighed twice each week. This gave a four-day ET period and a three-day ET period. If there was any systematic error in the procedure of obtaining data from the lysimeters, it should have shown up in an analysis of data from those two time intervals, since there would be an error once every three days versus once every four days.

An analysis of variance was run for each site using the time interval between weighings, as the factor of interest (see Appendix I). For the summer of 1977, there was no significant difference in ET between a three-day or four-day interval for site 2, however, sites 1 and 3 had ET averages that were significantly different at the 2% and 1% level, respectively. As a further check, an analysis of variance was run on all three sites, this time including site as a factor. A site-weighing period interaction showed a significant difference at the 2% level (see Appendix III). This verified that all three sites were not responding to the period between weighings in the same manner.

The procedure of determining ET from the lysimeters could not account for a site interaction, or the systematic error would have shown up for all three sites. One difference between the lysimeters themselves was that they were filled with soil from their respective sites. A lower ET for a four-day period than a three-day period could be an indication of water stress on the fourth day. If sites 1 and 3 had a fine-textures soil that would result in poor aeration and, therefore, poor root growth, then the soil near the surface would dry out quicker and result in stress earlier than if there were a deep,

Table 2. Particle size analysis of the soil from the three lysimeter sites in Fort Collins (hydrometer method).

Location	Sand %	Silt %	Clay %	Texture
Site 1				
Front yard	30.0	30.0	40.0	clay
Back yard	32.5	32.5	35.0	clay loam
Site 2				
Front yard	50.0	25.0	25.0	sandy clay loam
Back yard	67.5	17.5	15.0	sandy loam
Site 3				
Front yard	42.5	32.5	25.0	loam
Back yard	35.0	40.0	25.0	loam

well formed root system. A particle size analysis of the soils from the three sites supported the possibility of this theory (see Table 2).

For the summer of 1978, it was decided to weigh the lysimeter three times a week. This resulted in two, two-day periods and one, three-day period each week. To check if the stress problem of the previous summer had been eliminated, an analysis of variance was run on each of the 3 sites, using a three-day versus two-day time period as the factor of interest. There was a significantly higher ET on the two-day period for sites 1, 2 and 3, at the 1%, 1% and 10% levels, respectively (see Appendix II). A three-way analysis of variance was again run using site as a second factor. For 1978, however, there was no site-time period interaction that was significant (see Appendix IV). This indicates that all 3 sites were differing in the same manner on ET values from a two-day versus a three-day period.

There were two logical explanations for these results: 1. there was a systematic procedural error during 1978, or, 2. on the average, the weather was different for the two time periods of 1978 but not different for the two time periods of 1977. Since the procedure for 1978 was the same as for 1977, explanation number 2 was pursued.

Weather data from the Colorado State University Agronomy Research Farm just outside of Fort Collins, was obtained for both summers. The data was split into two groups for each summer corresponding to the lysimeter weighing periods (see Table 3). The maximum daily temperature and pan evaporation was averaged for each of these periods. The results shown in Table 2 indicate that explanation 2 was likely. In 1978, the two-day periods averaged 1.3°C hotter than the three-day periods. Pan evaporation averaged 10% higher for the two-day periods, while ET for

Table 3. Average ET values (mm/day), Pan evaporation and maximum temperature for periods between lysimeter weighings.

	1977		1978	
	3 day	4 day	2 day	3 day
Site 1	6.57	5.65	6.76	5.54
Site 2	5.50	5.41	5.03	4.23
Site 3	4.93	4.10	5.32	4.75
Farm Pan Evaporation (mm/day)	7.88	7.61	7.62	6.93
Farm Maximum Temperature (^{o}C)	26.75	26.71	26.50	25.42

sites 1, 2 and 3 was 22%, 19% and 12% higher, respectively. As temperature increases, ET increases more rapidly than evaporation, according to Wilcox and Sly (1974). Therefore, the greater increase in ET seems reasonable.

In summary:

1. There were probably no systematic errors due to procedure.
2. In 1977, the maximum temperature averages for the three and four-day periods were similar.
3. In 1978, the temperature averages of the two-day periods were higher than the three-day periods.
4. In 1977, stress was likely on the lysimeters of sites 1 and 3 during the fourth day, therefore, 3 irrigations per week were necessary to prevent stress sufficient to reduce ET.

Growth Chamber Study

Methods and Material

A growth chamber study was done during the fall of 1977 with the intent of determining the magnitude of various individual maintenance and environmental effects on ET. Day temperature, night temperature, mowing height and soil texture was varied. The Urban Lawn Project did not attempt to regulate any of these variables, but was designed to obtain a measurement of maximum possible ET values under typical lawn conditions. It was hoped that the growth chamber study would aid in the interpretation of some of the variability found with the lysimeter data from the Urban Lawn Project.

Lysimeters were made from 3.2-mm thick, 30.5-cm diameter, P.V.C. pipe. They were the same as those used in the Urban Lawn Project except that they were only 30.5-cm deep. The decreased depth was to facilitate handling since the shorter lysimeters weighed about 35 kg maximum as opposed to about 70 kg for the deeper ones.

Treatment consisted of two soil types (Midway clay and Ascalon fine sandy loam) and two mowing heights (2.5 and 5.0 cm). Each of the four treatments were replicated so that a total of eight lysimeters were involved in the study. Fertility and textural analysis data of these soils is listed in Appendix V and VI.

The lysimeters were kept on a greenhouse bench for six weeks while the sod become established. The sod, from a blend of Merion, Fylking and Adelphi Kentucky bluegrass cultivars, received fertilizer to maintain lush growth throughout the experiment. The lysimeters were rotated

through a weekly cycle of two days in the growth chamber and five days in the greenhouse. Only one replication of each treatment was in the growth chamber at any given time, therefore, there were two growth chamber cycles run each week.

The experiment in the growth chamber was in operation for eight weeks. For each weekly cycle the growth chamber was set for a different day and night temperature combination. A total of four day temperatures were run with two night temperatures. Throughout the trial the growth chamber was maintained at a twelve hour light-twelve hour dark cycle. Temperature, humidity and light intensity data are shown in Appendix VII and VIII.

The lysimeters were placed in the growth chamber in the evening after sunset and removed forty-eight hours later in an effort to retain a natural day-night cycle for the grass. The lysimeters were clipped to the proper height twenty-four hours before being placed into the growth chamber to allow the grass a recovery margin from any clipping shock.

Twenty-four hours before being placed into the growth chamber, the lysimeters were heavily watered and the plugs in the bottom were removed. Immediately before being placed into the growth chamber, the plugs were replaced and the lysimeters were weighed. All weighings were made to the nearest 0.03 kg. Forty-eight hours later, the lysimeters were removed from the growth chamber, weighed, and the plugs were removed from the bottom. The decrease in weight of the lysimeters while in the growth chamber is equal to the weight of the water lost by ET.

Results and Discussion

The data from the growth chamber study is listed in Table 4. A four-way analysis of variance was used to evaluate the effect of day temperature, night temperature, mowing height and soil temperature. All four factors had an influence on ET that was significant at the 1% probability level. Details of the analysis of variance are provided in Appendix IX.

Day Temperature

Figure 1 shows ET plotted as a function of day temperature for two night temperatures. Each point is an average of eight values from 2 soils, 2 mowing heights and 2 replications. All ET values for each daytime temperature were averaged and a regression was run which yielded the equation

$$ET = (0.2133 \text{ mm}/^{\circ}\text{C day})\ T_d - 0.9688 \text{ mm/day} \qquad R^2 = 0.975 \qquad (1)$$

where:

T_d = the day temperature in $^{\circ}$C

An equation such as (1) may have some use in the scheduling of irrigation for growth chamber studies.

Night Temperature

Throughout the experiment the values for ET of the 18°C night treatment averaged 13% higher than the values for the 8°C night treatment.

Table 4. Evapotranspiration (mm/day) as influenced by clipping height, soil texture, and day and night temperature. Each value represents the average of two observations.

Night Temperature (°C)	Day Temperature (°C)	2.5 cm Clipping Height		5.0 cm Clipping Height		Average
		Clay Soil	Sandy Loam Soil	Clay Soil	Sandy Loam Soil	
8	21	2.97	2.97	3.11	3.40	3.11
8	26	4.57	4.54	4.76	4.96	4.71
8	29	4.03	4.18	5.39	5.74	4.84
8	33	4.47	5.00	6.27	6.41	5.54
18	21	3.11	3.64	3.89	4.52	3.80
18	26	4.23	4.32	5.28	5.68	4.88
18	29	4.67	4.57	5.25	6.27	5.19
18	33	5.35	6.41	7.33	7.63	6.68
	Average	4.18	4.45	5.16	5.58	4.85

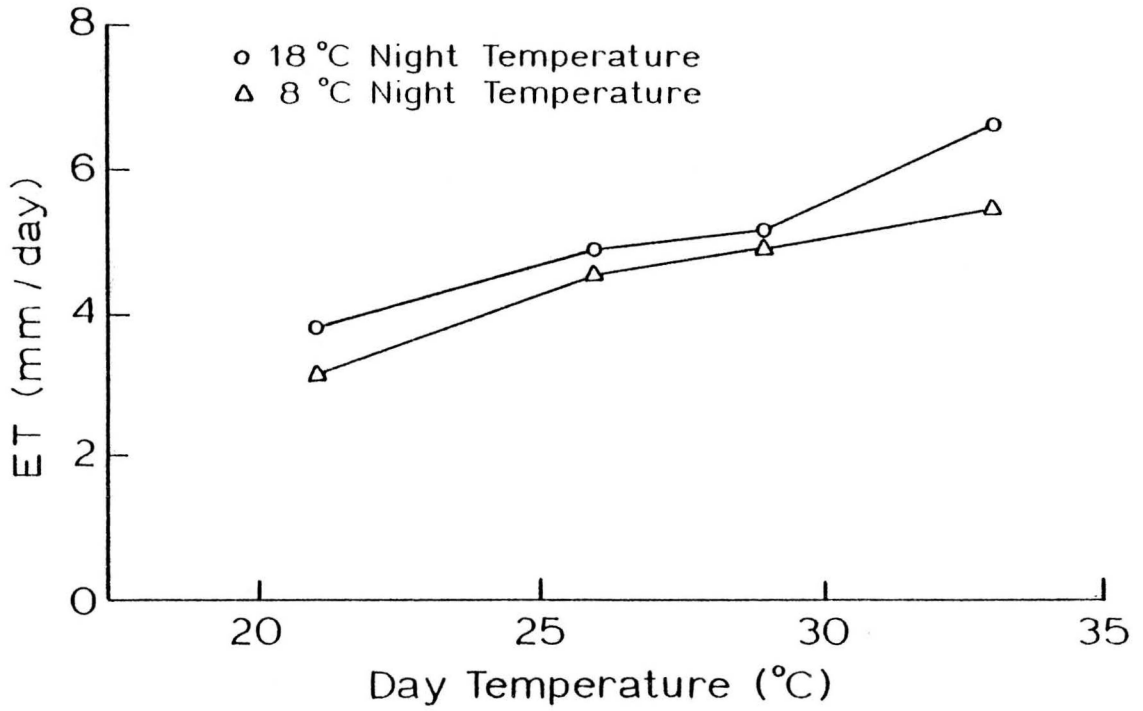


Figure 1. Evapotranspiration at 4-day temperatures for each of two night temperature levels. Each point is an average of eight values.

While this was not a large difference, it was, however, found to be a consistant difference.

There was a day-night temperature interaction that was significant at the 5% level. There seemed to be a slight trend for the ET rate to increase more with an increase in day temperature at the higher night temperature. This is demonstrated in Figure 1. The effect may in part be due to a higher soil temperature.

Mowing Height

The turf maintained at a 5-cm mowing height had, on the average, an ET rate 25% higher than the turf maintained at a 2.5-cm height. Taller turf in limited sized containers is influenced more by convective energy than its shorter counterpart due to a greater effective surface area of the canopy boundaries as well as greater leaf area. The surface boundary for the 5-cm grass was 25% greater than the 2.5-cm grass, which resulted in an increase in incident radiation. However, the greater influence of convective energy is suggested by an interaction between day temperature and mowing height that was significant at the 2% level. All treatments received the same daily radiation energy. Therefore, an increase in temperature resulted in an increase in convective energy.

Soil Texture

On the average, the grass growing in sandy loam had an ET rate 7% higher than the grass growing in clay. While this is not a large difference, it was consistent enough to be significant at the 1% probability level.

After the experiment was terminated, eight 10-cm diameter, 30-cm deep, soil cores were taken from the lysimeters that were maintained at a 2.5-cm mowing height. Four cores were from sandy loam and four were from clay soil. They were soaked in water twenty-four hours, then gently washed in a detergent solution. The sandy loam soil contained a large number of roots that were very thick. The clay soil had relatively few roots and those that is had were very small in diameter (see Figure 2).

It is not clear why, when water was not limiting, that soil texture had an influence on ET. From an examination of the roots, it seems possible that part of the effect was caused by a difference in the hydraulic conductivity of the roots themselves. In a lysimeter there is an effective water table at its base at the time drainage stops. A clay soil will have very little air content, even at the top of the lysimeter since this represents only 30-cm tension. Roots of Kentucky bluegrass will not grow well in soils with such poor aeration. The thin roots that do grow may not be able to conduct water, in response to the water potential gradient of the soil-plant-atmosphere system, as fast as thicker ones grown in sandy soil.

Soils with poor aeration become low in oxygen and high in carbon-dioxide due to the respiration of roots. Under these conditions root membranes become less permeable to water. This may have decreased water uptake of the grass grown on clay soil enough to affect ET.

Water uptake is related to root absorption area. The rate of water uptake is highest near the tip of growing roots. The roots growing in the clay soil had a much smaller total surface area of growing roots to absorb water than roots growing in the sandy loam soil.



Figure 2. Photographs of washed roots from duplicate core samples from lysimeters (1 and 2) containing two soil textures (C - clay, S - sand). Each core was 10 cm in diameter and 25-cm deep.

In summary; three possible explanations for the decreased ET of turf grown in clay soil are:

1. root surface area to absorb water was limiting.
2. decreased root membrane permeability caused by poor aeration.
3. low hydraulic conductivity of thin roots.

Canopy Temperature Study

Methods and Material

During the summer of 1978, a study was conducted in the field behind the Colorado State University Agricultural Engineering Research Center to determine if canopy temperature could be used as a practical indication of whether turf was utilizing water at a maximum rate.

Eight 30-cm deep lysimeters were filled with sand and sod was placed on the surface. The lysimeters were placed in a row adjacent to a 1,000 m^2 plot of well-maintained turf such that they were in essentially identical microclimates.

After being grown for two months, the maximum water level for the lysimeters was determined by watering heavily, allowing to drain for 24 hours, then weighing. ET was determined daily by weighing the lysimeters, which were then returned to maximum moisture level. Canopy temperature measurements were made periodically, during the days that were considered critical, with a Barnes 14-220 infrared thermometer. On August 4, irrigation was withheld for 8 days from four of the lysimeters which left the canopies completely desiccated. Two of the lysimeters were then returned to maximum water content to allow regrowth. Water was then

withheld from two of the lysimeters which had been maintained at the maximum water level. This procedure was designed to allow ET and canopy temperature to be compared for the following four treatments under identical environmental conditions.

A. lush, turgid canopy

B. lush, wilted canopy

C. dead, canopy with some regrowth

D. dead, dry canopy

Climate data collected at the site consisted of air temperature, humidity, solar radiation and rainfall. Pan evaporation data were also collected daily (see Appendix X).

The study was terminated on August 19, due to rainy weather.

Calibration of Infrared Thermometer

A calibration of the Barnes 14-220 infrared thermometer was made to insure that no significant error in canopy temperature measurements was incurred due to the response of the instrument. The Colorado State University Blackbody was utilized with the following alterations (see Figure 3).

1. Ethylene glycol was used in the bath instead of alcohol
2. A mercury thermometer was used to measure the cone temperature instead of a thermister

The fluid bath was lowered to 5°C and raised at the rate of 6°C/hr. Temperature readings were taken at various times throughout the day and a regression was run between the mercury thermometer and the infrared thermometer.

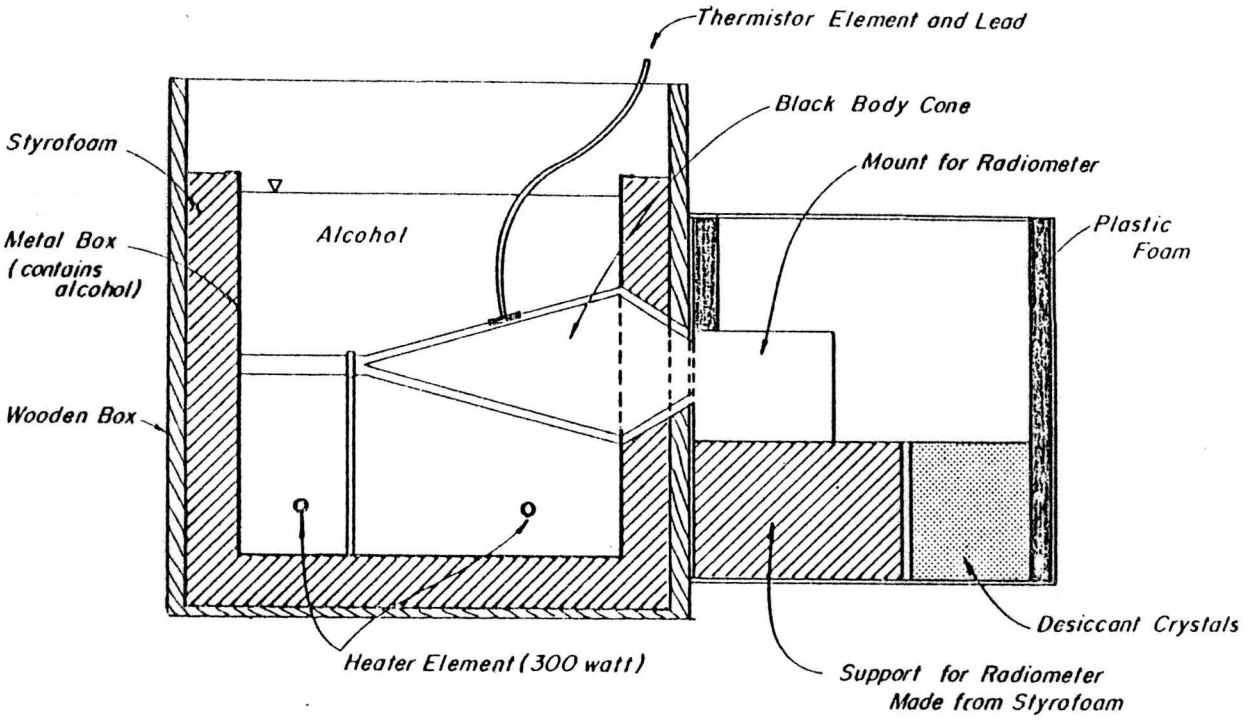


Figure 3. Diagram of CSU Laboratory Blackbody used to calibrate the Barnes 14-220 infrared thermometer. (After Salomonson and Marlatt 1964)

Calculation of Turf Emissivity

Small differences in emissivity (ε) can result in significant errors when measuring the temperature of an object from its radiation. The Stephan-Boltzman equation states:

$$R = \varepsilon\sigma T^4 \qquad (2)$$

where:

R = the energy flux of the electromagnetic radiation from any surface

ε = the emissivity, or efficiency with which the surface radiates

σ = the Stephan-Boltzman constant

T = surface temperature (^{o}K)

The literature reports values for ε of live vegetation of around 0.95 to 0.97. However, no values for ε of dead vegetation were found. It was, therefore, essential to determine if there were any differences in the ε of live and dead turf if valid interpretations were to be made from the canopy temperature measurements.

To calculate ε a "thermo-shield" (see Figure 4) was constructed to thermally isolate the turf canopy of a lysimeter from its environment. Yellow Springs thermistors, which were accurate to within $0.3^{o}C$, were imbedded in the turf canopy. At 15 minute intervals, temperature readings were taken with the thermistors and with the I.R. thermometer. By knowing the actual temperature, as determined with the thermistors, and the measured temperature, using the infrared thermometer, ε was calculated

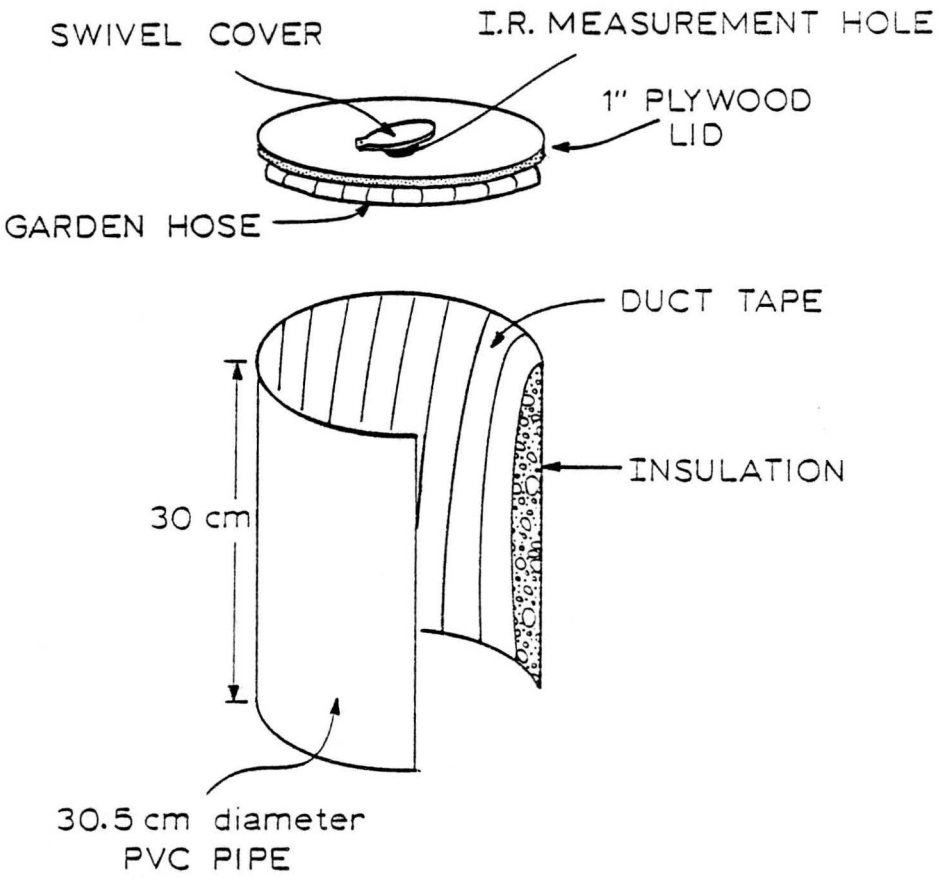


Figure 4. Diagram of the "thermo-shield" used to calculate the emissivity of live and dead turf canopies.

Results and Discussion

Response of Infrared Thermometer

The response of the I.R. thermometer was plotted against a mercury thermometer (see Figure 5). A regression was run and it yielded the equation

$$y = 0.92x + 0.22 \qquad r = 0.997 \tag{3}$$

where:

x = temperature in ^{o}C using I.R. thermometer

y = temperature using mercury thermometer

The meaning of this equation is that the I.R. thermometer gave a reading of about 8% high for the temperature of the black body over the range of 0 to 50^{o}C, e.g, at room temperature, 25^{o}C, the I.R. thermometer read 2^{o}C high.

The basic temperature equation for an ideal infrared thermometer is:

$$T_a = ((T_m)^4/\varepsilon)^{1/4} \tag{4}$$

where:

T_a = actual temperature in ^{o}K

T_m = measured temperature using the infrared thermometer

ε = emissivity of measured object

This equation assumes no error due to the response of the instrument. To get the equation for the Barnes 14-220, the basic temperature equation must be combined with the regression equation. First of all, the regression

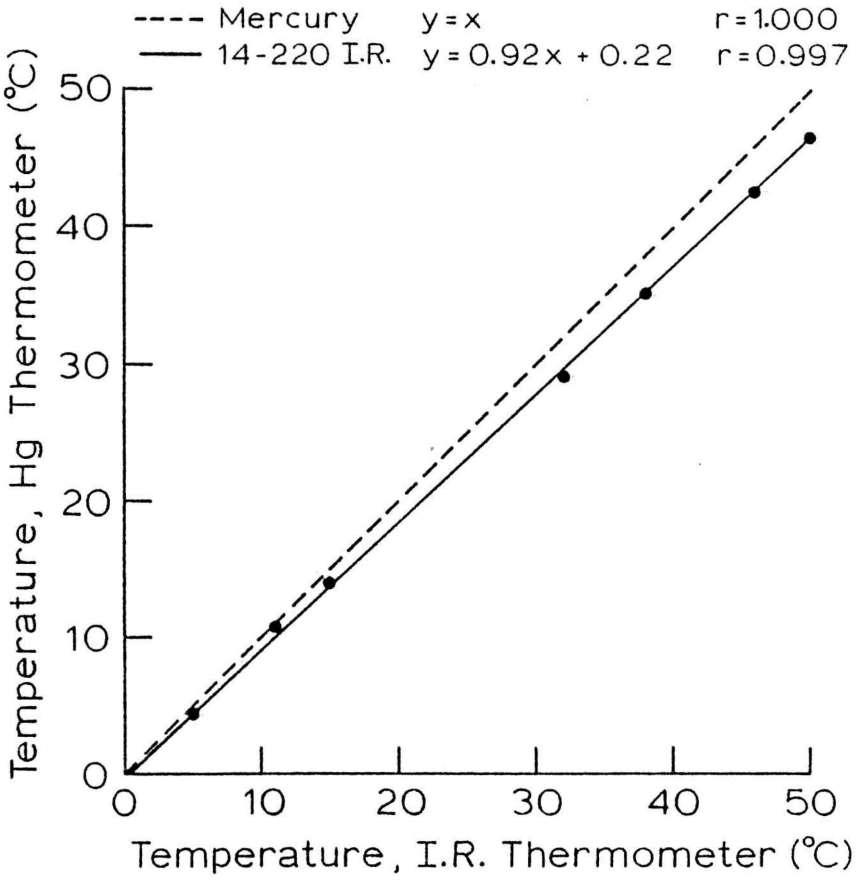


Figure 5. Calibration line for the Barnes 14-220 infrared thermometer.

response equation must be changed to correspond to the system in degrees Kelvin. This is done by merely changing the y intercept; therefore, equation 3 becomes

$$y = 0.92x + 22.44 \tag{5}$$

where x and y are now expressed in ^{o}K

Equations 4 and 5 combine to yield

$$T_a = 0.92\ ((T_m)^4/\varepsilon)^{\frac{1}{4}} + 22.44 \tag{6}$$

To facilitate use, equation 6 can be changed so that T_a and T_m are expressed in ^{o}C which are the units of measurement of the I.R. thermometer.

$$T_a = 0.92\ ((T_m + 273.15)^4/\varepsilon)^{\frac{1}{4}} - 250.71 \tag{7}$$

Equation 7 is the response equation of the Barnes 14-220.

Emissivity of Live and Dead Turf Canopies

The temperature of live and dead turf canopies was measured with both thermistors and the infrared thermometer (see Table 5). The emissivity was calculated by rearranging the response equation of the infrared thermometer (equation 7) to give

$$\varepsilon = \frac{(T_m + 273.15)^4}{\left[\frac{(T_a + 250.71)}{.92}\right]^4} \tag{8}$$

where:

T_m = the temperature reading from the I.R. thermometer in ^{o}C

T_a = the actual temperature using thermistors

Table 5. Measured temperature and calculated emissivity values for live and dead turf foliage at 15 minute intervals following placement of the "thermo-shield" over the lysimeters.

		Temperature (^{o}C)							Emissivity (ε)	
		Thermister								
Day 1	Minutes	A	B	C	D	E	Average	Infra-red	Calculated	Average
Dead	15	23.5	24.0	24.0	23.5	23.4	23.7	21.8	.957	
	30	24.1	24.1	24.1	23.5	23.5	23.9	22.0	.957	
	45	24.8	24.5	24.4	23.6	23.6	24.2	22.5	.959	.958
Live	15	26.5	26.0	25.4	25.0	25.5	25.7	24.9	.969	
	30	26.9	26.9	25.8	25.8	26.0	26.3	24.9	.955	
	45	26.9	26.9	26.0	26.0	26.0	26.4	24.0	.948	.957
Day 2										
Dead	15	30.0	29.8	30.7	31.1	30.7	30.5	29.0	.955	
	30	30.4	30.3	31.0	31.1	31.0	30.8	29.3	.955	
	45	30.8	30.8	31.0	31.0	31.0	30.9	29.3	.953	.954
Live	15	26.3	27.2	26.4	26.9	26.4	26.6	25.0	.957	
	30	27.1	27.8	26.8	27.0	26.7	27.1	25.5	.957	
	45	27.5	28.0	27.0	27.3	27.0	27.4	26.0	.960	
	60	27.9	28.3	27.3	27.8	27.3	27.7	26.0	.955	.957
									Dead Average	.956
									Live Average	.957

The emissivity of live and dead turf canopies was calcualted to be .957 and .956, respectively.

The ε value for live turf agrees well with values for live vegetation reported in the literature. The value of ε calculated for the dead truf should, therefore, be valid. Temperature readings taken of live, dead and mixtures of live and dead turf should not be subject to errors due to emissivity variation.

Using equation 8, if the Barnes 14-220 gave a reading for a turf canopy temperature of 25°C, then the real temperature would calculate to be 26.6°C. This gives an error of 1.6°C. This error is not serious when comparing the relative temperature of turf canopies as an indication of their water status. A difference of 10°C in two canopies would indicate a very significant water stress in the hotter one and this difference would include only a 0.5°C error due to the reading of the I.R. thermometer.

Canopy Temperature

In Figure 6, the relative ET of the four lysimeter canopy treatments is plotted with time. The relative ET is the actual ET divided by the ET of the control, which was the lush, turgid canopy. The actual ET is listed in Appendix XI.

Plotted below the relative ET is the relative temperature which is the temperature of each treatment divided by the temperature of the control. The actual temperature is listed in Appendix XII. As can be seen in Figure 6, there is a close correlation between relative ET and relative temperature.

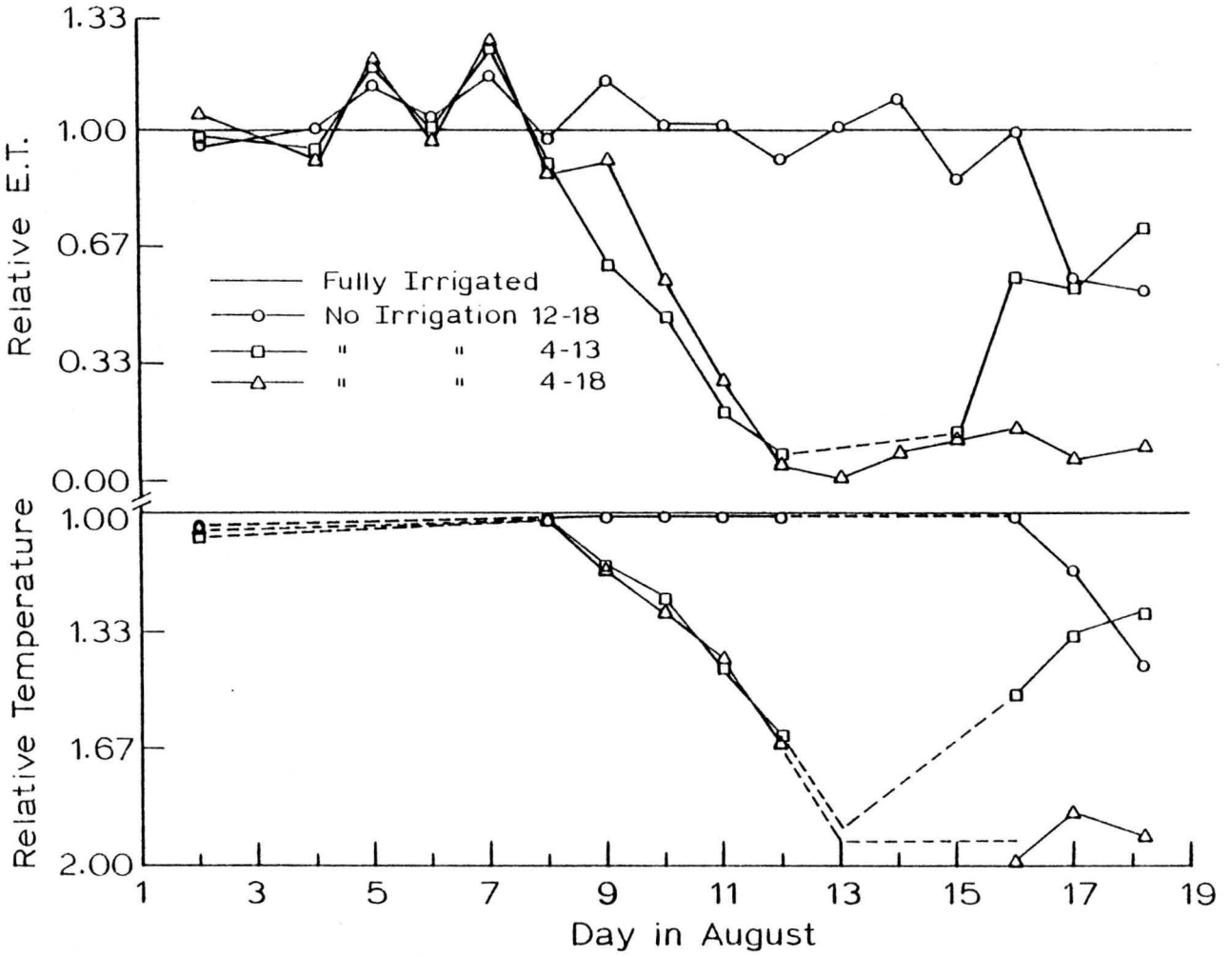


Figure 6. Relative ET and canopy temperatures for three irrigation schedules relative to fully irrigated turf. (Each point is an average of two replications)

The relative temperature curve has less variation than the relative ET curve. It seems possible that canopy temperature could be utilized as a convenient indication of whether turf was experiencing stress or whether it was utilizing water at a maximum rate.

Figure 7 shows a color photograph and a color infrared photograph of the four treatments on day 18. It would be easy to erroneously deduce from visual and infrared observation that treatment B was utilizing more water than treatment C. However, ET measurement from weighing the lysimeters and temperature measurements using the infrared thermometer, both confirmed that treatment C was using 30% more water than treatment B.

This experiment was ended on August 18, 1978 due to the arrival of rainy weather.

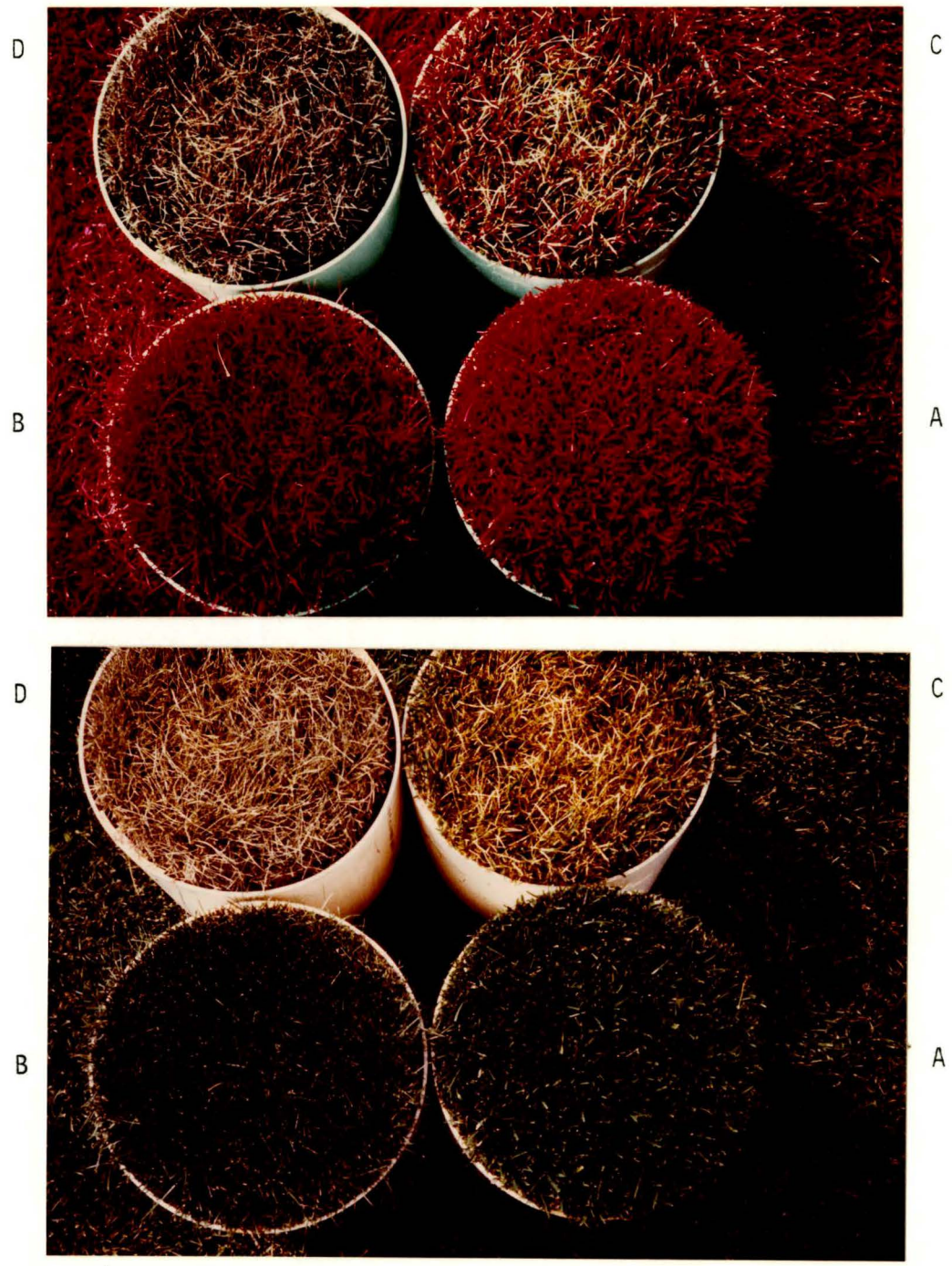


Figure 7. Color infrared and color photographs of turf in the canopy temperature study, taken on August 18, 1979. Treatments are identified in Figure 6.

SUMMARY AND CONCLUSIONS

Each component of the soil-plant-atmosphere system has a complex influence on ET. Reconstructing the ecosystem to be studied into lysimeters, will always have some shortcomings. Minimizing error usually requires that a thorough evaluation of the entire lysimeter system be made so that its design allows effective response to the environment in the intended manner.

Thirty small lysimeters were placed in urban lawns of Fort Collins and Northglenn, Colorado. The reliability of the procedures for obtaining data from these lysimeters was analysed. The Urban Lawn Project yielded good data for typical ET rates of urban lawns on the Colorado plains. Urban lawns, however, did not prove to be a good place to study microclimate effects on ET due to the lack of control over lysimeter sites. It was also determined that during 1977, the lysimeters may not have been irrigated frequently enough to prevent the turf in some lawns from experiencing water stress resulting in less than maximum ET.

A study on ET was done in a growth chamber to facilitate close examination of effects caused by day temperature, night temperature, mowing height and soil texture. The response of turf ET to temperature had much less variability than in the Urban Lawn Project, due to the greater control of environment. Evapotranspiration increased as canopy height increased, but this response may not necessarily be exactly the same under field conditions. Field ET may be greater for higher canopy heights only on windy days. The growth chamber study also reinforced

the importance of evaluating soil conditions in lysimeters. Soil is both a storage reservoir for water and a growth media for roots. Even if soil contains adequate water for plant growth, ET may be restricted if the soil environment does not satisfy all the requirements of a good root growth media.

Prior to use for canopy temperature measurement a Barnes 14-220 infrared thermometer was calibrated using a specially designed black-body. Error due to the response of the I.R. thermometer was small. The thermal emissivity of live and dead turf canopies was found to be the same. Therefore, temperature measurements using an I.R. thermometer can be made of turf canopies varying in quality without error due to emissivity differences.

Canopy temperature proved to be an effective method of detecting water stress in turf. Average daily canopy temperature varied less than lysimeter data and, therefore, was more reliable for detecting water stress. Canopy temperature measurements using an infrared thermometer proved more reliable for determining relative water use of turf varying in quality than predictions made by visual observation or by color infrared photography.

Factors affecting plant growth are so numerous that it is difficult to eliminate variability from even what is intended to be identical treatments. Environments which were considered similar in the Urban Lawn Project often yielded quite different data. There is always a reason for data being what it is. The question is, are we clever enough to discover it?

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Appendix I. Analysis of variance of urban lawn data for 1977. Factor 1 indicates a 3-day or 4-day weighing period. Factor 2 has 5 levels corresponding to the location of the lysimeters within each site.

Site	Source	DF	Sum of Squares	Mean Square	F-Ratio	P(F>Comp F)
	Total	9				
1			0.04908			
	1	1	0.02417	0.02417	17.72274	0.01359
	2	4	0.01946	0.00486	3.56744	0.12282
	12	4	0.00545	0.00136		
2			0.04313			
	1	1	0.00020	0.00020	0.12353	
	2	4	0.03631	0.00908	5.48915	0.06392
	12	4	0.00662	0.00165		
3			0.02694			
	1	1	0.01733	0.01733	154.85267	0.00024
	2	4	0.00917	0.00229	20.47494	0.00630
	12	4	0.00045	0.00011		

Appendix II. Analysis of variance of urban lawn data for 1978. Factor 1 indicates a 2-day or 3-day weighing period. Factor 2 has 5 levels corresponding to the location of the lysimeters within each site.

Site	Source	DF	Sum of Squares	Mean Square	F-Ratio	P(F>Comp F)
	Total	9				
1			0.20124			
	1	1	0.03709	0.03709	35.17393	0.00405
	2	4	0.15993	0.03998	37.91905	0.00195
	12	4	0.00422	0.00105		
2			0.06752			
	1	1	0.01618	0.01618	22.16992	0.00925
	2	4	0.04842	0.01211	16.59056	0.00933
	12	4	0.00292	0.00073		
3			0.04828			
	1	1	0.00818	0.00818	5.36308	0.08151
	2	4	0.03400	0.00850	5.57326	0.06239
	12	4	0.00610	0.00153		

Appendix III. Three-way analysis of variance of urban lawn data for 1977. Factor 1 corresponds to weighing periods. Factor 2 has 3 levels, representing the 3 sites. Factor 3 has 5 levels corresponding to the location of lysimeters within each site. The 1-2 interaction shows a difference in how sites reacted to the two weighing periods.

Source	DF	Sum of Squares	Mean Square	F-Ratio	P(F>Comp F)
Total	29	0.25253			
1	1	0.03028	0.03028	42.85572	0.00018
2	2	0.13338	0.06669	94.38545	0.00000
12	2	0.01142	0.00571	8.08282	0.01201
3	4	0.04163	0.01041	14.72819	0.00092
13	4	0.00687	0.00172	2.42909	0.13279
23	8	0.02331	0.00291	4.12433	0.03064
123	8	0.00565	0.00071		

Appendix IV. Three-way analysis of variance of urban lawn data for 1978. Factor 1 corresponds to weighing periods. Factor 2 has 3 levels, representing the 3 sites. Factor 3 has 5 levels corresponding to the location of lysimeters within each site. The 1-2 interaction shows little difference in how sites reacted to the two weighing periods.

Source	DF	Sum of Squares	Mean Square	F-Ratio	P(F>Comp F)
Total	29	0.56024			
1	1	0.05609	0.05609	45.37022	0.00015
2	2	0.24320	0.12160	98.35917	0.00000
12	2	0.00535	0.00268	2.16504	0.17727
3	4	0.10971	0.02743	22.18439	0.00022
13	4	0.00335	0.00084	0.67675	
23	8	0.13265	0.01658	13.41178	0.00068
123	8	0.00989	0.00124		

Appendix V. Fertility test of soils used in growth chamber study as reported by the state soil testing laboratory, Fort Collins, Colorado.

Soil	pH	mmhos. (Salts)	Lime	% O.M.	P P.P.M.	K P.P.M.	NO_3-N P.P.M.	Zn P.P.M.	Fe P.P.M.
Midway Clay	7.7	1.2	H	1.7	1	175	19	.7	3.6
Ascolon Fine Sandy Loam	7.6	0.5	L	1.5	5	208	4	.4	9.2

Appendix VI. Particle size analysis of soil used for growth chamber study (hydrometer method).

Soil	Sand %	Silt %	Clay %
Midway clay	21.9	35.6	42.5
Ascolon Fine Sandy Loam	63.3	24.2	12.5

Appendix VII. Temperature and humidity as recorded by the hydrothermograph for the weekly growth chamber trials.

Week	Temperature ^{o}C		Relative Humidity %	
	Day	Night	Day	Night
1	26	8	45	74
2	26	18	52	78
3	33	18	43	83
4	29	18	46	80
5	29	8	38	82
6	33	8	33	81
7	21	8	60	82
8	21	18	54	62

Appendix VIII. Light energy as recorded with a Robitzsch Bimetallic Actinometer in growth chamber during the light cycle.

Florescent	1.7 langleys/minute
Incandescent	1.1 langleys/minute
Total	2.8 langleys/minute

Appendix IX. Four-way analysis of variance of growth chamber data with: Factor 1 = light cycle temperature; Factor 2 = dark cycle temperature; Factor 3 = mowing height; Factor 4 = soil texture.

Source	DF	Sum of Squares	Mean Square	F-Ratio	P(F>Comp F)
Total	63	98.11820			
1	3	57.25846	19.08615	79.45116	0.00000
2	1	5.59323	6.59323	23.28328	0.00003
12	3	2.16996	0.72332	3.01101	0.04445
3	1	17.85063	17.85063	74.30794	0.00000
13	3	2.74901	0.91634	3.81450	0.01917
23	1	0.28623	0.28623	1.19149	0.28318
123	3	0.86274	0.28758	1.19712	0.32655
4	1	1.87006	1.87006	7.78460	0.00881
14	3	0.24238	0.08079	0.33633	
24	1	0.34516	0.34516	1.43680	0.23946
124	3	0.04616	0.01539	0.06405	
34	1	0.08556	0.08556	0.35615	
134	3	0.81071	0.27024	1.12493	0.35361
234	1	0.00951	0.00951	0.03957	
1234	3	0.25123	0.08374	0.34861	
Error	32	7.68720	0.24023		

Appendix X. Weather data collected at the Agricultural Engineering Research Center for the period of the canopy temperature study (August 1978).

Day	Ambient Temperature (^{0}C)		Relative Humidity (%)		Solar ($cal\text{-}cm^{-2}\ day^{-1}$)	Pan Evaporation (mm/day)	Precipitation (mm/day)
	Maximum	Minimum	Maximum	Minimum			
1	24	9	95	36	619	6.8	0.0
2	28	11	95	33	505	14.8	0.4
3	27	12	100	48	330	14.3	0.7
4	13	8	100	85	188	6.3	0.3
5	21	8	89	36	673	7.5	0.0
6	27	10	83	18	653	7.8	0.0
7	28	10	97	20	443	6.8	0.1
8	28	12	72	24	618	7.8	0.0
9	29	9	100	26	516	8.3	0.1
10	24	12	74	37	542	6.5	0.0
11	27	11	85	27	505	7.8	0.0
12	31	11	90	20	470	7.3	0.0
13	30	14	83	26	476	7.8	0.0
14	29	11	98	32	449	12.5	0.4
15	22	9	55	23	478	8.8	0.0
16	21	7	68	25	656	6.3	0.0
17	31	11	50	12	653	10.8	0.0
18	31	11	93	12	531	10.8	0.1

Appendix XI. Measured ET using lysimeters, for the 4 treatments used in the canopy temperature study of August 1978.

Day	Treatment (mm/day)			
	A	B	C	D
2	6.9	6.5	6.7	7.5
4	7.7	7.7	7.3	7.1
5	7.2	8.2	8.5	8.6
6	9.3	9.7	9.3	8.9
7	6.1	7.1	7.5	7.7
8	10.3	10.1	9.3	9.1
9	6.6	7.6	4.1	6.1
10	7.3	7.3	3.4	4.2
11	9.3	9.3	1.9	2.7
12	8.5	7.8	0.7	0.5
13	9.5	9.5	-	0.3
14	8.5	9.3	-	0.7
15	7.2	6.2	1.0	1.0
16	8.9	8.8	5.2	1.4
17	12.1	7.0	6.6	0.8
18	10.9	6.0	7.8	1.2

Appendix XII. Average canopy temperature between 11:00 AM and 3:00 PM, August 1978, using the infrared thermometer.

Day	Treatment				Ambient Air
	A	B	C	D	
1	25.7	26.9	27.8	27.3	29.3
7	28.4	28.7	28.7	28.5	29.0
8	24.1	24.1	27.9	28.2	29.4
9	23.3	23.7	29.0	30.1	24.8
10	21.6	21.6	31.1	30.5	26.2
11	23.8	23.9	38.7	39.3	24.0
15	21.3	21.5	32.1	42.5	22.3
16	21.2	24.8	28.5	39.0	27.0
17	22.2	31.8	28.4	42.4	28.0