TURFGRASS IRRIGATION WITH MUNICIPAL EFFLUENT: NITROGEN FATE, TURF CROP COEFFICIENTS AND WATER REQUIREMENTS

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EXECUTIVE SUMMARY

The fate of applied nitrogen (N) and water use in high maintenance turfgrass systems are being studied using two large weighing lysimeters located at the University of Arizona Karsten Turfgrass Research Center. The lysimeters, 13' deep and 8' in diameter, weigh approximately 100,000 lbs each and employ truck scales to measure changes in lysimeter mass due to evaporation. Sampling ports, located at a depth of 3.3' and then every additional 1.6' to a depth of 11.6', provide access to the lysimeter soil for extraction of soil water and measurement of soil water status. The turfgrass system under study consists of 'Tifway' bermudagrass in the summer and 'Froghair' intermediate ryegrass during the winter. One lysimeter is irrigated with potable, well water while the second lysimeter is irrigated with reclaimed municipal effluent. Irrigation is applied at rates sufficient to avoid water stress and ensure necessary leaching of salts. Nitrogen, applied as labeled (N^{15}) ammonium sulfate, is applied to both lysimeters every two weeks. The rate of N applied to the lysimeter receiving wastewater is adjusted downward to ensure both lysimeters receive similar levels of N. A complete meteorological station is located at the lysimeter facility to provide environmental data required for estimating reference evapotranspiration (ETo).

Leachate data continues to show negligible amounts of fertilizer N leaching through the lysimeters. Tissue analysis reveals less than 30% of the applied N resides in the clippings. Lysimeter soil samples were extracted in June to 1) determine how much fertilizer N was sequestered in the thatch and soil and 2) make a preliminary assessment of the potential for denitrification in the lysimeters. Two-thirds of the applied N can be accounted for in the turf clippings, thatch and near surface soil layers in turf irrigated with potable water. Seventy-five percent of the applied N is found in clippings, thatch and near surface soil layers when effluent is used as the irrigation water. Loss of N through denitrification appears to be a significant in both lysimeters. Rates of denitrification were found to be 0.021 and 0.028 lb N_2O-N/acre/day for turf irrigated with potable and effluent water, respectively. Potential denitrification rates were determined to be much higher.

Turf water use is determined from daily changes in lysimeter mass with appropriate compensation for irrigation and rainfall. The ratio of actual turf water use to ETo, referred to as the crop coefficient (Kc), is required to convert ETo to turf water use for irrigation purposes. Five popular methods of estimating ETo are presently under evaluation -- the Penman Equations used by the four regional public weather networks (Arizona, California, New Mexico and Southern Nevada) and the Penman-Montieth Equation. The five methods of estimating ETo differ by as much as 30%, showing a clear need to match Kc with the method of ETo estimation (Figure 1). Appropriate bermudagrass Kcs for the five methods of estimating ETo varied from 0.65 for the New Mexico Penman Equation to 0.86 for the California Penman Equation. Ryegrass Kc values ranged from 0.55 for the New Mexico Penman Equation to 0.86 for the California Penman Equation. The Kcs are relatively constant over the summer months indicating a single Kc value can be used for much of the summer. Winter Kcs are more variable, particularly for the New Mexico and Nevada Penman Equations, suggesting the need to employ more than one Kc during the winter turf season. Turf irrigated with effluent generated higher rates of biomass accumulation which raised seasonal Kcs by about 3%.

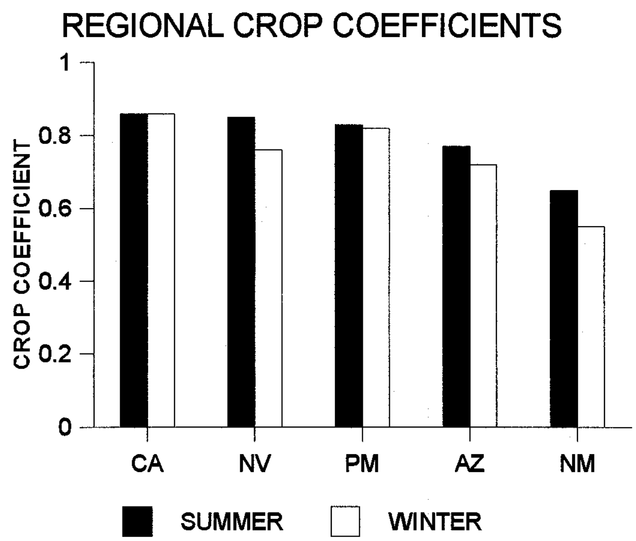

Figure 1. Summer and Winter Kc values developed for five regional procdures (CA: California, NV: Nevada, PM: Penman-Montieth, AZ: Arizona and NM: New Mexico) used to estimate ETo in the Desert Southwest.

TURFGRASS IRRIGATION WITH MUNICIPAL EFFLUENT: NITROGEN FATE, TURF CROP COEFFICIENTS AND WATER REQUIREMENTS

1997 ANNUAL PROGRESS REPORT

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Project Description: This project is designed to 1) determine the potential movement of nitrogen (N) contained in treated (secondary) municipal wastewater used to irrigate turf; 2) determine how effluent irrigation influences water and N requirements; 3) develop turfgrass crop coefficients (Kcs) for use with five Penman Equations widely used in the Southwest for estimating reference evapotranspiration (ETo); and 4) develop a database containing weather and turfgrass evapotranspiration data which can be used by the public and private sectors to develop and/or test the accuracy of Kcs and/or methods of estimating turf ET. The study is being conducted on two large weighing lysimeters located at the University of Arizona Desert Turfgrass Research Facility located in Tucson, Arizona.

INTRODUCTION

The project entitled "Turfgrass Irrigation with Municipal Effluent: Nitrogen Fate, Turf Crop Coefficients and Water Requirements" was initiated in the fall of 1994 and has the following objectives: 1) determine the potential movement of nitrogen (N) contained in treated (secondary) municipal wastewater (reclaimed water) used to irrigate turf; 2) determine how effluent irrigation influences water and N requirements; 3) develop turfgrass crop coefficients (Kcs) for use with five Penman Equations widely used in the Southwest for estimating reference evapotranspiration (ETo); and 4) develop a database containing weather and turfgrass evapotranspiration data which can be used by the public and private sectors to develop and/or test the accuracy of Kcs and/or methods of estimating turf ET. The study is being conducted on two large weighing lysimeters located at the University of Arizona Desert Turfgrass Research Facility located in Tucson, Arizona. This annual progress report summarizes research results obtained during the past year.

METHODS

STUDY SITE

The lysimeter facility located at the Karsten Laboratory and Desert Turfgrass Research Facility serves as the study site for this project. Two lysimeters are located at the facility, each 2.5 m in diameter and 4 m deep. Each lysimeter rests on a modified truck scale which can measure total lysimeter mass to an accuracy of +/- 500 g (equivalent to 0.10 mm of water depth). Each lysimeter is equipped with a subsurface soil monitoring system which facilitates regular sampling of the soil solution as well as soil moisture status at depths of 1.0, 2.0, 3.0 and 4.0 m below the surface.

The warm Southern Arizona location allows the facility to be utilized all year. 'Tifway' bermudagrass (*Cynodon dactylon* L.), established on the lysimeters in the summer of 1994, serves as the warm season turf. 'Froghair' intermediate ryegrass (*Lolium multiflorum x perenne*) is overseeded on the lysimeters in October and serves as the winter turf surface. The grass is mowed two or three times per week and mowing height is set at 2.2 cm in summer and 2.5 cm in winter. All clippings are collected to facilitate the fate of N portion of the study. A dual irrigation system provides access to two water sources for irrigation -- potable well water and treated municipal effluent. For the present study, the west lysimeter is irrigated with effluent while the east lysimeter receives potable irrigation water.

A meteorological monitoring site is located approximately 10 m south of the lysimeters and consists of a series of meteorological towers centered within a large expanse of tall fescue grass maintained at a height of approximately 8 cm. Data acquired include air temperature and wind speed at 1.0, 2.0 and 3.0 m above ground level (agl); incoming solar radiation and net radiation at 1.0 m agl; reflected solar radiation at 0.75 m agl; relative humidity at 2 m agl and soil heat flux. All meteorological instruments are monitored using automated data loggers programmed to store relevant parameter means and/or totals every ten minutes.

FATE OF NITROGEN

Nitrogen fertilizer has been applied since 10 April 1995 as $(^{15}NH_4)_2SO_4$ (2.0 atom% 15N) so the fate of fertilizer N can be traced. The fertilizer is applied in liquid form at two to three week intervals with applications of the labeled fertilizer adjusted to compensate for differences in N concentration in the irrigation water. Nearly equal amounts of N have been applied to each lysimeter over the course of the study. Applications of P, K, and micronutrient fertilizers were made periodically to each lysimeter in equal amounts.

Wastewater and potable irrigation water samples were analyzed periodically for NH_4^+ and NO_3^-. The wastewater contained an average of 13 mg N/L as NH_4^+ and NO_3^-, and the potable irrigation water contained 3 mg N/L as NO_3^-. Nitrogen in irrigation water samples and solution samples from the lysimeters were analyzed by steam distillation and titration. Nitrogen in turfgrass samples was analyzed by steam distillation following micro-Kjeldahl digestion. Nitrogen-15 enrichments in grass and solution samples were analyzed by mass spectrometry.

CROP COEFFICIENT EVALUATION

Crop coefficients (Kcs), defined at the ratio of actual evapotranspiration (ETa) to reference evapotranspiration (ETo), are being developed for use with five forms of the Penman Equation in use in the Desert Southwest. Four of the selected Penman Equations are used by the public weather networks in Arizona, California, New Mexico and Southern Nevada to provide estimates of ETo for irrigation management. The fifth equation--a Penman-Montieth Equation--has been evaluated extensively against lysimeters and is commonly used by the agricultural and civil engineering community.

Meteorological data obtained from the on-site meteorological station are used to compute daily ETo values for each of the five aforementioned ETo procedures. Daily values of actual turf ET are then obtained from the daily mass change of each lysimeter, with appropriate compensation for irrigation and rainfall. Days with periods of extended rainfall and very low ETo (rainy, overcast winter days), or days when lysimeter data are in question are dropped prior to analysis. Crop coefficients are then computed for each month by 1) dividing ETa by ETo each day, then computing the average monthly Kc value and 2) dividing total monthly ETa by total monthly ETo to obtain a monthly Kc. The first computation procedure allows assessment of day-to-day variation in Kc, while the second procedure helps eliminate the impact of an occasional high or low Kc (occurs during overcast, rainy conditions). Both methods of monthly Kc computation agree, except during months with numerous cloudy days.

RESULTS & DISCUSSION

CROP COEFFICIENT EVALUATION

Overseeded Winter Turf

Crop coefficients appropriate for use with the four regional Penman Equations and the Penman Monteith Equation have now been developed. Figures 1-5 and Tables 1-5 show the monthly crop coefficients for overseeded intermediate ryegrass developed during the winters of 1994/95, 1995/96 and 1996/97. Data from both lysimeters are averaged in Figures 1-5 since we observed only minor differences in water use (~2-3% when averaged across 3 years) as a result of irrigation water. A horizontal arrow is placed on the graph in each figure to locate and lable the average seasonal (winter) crop coefficient for the three winters. It is clear from Figures 1-5 that crop coefficients appropriate for a particular ETo procedure do differ. Winter average crop coefficients vary from 0.55 for the New Mexico ETo procedure to 0.86 for the California Penman Equation. The ETo procedure is the cause for the difference in Kc values since the actual turf water use data (from lysimeters) and the weather data used to generate ETo are the same in the five cases presented in Figures 1-5. Each ETo procedure simply generates a different value of ETo when supplied with the same weather data.

Figures 1-5 also provide insight into the seasonal stability of monthly Kc values. A constant Kc value for a particular turf season would be preferable to the golf industry to minimize in-season adjustments in the computation of irrigation requirements. An examination of Figures 1-5 and Tables 1-5 reveals two trends that might generate concern regarding the use of a single Kc value for the winter turf season in the Desert Southwest. The trend of greatest concern is most evident in the Kc data presented for the New Mexico and Nevada ETo procedures. The crop coefficients tend to track seasonal temperature for these procedures -- declining during cold months and increasing during the warmer months. Use of a constant winter Kc value with these two ETo procedures would probably not be a good idea since excess water would be applied to turf during December and January. The apparent impact of temperature on the Kc value is not as clear for the three remaining ETo procedures, though Kcs developed for both the California and the Penman Montieth procedures indicate higher Kcs are appropriate during at least one of the warmer winter months -- November or April.

It is not clear whether the seasonal Kc pattern observed in Figures 1-5 indicates an inherent weakness in the ETo procedure or simply reflects changes in turf performance. Overseeded turf tends to improve in quality and density as the winter turf season progresses; thus, increases in Kc values during the late winter may reflect higher water use associated with a more dense turf surface. We have also observed higher biomass accumulation and turf water use when the turf is irrigated with effluent -- a response we attribute to improve plant nutrition.

The second factor impacting the use of a seasonal Kc is the year-to-year variation in monthly Kc values obtained in this study. There are clear differences in Kc across years which we attribute to both turf quality and weakness in the ETo computation. Turf quality plays a role in overall water use because turf maintained at fairway height has insufficient leaf area to transpire at potential or reference rates. Reference ET is defined as the ET from a tall (8-15 cm), well-watered, cool season grass. The height requirement for ETo assures the grass has sufficient biomass to transpire at maximum rates. Cultural or weather factors that impact turf quality and/or density impact the amount and quality of the transpiring surface and thus impact overall water use.

Weakness in the ETo procedure may also drive the year-to-year Kc differences. The ETo procedures were developed for use during agricultural growing seasons and work best during periods of higher evaporative demand (spring, summer and fall). We have found the ETo procedures to be less reliable during the winter months, especially during periods of cloudy, humid weather when ETo is small.

Overall, however, we believe the Kcs presented in Figures 1-5 can be used with reasonable reliability. We note that the average Kc values presented in Figures 1-5 were developed over a three year period (Tables 1-5) which include a wide variety of winter weather, ranging from warm and dry to cool and wet conditions.

Summer Turf

Crop coefficients appropriate for use with bermudagrass are presented in Figures 6-10 and Tables 1-5. Data from turf irrigated with potable and effluent water were merged to generate Figures 6-10. We observed only minor enhancement in water use of turf irrigated with effluent (~3%), and chose to merge the data for presentation. Seasonal Kcs proved to be similar for the California Penman (Kc=0.86), the Penman-Montieth (Kc=0.83) and the Nevada Penman (Kc=0.85), suggesting these ETo methods are quite comparable during the summer months. The Arizona Penman procedure generated a slightly lower seasonal Kc of 0.77 while the Kc for New Mexico Penman averaged 0.65 for the summer months. A more detailed look at Figures 6-10 reveal slightly reduced Kcs during the month of June. We believe this decrease is due to the transition from the overseeded ryegrass to bermudagrass. The research study site rests in a river bottom prone to cool night temperatures. Summer transition to bermudagrass is slowed by this cool night weather, and often is not complete until late June. Warmer nights associated with the arrival of monsoon humidity typically produced marked improvement in bermudagrass growth in July and August. The higher Kc values observed during July and August are at least in part due to improved turf growth and density.

Figures 6-10 suggest a uniform summer Kc is possible for all five methods, especially if the turf is growing is a soil with reasonable water holding capacity. Use of a singular seasonal Kc could lead to a slight over watering in June; however, if the excess water can be stored in the root zone, the turf would likely remove this water surplus in July and August.

Crop Coefficient Summary

Figure 11 presents both seasonal mean Kc (winter and summer) values for each ETo procedure.

Crop coefficients proved to be remarkably consistent across both turf seasons for the California Penman procedure (Kc=0.86) and the Penman-Montieth procedure (Kc=0.83), suggesting a single annual Kc could be employed when using either procedure to estimate turf ET. The remaining ETo procedures will require at least a seasonal adjustment in Kc, because winter Kcs are significantly lower than summer Kcs. Our earlier precaution regarding the monthly Kc variation for the Nevada and New Mexico Penman procedures still stands -- monthly Kc adjustments may be required when using the Nevada and New Mexico Penman Equations in winter.

The results presented in Figures 1-11 drive home the need to match Kc values with ETo procedures. One could conceivably get away with using a Kc of ~0.8 for summer turf when using the California, Nevada, Penman-Montieth and Arizona ETo procedures; however, using the New Mexico summer Kc of 0.65 with the California Penman Equation would underestimate irrigation need by about 25%.

A mismatch of Kc and ETo procedure would be even more dangerous in winter due to greater variation in computed ETo at that time of year. Crop coefficients appropriate for use with winter overseeded turf range from less than 0.50 (cold months in New Mexico) to in excess of 0.90 for the Penman-Montieth procedure used during April. Errors in computed irrigation requirements can approach 100% if Kcs and ETo procedures are mismatched in winter.

FATE OF NITROGEN

We have noted in previous reports that soil solution samples and drainage water obtained from both lysimeters contained virtually no NO_3^--N, even though N use efficiency was less than 30%. We hypothesized that sequestration of fertilizer N in thatch and soil organic matter <u>and</u> denitrification could be the reason we observed no leaching of NO_3^- with such low N-use efficiency. Soil samples to a depth of 60 cm were collected from the lysimeters on 6 June 1997 to determine how much applied nitrogen is stored in the root and crown tissue and the upper soil layers. Analyses of these soil samples are now complete and the results are presented in Table 6 along with data on total N applied. The sampling data indicate that approximately 40% of all ^{15}N-labeled fertilizer applied to each lysimeter is contained in the root/crown biomass plus soil organic matter in the top 5 cm of the lysimeters. Analysis of ^{15}N data for deeper soil layers has not been completed. The large amount of ^{15}N found in the soil organic matter is very consistent with our hypothesis that N storage in organic matter has been a very important fate of fertilizer N applied to these lysimeters. When all ^{15}N analysis is complete, it is probable that a significant amount of fertilizer N will be accounted for in the soil organic matter.

As shown in Table 6, 66% and 75% of all ^{15}N applied to the East (potable) and West (effluent) lysimeters, respectively, can be accounted for in turf clippings, root and crown biomass, and soil organic matter in the top 5 cm. Our leachate data continue to indicate negligible amounts of fertilizer N leaching through the lysimeters, even though irrigation regimes have ensured a steady rate of drainage throughout the period of study. Actual denitrification rates were determined from the soil samples obtained in June. Denitrification rates were determined to be 24 and 32 g N_2O-N/ha/day from the lysimeters irrigated with potable and effluent water, respectively. Potential denitrification rates (all potentially limiting factors removed) were 1400 and 1800 g N_2O-N/ha/day. These data indicate a very significant potential exists for denitrification from the lysimeters. It is therefore probable that denitrification represents the major loss of N from this turf system.

FUTURE PLANS

The turf water/crop coefficient portion of this study is now complete. We are now working to complete the database containing data on turf water use and meteorological conditions which we will provide to the irrigation industry for use in calibrating new ETo procedures and computing Kc values for existing ETo procedures. Work related to the fate of N fertilizer will focus on completing remaining analyses on soil and water samples. We are continuing on with ^{15}N applications with the hope that new funding can sustain this work. An extension of this work will focus on evaluating when sequestration of fertilizer N by soil organic matter reaches steady state and evaluation of denitrification as a potential fate for fertilizer N in desert turf systems.

Table 1. Monthly crop coefficients developed using the New Mexico Penman Equation. No Kc values are presented for October when overseeded turf is established.

MONTHLY CROP COEFFICIENTS: NEW MEXICO PENMAN EQUATION								
MONTH/ YEAR	POTABLE	EFFLUENT	MONTH/ YEAR	EFFLUENT	POTABLE	MONTH/ YEAR	EFFLUENT	POTABLE
NOV 94	0.52	0.56	NOV 95	0.48	0.51	NOV 96	0.53	0.56
DEC 94	0.43	0.41	DEC 95	0.47	0.50	DEC 96	0.50	0.48
JAN 95	0.45	0.45	JAN 96	0.48	0.47	JAN 97	0.53	0.52
FEB 95	0.53	0.55	FEB 96	0.57	0.58	FEB 97	0.51	0.51
MAR 95	0.64	0.67	MAR 96	0.60	0.62	MAR 97	0.55	0.58
APR 95	0.64	0.73	APR 96	0.64	0.68	APR 97	0.65	0.68
MAY 95	0.66	0.70	MAY 96	0.63	0.65			
JUN 95	0.63	0.68	JUN 96	0.59	0.60			
JUL 95	0.61	0.64	JUL 96	0.70	0.69			
AUG 95	0.74	0.71	AUG 96	0.68	0.68			
SEP 95	0.67	0.64	SEP 96	0.60	0.58			

Table 2 Monthly crop coefficients developed using the California Penman Equation. No Kc values are presented for October when overseeded turf is established.

MONTHLY CROP COEFFICIENTS: CALIFORNIA PENMAN EQUATION								
MONTH/ YEAR	POTABLE	EFFLUENT	MONTH/ YEAR	EFFLUENT	POTABLE	MONTH/ YEAR	EFFLUENT	POTABLE
NOV 94	0.92	1.00	NOV 95	0.90	0.97	NOV 96	0.90	0.95
DEC 94	0.78	0.75	DEC 95	0.89	0.93	DEC 96	0.94	0.91
JAN 95	0.89	0.89	JAN 96	0.81	0.80	JAN 97	0.92	0.90
FEB 95	0.79	0.82	FEB 96	0.86	0.86	FEB 97	0.76	0.76
MAR 95	0.88	0.92	MAR 96	0.79	0.82	MAR 97	0.76	0.80
APR 95	0.84	0.94	APR 96	0.81	0.86	APR 97	0.83	0.87
MAY 95	0.84	0.89	MAY 96	0.81	0.81			
JUN 95	0.83	0.89	JUN 96	0.79	0.81			
JUL 95	0.83	0.87	JUL 96	0.92	0.91			
AUG 95	0.97	0.93	AUG 96	0.85	0.85			
SEP 95	0.88	0.85	SEP 96	0.83	0.80			

Table 3. Monthly crop coefficients developed using the Arizona Penman Equation. No Kc values are presented for October when overseeded turf is established.

MONTHLY CROP COEFFICIENTS: ARIZONA PENMAN EQUATION								
MONTH/ YEAR	POTABLE	EFFLUENT	MONTH/ YEAR	EFFLUENT	POTABLE	MONTH/ YEAR	EFFLUENT	POTABLE
NOV 94	0.72	0.78	NOV 95	0.73	0.79	NOV 96	0.73	0.77
DEC 94	0623	0.60	DEC 95	0.68	0.71	DEC 96	0.70	0.68
JAN 95	0.69	0.68	JAN 96	0.76	0.76	JAN 97	0.73	0.71
FEB 95	0.68	0.70	FEB 96	0.75	0.75	FEB 97	0.65	0.64
MAR 95	0.77	0.81	MAR 96	0.70	0.73	MAR 97	0.67	0.71
APR 95	0.75	0.85	APR 96	0.73	0.77	APR 97	0.75	0.78
MAY 95	0.76	0.81	MAY 96	0.72	0.75			
JUN 95	0.74	0.79	JUN 96	0.69	0.71			
JUL 95	0.73	0.76	JUL 96	0.82	0.82			
AUG 95	0.87	0.83	AUG 96	0.78	0.78			
SEP 95	0.79	0.76	SEP 96	0.72	0.70			

Table 4. Monthly crop coefficients developed using the Nevada Penman Equation. No Kc values are presented for October when overseeded turf is established.

MONTHLY CROP COEFFICIENTS: NEVADA PENMAN EQUATION								
MONTH/ YEAR	POTABLE	EFFLUENT	MONTH/ YEAR	EFFLUENT	POTABLE	MONTH/ YEAR	EFFLUENT	POTABLE
NOV 94	0.74	0.80	NOV 95	0.67	0.72	NOV 96	0.76	0.80
DEC 94	0.64	0.62	DEC 95	0.67	0.70	DEC 96	0.71	0.68
JAN 95	0.64	0.64	JAN 96	0.69	0.69	JAN 97	0.73	0.71
FEB 95	0.78	0.81	FEB 96	0.75	0.76	FEB 97	0.70	0.69
MAR 95	0.86	0.90	MAR 96	0.81	0.83	MAR 97	0.74	0.78
APR 95	0.82	0.93	APR 96	0.81	0.86	APR 97	0.89	0.93
MAY 95	0.86	0.91	MAY 96	0.77	0.80			
JUN 95	0.78	0.83	JUN 96	0.69	0.71			
JUL 95	0.75	0.78	JUL 96	0.91	0.90			
AUG 95	0.99	0.95	AUG 96	0.92	0.92			
SEP 95	0.91	0.87	SEP 96	0.86	0.83			

Table 5. Monthly crop coefficients developed using the Penman-Montieth Equation. No Kc values are presented for October when overseeded turf is established.

MONTHLY CROP COEFFICIENTS: PENMAN-MONTIETH EQUATION								
MONTH/ YEAR	POTABLE	EFFLUENT	MONTH/ YEAR	EFFLUENT	POTABLE	MONTH/ YEAR	EFFLUENT	POTABLE
NOV 94	0.78	0.84	NOV 95	0.76	0.82	NOV 96	0.85	0.88
DEC 94	0.73	0.70	DEC 95	0.81	0.84	DEC 96	0.82	0.79
JAN 95	0.75	0.75	JAN 96	0.76	0.76	JAN 97	0.80	0.78
FEB 95	0.82	0.85	FEB 96	0.78	0.79	FEB 97	0.77	0.76
MAR 95	0.88	0.93	MAR 96	0.85	0.88	MAR 97	0.79	0.83
APR 95	0.88	1.00	APR 96	0.86	0.92	APR 97	0.90	0.95
MAY 95	0.88	0.93	MAY 96	0.82	0.86			
JUN 95	0.83	0.89	JUN 96	0.74	0.76			
JUL 95	0.75	0.78	JUL 96	0.83	0.82			
AUG 95	0.90	0.87	AUG 96	0.82	0.81			
SEP 95	0.87	0.83	SEP 96	0.82	0.79			

Table 6. Fate of N and ^{15}N as of 6 June 1997.

Lysimeter	N Applied kg/ha	^{15}N Applied kg/ha	Turf N kg/ha	Turf ^{15}N kg/ha	Root & crown N kg/ha	Root & crown ^{15}N kg/ha	Soil N 0-5 cm kg/ha	Soil ^{15}N 0-5 cm kg/ha
East (potable)	800	660	310	150	230	107	370	180
West (effluent)	770	180	400	50	150	20	350	65

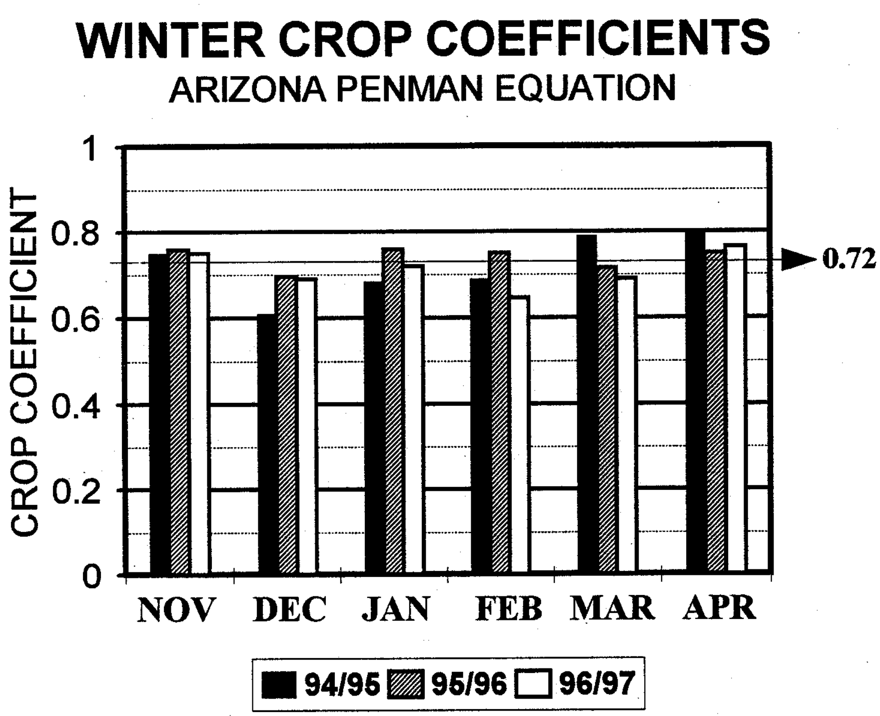

Figure 1. Monthly ryegrass Kc values obtained during the winters of 1994/95, 1995/96 and 1996/97 for use with the Arizona Penman Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

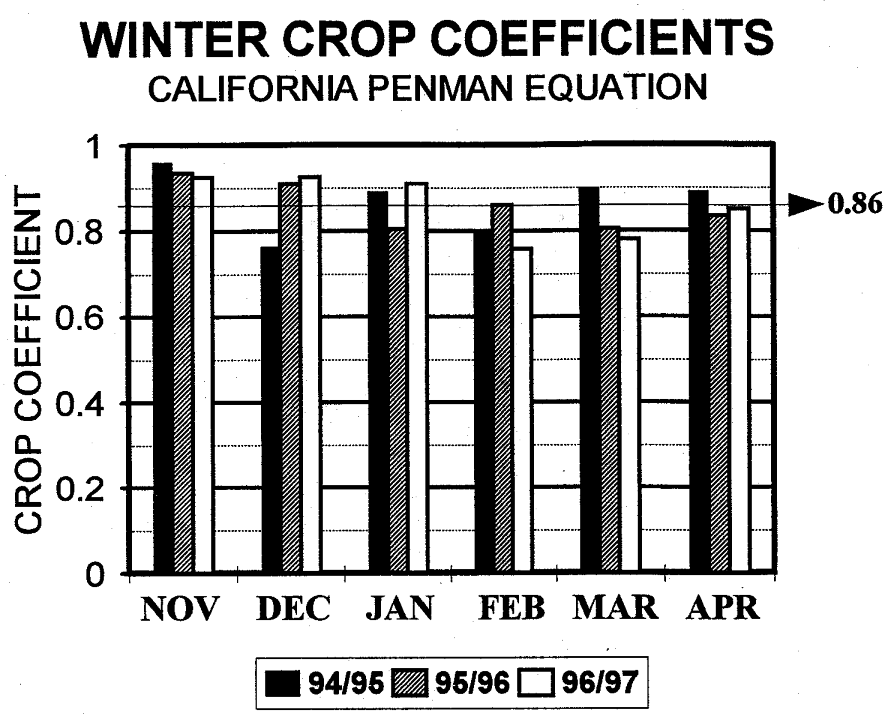

Figure 2. Monthly ryegrass Kc values obtained during the winters of 1994/95, 1995/96 and 1996/97 for use with the California Penman Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

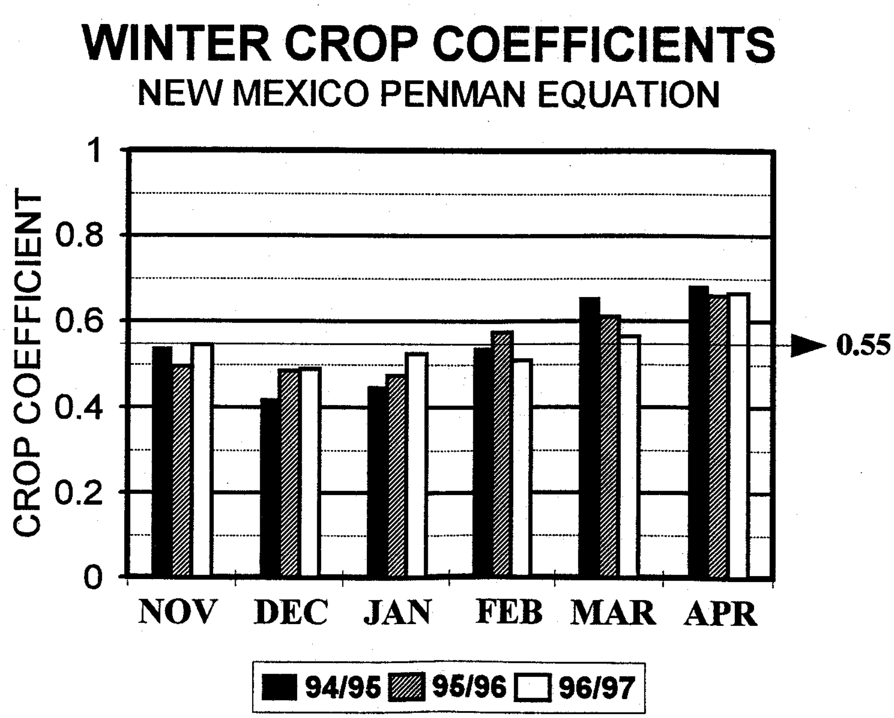

Figure 3. Monthly ryegrass Kc values obtained during the winters of 1994/95, 1995/96 and 1996/97 for use with the New Mexico Penman Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

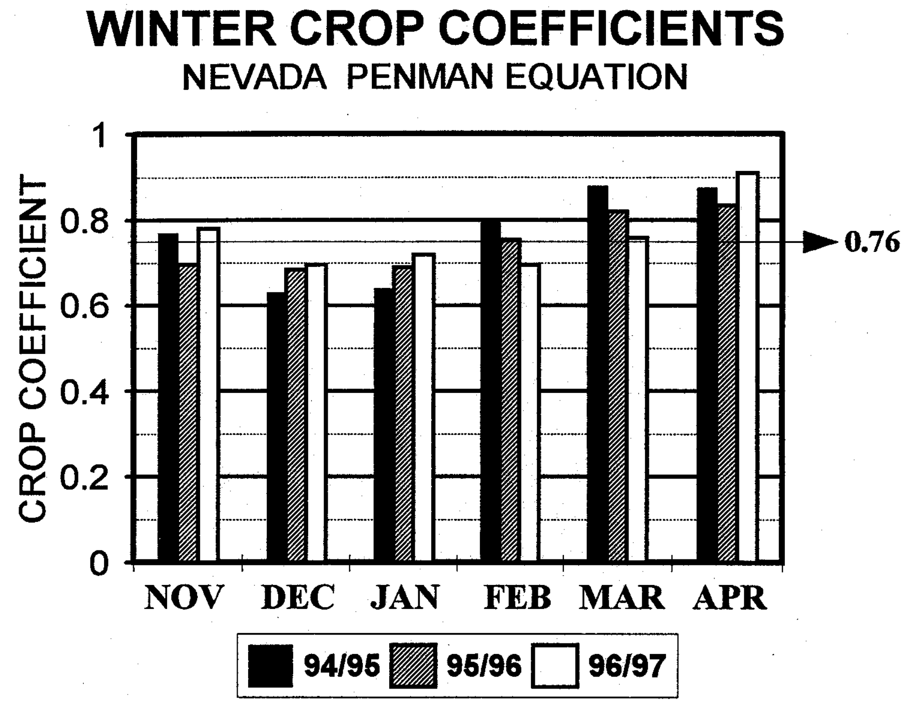

Figure 4. Monthly ryegrass Kc values obtained during the winters of 1994/95, 1995/96 and 1996/97 for use with the Nevada Penman Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

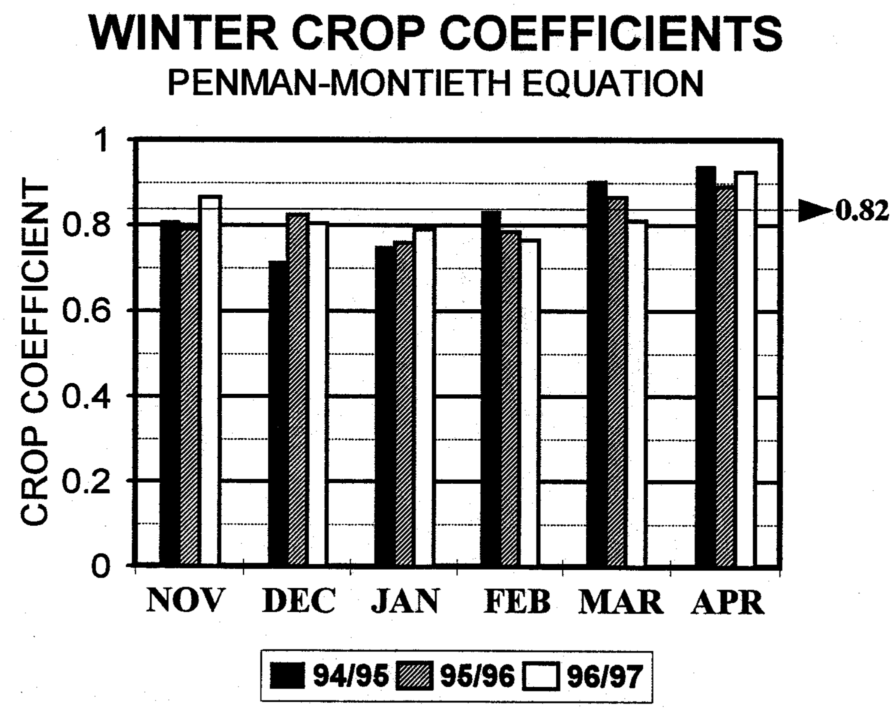

Figure 5. Monthly ryegrass Kc values obtained during the winters of 1994/95, 1995/96 and 1996/97 for use with the Penman-Montieth Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

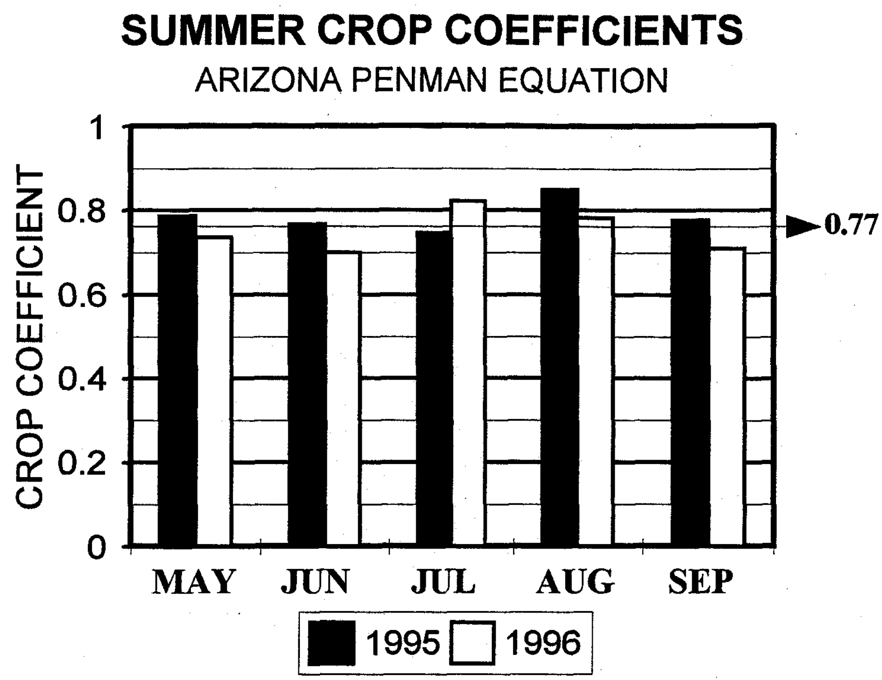

Figure 6. Monthly bermudagrass Kc values obtained during the summers of 1995 and 1996 for use with the Arizona Penman Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

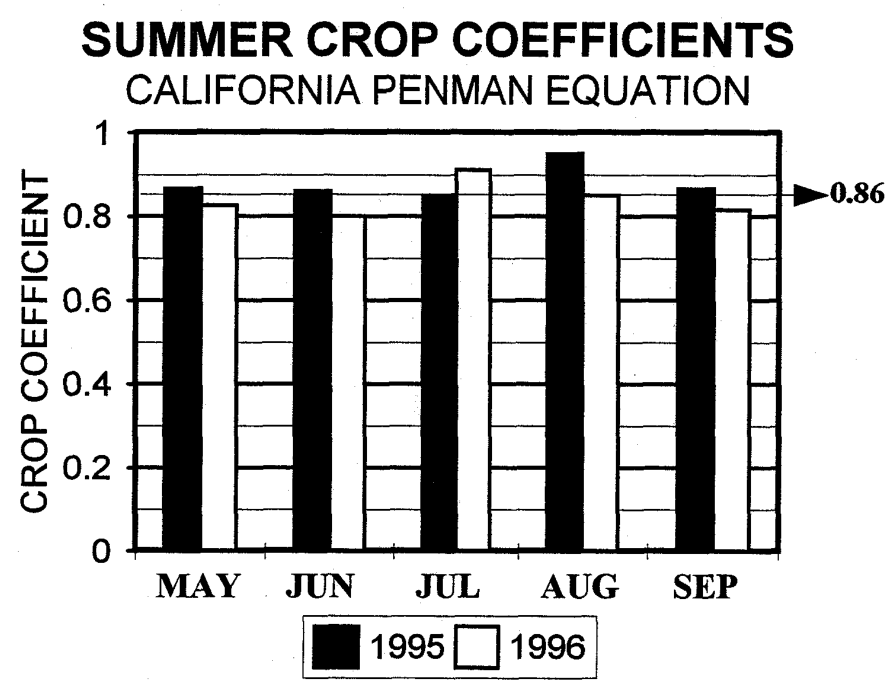

Figure 7. Monthly bermudagrass Kc values obtained during the summers of 1995 and 1996 for use with the California Penman Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

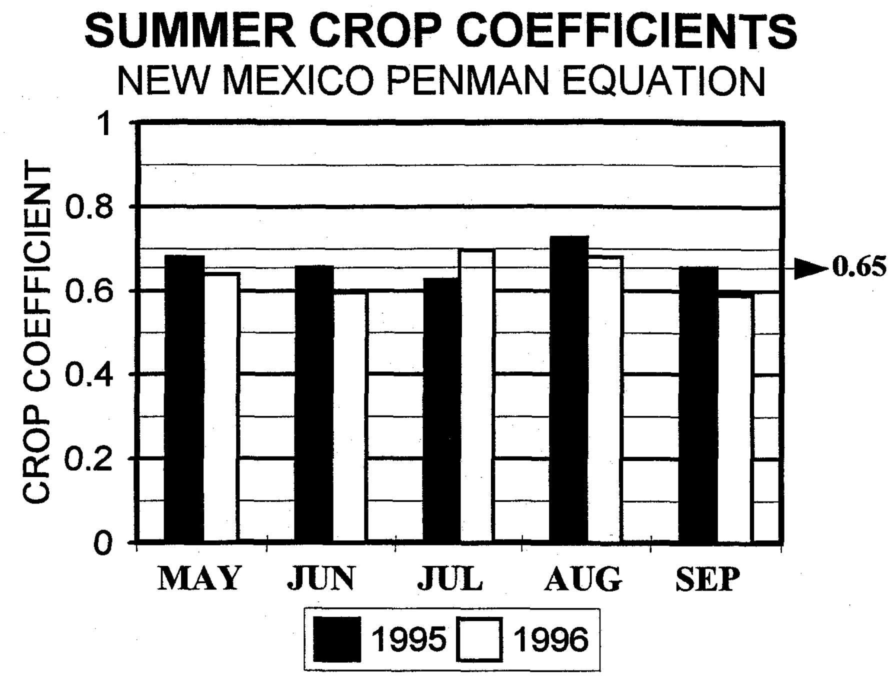

Figure 8. Monthly bermudagrass Kc values obtained during the summers of 1995 and 1996 for use with the New Mexico Penman Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

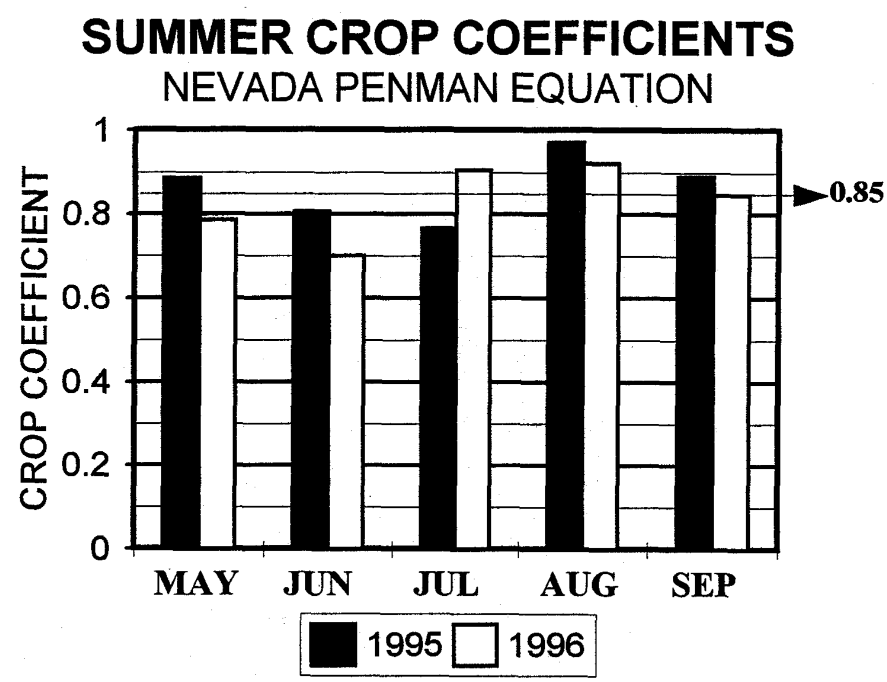

Figure 9. Monthly bermudagrass Kc values obtained during the summers of 1995 and 1996 for use with the Nevada Penman Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

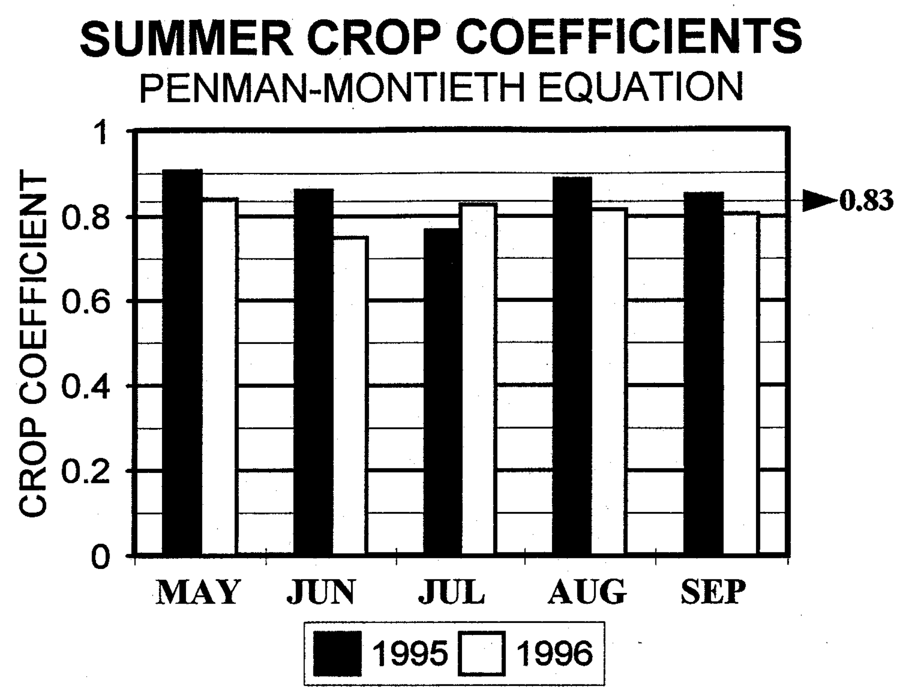

Figure 10. Monthly bermudagrass Kc values obtained during the summers of 1995 and 1996 for use with the Penman-Montieth Equation. Crop coefficients presented represent averages of data obtained from ryegrass irrigated with potable and effluent water.

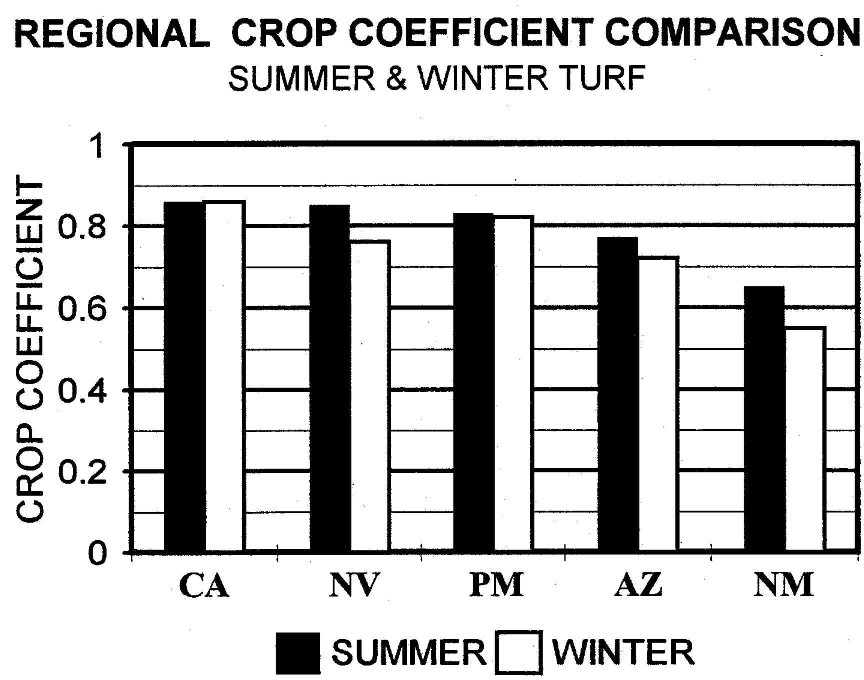

Figure 11. Seasonal (summer or winter) turf Kc values developed for five regional procedures used to estimate ETo (CA: California, NV: Nevada, PM: Penman Monteith, AZ: Arizona, NM: New Mexico). Data presented are average values obtained over multiple turf seasons using both irrigation waters (potable and effluent).

PERSONNEL

Dr. Paul Brown

Dr. Brown is an Extension Specialist and Research Scientist in the Department of Soil, Water and Environmental Science at the University of Arizona. He designed, developed and currently oversees the operation of the Arizona Meteorological Network which supplies ET and other weather-based management information to the state's horticultural and agricultural producers. He oversees the operation of the Large Weighing Lysimeter Facility at the Karsten Desert Turf Research Facility, and is actively involved in research on turf water use.

Dr. Tom Thompson

Dr. Thompson is an Associate Professor in the Department of Soil, Water and Environmental Science at the University of Arizona. Dr. Thompson's area of expertise is soil fertility and plant nutrition. He is actively involved in research examining the fate of nutrient nitrogen in several plant systems, including turfgrass.

Dr. Michael Young

Dr. Michael Young is an Assistant Research Scientist in the Department of Soil, Water and Environmental Science at the University of Arizona. Dr. Young developed the weighing lysimeter facility at the Karsten Desert Turf Research Facility as part of his Ph.D. dissertation at the University of Arizona. He is actively involved in research on water transport, salinity, soil moisture monitoring and has extensive experience with Time Domain Reflectometry.

Dr. David Kopec

Dr Kopec is the Extension Turf Specialist in the Department of Plant Sciences at the University of Arizona. He is actively involved in a wide range of research projects, including several past studies pertaining to water use of turfgrass. Dr. Kopec assists with the management of the Karsten Turf Facility and his office is located at the facility.

Mr. Brian Whitlark

Mr. Whitlark is a graduate student working on his M.S. in Soil, Water and Environmental Science. He is using the Large Weighing Lysimeters for his research on turf water management.