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

1996 ANNUAL PROGRESS REPORT

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EXECUTIVE SUMMARY

The fate of applied nitrogen (N) and turfgrass water use in high maintenance turfgrass systems irrigated with potable (well) water and effluent (wastewater) are being studied using two large weighing lysimeters located at the University of Arizona Karsten Turfgrass Research Center. Each water source is applied to a single lysimeter at rates sufficient to prevent water stress of 'Tifway' bermudagrass (summer) and 'Froghair' intermediate ryegrass (winter). 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. 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).

Turf responded positively to irrigation with wastewater, and generated more biomass than turf irrigated with potable water. The first 14 months of the study revealed nitrogen uptake of 223 lbs N/A and overall N use efficiency of 61% for turf irrigated with wastewater. This compares positively with a N uptake rate of 173 lbs N/A and a N use efficiency of 42% for turf irrigated with potable water during the same period.

The uptake of fertilizer N in aboveground biomass was lower than for total N uptake. Fertilizer uptake efficiency totaled 26% and 22% for turf irrigated with wastewater and potable water, respectively. The low uptake efficiency of fertilizer N is not fully understood, though analysis of soil solution samples and drainage water indicate the losses are not due to leaching. Possible causes may be immobilization in the below ground plant and microbial biomass or loss through denitrification.

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. Results from the second year of study show 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. Appropriate bermudagrass Kcs for the five methods of estimating ETo varied from 0.64 to 0.85 for turf irrigated with potable water and 0.66 to 0.86 for turf irrigated with wastewater. Ryegrass Kc values ranged from 0.57 to 0.80 for turf irrigated with potable water and 0.57 to 0.84 for turf irrigated with wastewater. The higher water use (Kcs) observed with wastewater irrigation was associated with higher biomass production. Comparison of seasonal Kcs for 1995 and 1996 revealed slightly lower Kcs in 1996, regardless of ETo procedure.

This project will conclude at the end of the winter turf season in May of 1997. The investigators will focus their future efforts on completing the remaining analyses and writing the final project report

Project expenditures totaled $21,535 in the year ended 31 October 1996. Outlays for technician salaries and a graduate stipend totaled $14,412. Outlays for project operations, travel to professional meetings and indirect costs totaled $3,163, $1,141 and $2819, respectively. Personnel time devoted to this research were as follows: Paul Brown (PI:20%), Tom Thompson (PI:10%), Duane Otto (Graduate Student:25%), Telesphory Machibya (Lysimeter Technician: 40%) and Scott White (Lab Technician: 10%).

INTRODUCTION

The project entitled "Turfgrass Irrigation with Municipal Effluent: Nitrogen Fate, Turf Crop Coefficients and Water Requirements" was approved for funding by the United States Golf Association in 1993. The project 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 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 facility has a dual irrigation system to facilitate irrigation with either potable or effluent irrigation water. For the present study, the West lysimeter is irrigated with secondary effluent (wastewater) 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.

LYSIMETER QUALITY CONTROL PROCEDURES

The lysimeters are in essence two large analytical balances which measure changes in mass. A series of quality control and quality assurance (QC/QA) measures are used to ensure proper lysimeter operation, including 1) periodic calibration with known weights; 2) comparison of mass losses resulting from drainage with measured volumes of drainage water; 3) comparison of mass gains due to irrigation with known irrigation system precipitation rates; 4) comparison of mass gains due to precipitation with measured values of precipitation obtained on site; and 5) manual inspection of all incoming data. Calibration with known weights is performed quarterly or when incoming lysimeter data or other quality assurance measures suggest a problem. Calibrations are usually performed at night with the lysimeters covered with plastic to prevent evaporation. Calibrations include 1) sequentially adding (then subtracting) known masses (in increments of 0.5 to 4.0 kg) to simulate an expected diurnal range of lysimeter mass change (10 - 40 kg); 2) adding and subtracting a known single mass to assess the repeatability of the lysimeter scales; and 3) leaving the lysimeters covered for an entire evening with no additions/subtractions of mass to assess the stability of the lysimeter scales.

Weekly comparisons of lysimeter mass change (losses) when the drainage tanks are emptied provide a second means of calibration. Drainage water, which is stored in tanks on the lysimeters, is removed once a week by the lysimeter technician. The volume of drainage water is measured, converted to an equivalent mass in kg and compared to the change in mass recorded by the lysimeter scales.

Comparisons of mass gains associated with irrigation and precipitation events provide additional opportunities for evaluating lysimeter performance. Irrigation is applied daily except during rainy periods. Irrigation run times are recorded by the DTRF irrigation computer and are converted to a mass addition (from system precipitation test) which is compared with the mass gain recorded by the lysimeter. An analogous technique is used to compute the mass addition from precipitation measurements for comparison with lysimeter mass gains. Both of these tests help identify system problems, but are not exceptionally accurate due to uncertainties pertaining to quantifying the mass gains. Wind, pressure fluctuations and system losses impact the accuracy of estimating the mass added by irrigation from measured run times. Mass gains estimated from measured values of precipitation are generally underestimated since tipping bucket rainguages generally underestimate precipitation.

The aforementioned calibration/quality control procedures, collectively, provide an effective means of ensuring accurate water use estimates from the lysimeters. The authors believe that once the lysimeters pass the quality control measures, the major remaining concern rests with the representiveness of the turf grown on the lysimeters. We continue to work very diligently to ensure a high quality turf surface.

FATE OF NITROGEN

The nitrogen (N) fate experiment was initiated on the two lysimeters on 10 April, 1995. All N fertilizer was applied as $(^{15}NH_4)_2SO_4$ (2.0 atom% 15N) so that the fate of this fertilizer N could be traced. Nitrogen fertilizer was applied in liquid form at two to three week intervals. During the experiment, we attempted to maintain approximately equal amounts of N applications to each lysimeter. 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 (AZ), California (CA), New Mexico (NM) and Southern Nevada (SN) to provide estimates of ETo for irrigation management. The fifth equation--a Penman-Montieth Equation(PM)--has been evaluated extensively against lysimeters and is 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. Crop coefficients are the computed for each day by dividing ETa by ETo obtained from each of the five ETo procedures.

Two ETo computational procedures were altered during 1996 in response to personal communications or recently published information. The procedures subjected to computational change include the California Penman Equation and the Penman Montieth Equation. The change in the California Penman impacts the procedure used to estimate net radiation, and was implemented following several conversations (July 1996) with Simon Etching of the California Department of Water Resources. The change to the California procedure involved using a modified version of the net radiation procedure presented by Dong et al. (1992).

The change in the Penman Montieth Equation was made in response to a recent international thrust to standardize ETo computations (Allen et al. 1994). We believe this new equation is superior to Allen's earlier version (Allen et al. 1989) and likely will receive reasonable support and use on an international basis. Thus, we feel it is imperative to include this procedure in our study. We further note that a small weather network operating in Las Vegas is using this new procedure for ETo estimation (personal communication with Dale Devitt); thus, use of this procedure in our study will have direct benefit to this region.

ETo computations resulting from these revised procedures have been completed for all data collected since November of 1995; thus, all data reported in this annual progress report include these recent changes. We are presently working on the revising the California and Penman Montieth ETo data collected between August 1994 and September 1995.

RESULTS & DISCUSSION

FATE OF NITROGEN

The irrigation amounts applied on the lysimeters from 10 April, 1995 to 28 May, 1996 were virtually identical (Fig. 1). The amounts of N applied to the lysimeters for this period were 411 and 457 kg N/ha for the West and East lysimeters, respectively (Fig. 2). The West lysimeter received 335 kg N/ha as NH_4^+ and NO_3^- from the wastewater and 77 kg N/ha as labeled N fertilizer (Fig. 3). The East lysimeter received 80 kg N/ha in the potable irrigation water, and 377 kg N/ha as labeled N fertilizer (Fig. 4).

Total aboveground biomass production was higher on the West lysimeter than the East lysimeter (Fig. 5 & 6). This is surprising, because the East lysimeter received greater amounts of N (Fig. 2). Furthermore, the lysimeters received equal applications of other nutrients. Although the total amount of N applied was higher on the East lysimeter, the application of significant amounts of N on a daily basis to the West lysimeter may have enhanced overall N availability. During the summer months, irrigation of the West lysimeter resulted in an application of about 1 kg/N/ha/day. This steady application of N, compared to the periodic applications on the East lysimeter, may have increased overall N availability.

Nitrogen uptake was also higher on the West lysimeter (Fig. 7). Total N uptake on the West lysimeter was 250 kg N/ha, resulting in an overall N use efficiency of 61% in the aboveground biomass. Total N uptake on the East lysimeter was 194 kg N/ha, resulting in an overall N use efficiency of 42% in the aboveground biomass (Fig. 8). Again, the more uniform nature of N application on the West lysimeter may account for the higher N uptake. The aboveground uptake of fertilizer N was lower than for total N. Total fertilizer N uptake on the West lysimeter was 20.1 kg N/ha, resulting in an overall N use efficiency of 26% in the aboveground biomass. Total fertilizer N uptake on the East lysimeter was 83.3 kg N/ha, resulting in an overall N use efficiency of 22% in the aboveground biomass. Therefore, uptake efficiency of fertilizer N was considerably lower than for N applied in the irrigation water.

The low uptake of fertilizer N may be due to several factors that could not be evaluated in this study. First, the $^{15}NH_4^+$ applied in the fertilizer may have been preferentially immobilized by soil microorganisms. Most soil microorganisms prefer NH_4^+ over NO_3^-. Another possibility is that considerable amounts of applied fertilizer N remain in the below ground plant and microbial biomass. However, these possibilities can only be evaluated with significant disturbance of the lysimeter surfaces. The low uptake of fertilizer N may also be due to rapid transport of the fertilizer N through the lysimeters. However, our data for N composition in the leachate do not support this hypothesis (Fig. 9 & 10). We measured very little N in solution samples and drainage water after the first 150 days of the study. A final possibility is that considerable amounts of denitrification may be occurring in the lysimeters. Our current methodology did not permit quantification of denitrification, so additional experiments must be conducted to evaluate this possibility.

In summary, the turf responded well to wastewater application, and yielded higher than turf without wastewater. Overall N use efficiency was higher and apparent N losses were also lower with wastewater application. Aboveground plant uptake of fertilizer N was lower than expected, but we detected little NO_3^- leached below the root zone. Therefore, the most likely explanations for the low recovery of fertilizer N are 1) storage of fertilizer N in below ground root and microbial biomass, and 2) denitrification of fertilizer N.

CROP COEFFICIENT EVALUATION

Ryegrass Crop Coefficients: Winter 1995/96

Seasonal ryegrass Kcs obtained during the winter of 1995/96 for each ETo estimation procedure are presented in Figure 11. Both water use and biomass accumulation (Fig. 5&6) were greater on the lysimeter irrigated with wastewater, indicating better turf performance with this water source during the winter months. The difference in water use for the season amounted to about 5% and is reflected in the higher Kc values for turf irrigated with reclaimed water (Fig. 11).

Crop coefficients appropriate for the five ETo procedures differed, indicating the procedures generate difference ETo values when provided the same meteorological data (Fig. 11). Seasonal Kc values ranged from 0.54 (potable) to 0.57 (wastewater) for the New Mexico procedure to 0.80 (potable) to 0.84 (wastewater) for the Penman Montieth procedure. Crop coefficients appropriate for the Nevada and California ETo procedures were identical, averaging 0.78 and 0.81 for potable and wastewater, respectively. Seasonal ryegrass Kcs for the Arizona Penman were approximately 10% lower than for California and Nevada, averaging 0.71 and 0.74 for potable and wastewater, respectively.

Season-long consistency is an important practical issue when using ETo to assist with irrigation scheduling. Use of a constant Kc value for an entire turf season would be preferable in an operational setting. Figure 12 shows the monthly Kc values for ryegrass irrigated with wastewater during the winter of 1995/96. The results in Figure 12 suggest that two Kc values may be needed to cover the winter turf season: one for use during the warmer months of November, December, March and April and a second, lower value during the colder months of January and February. The month-to-month consistency of Kcs is better with the Arizona and California Penman procedures and the Penman Montieth procedures. The Nevada and New Mexico Penman Equations generate less stable Kc values, with Kc values trending lower from November through January, then increasing from January through April. A similar pattern of winter monthly Kcs was observed by Devitt et al. (1992) with the Nevada Penman procedure, though Devitt et al. reported lower Kc values than are reported here.

Bermudagrass Crop Coefficients: Summer of 1996

Seasonal Kcs for the May through August summer turf season are presented in Figure 13. Water use of turf irrigated with reclaimed water was slightly higher as was biomass accumulation over the period (Fig. 5&6). Seasonal Kc values ranged from 0.64 (potable) and 0.66 (wastewater) for the New Mexico procedure to 0.85 (potable) and 0.86 (wastewater) for the Nevada ETo procedure. Seasonal Kcs determined for the Arizona, California and the Penman Montieth procedures were nearly identical, averaging 0.76, 0.77 and 0.79 for potable water and 0.77, 0.79 and 0.80 for wastewater, respectively.

The month-to-month consistency of summer Kc values was reasonably good for all procedures except the Nevada Penman procedure (Fig. 14). The dip in the June Kc values reflects lower water use associated with a poor transition to full bermudagrass cover . The bermudagrass emerged from dormancy rather slowly in May, due to strong competition from the ryegrass. The ryegrass succumbed to the heat in late May, leaving a relatively thin bermudagrass surface which required an additional couple of weeks to attain full cover and reasonable growth rates. Crop coefficients declined by approximately 10% during this period when the turf was thin.

Consistency in Kc values from one year to the next is also an issue of importance. As indicated in the Methods, we changed the procedures for estimating ETo via the California and Penman Montieth procedures and we are presently recalculating ETo and Kcs for calendar year 1995. However, we did not change the Arizona and New Mexico procedures so we can compare Kcs obtained from these two procedures for year-to-year consistency. Figure 15 shows this comparison between the 1995 and 1996 bermudagrass seasons. 1996 Kc values were slightly below 1995 values for both methods. The cause of this is not fully understood. One possibility is that increasing surface biomass and thatch reduced surface evaporation in 1996 and lowered the overall Kc rate. Another plausible possibility is that the respective Penman equations do perfectly reflect environmental demand. The summer humidity period (monsoon) was much longer in 1996 than in 1995, so the change in Kc between years may reflect inadequate response of the equations to humidity. We have observed a similar reduction in Kc values between the winter turf seasons of 1994/95 and 1995/96 (not shown) which, from a meteorological perspective, were quite different winters.

FUTURE PLANS

This project will conclude with the end of the 1996/97 winter turf season. We have requested and received an extension to continue this work until May 1997 to 1) obtain two full years of study on the fate of N and 2) provide a third winter period for Kc analysis. Results from the fate of N study indicate little loss of N through leaching, but we would like to study a second overseed period to observe whether the higher watering rates required to establish the winter turf surface, combined with seasonal turnover/decomposition of turf biomass, will produce any detectable loss of N via leaching. This analysis carries the side benefit of allowing a third season for Kc analysis on the ryegrass. We feel far less is known about 1) turf water use during the winter months and 2) performance of the five ETo procedures during the winter. The latter is an important issue since most of the ETo procedures were developed for use in the summer months for traditional crop irrigation.

Other areas of emphasis in the final six months of the project will be 1) finish the recalculation of ETo for the revised California and Penman Monteith Eto procedures and 2) complete the turf water use-weather database.

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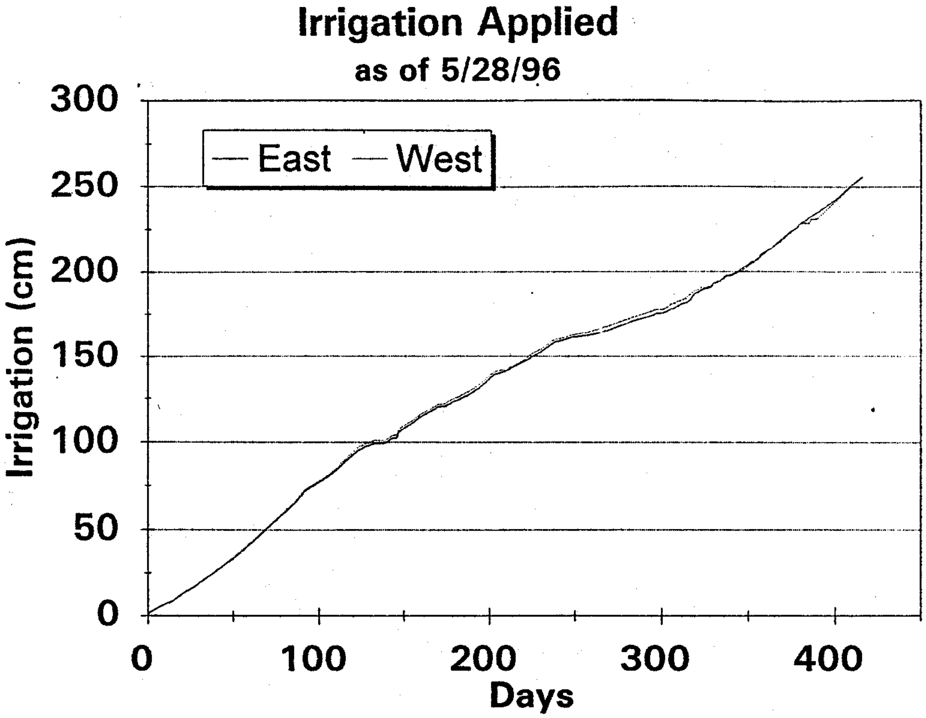

Figure 1. Irrigation water applied to each lysimeter over the period 10 April 1995 (Day 0) through 28 May 1996. Potable and wastewater serve as the irrigation water on the East and West lysimeters, respectively.

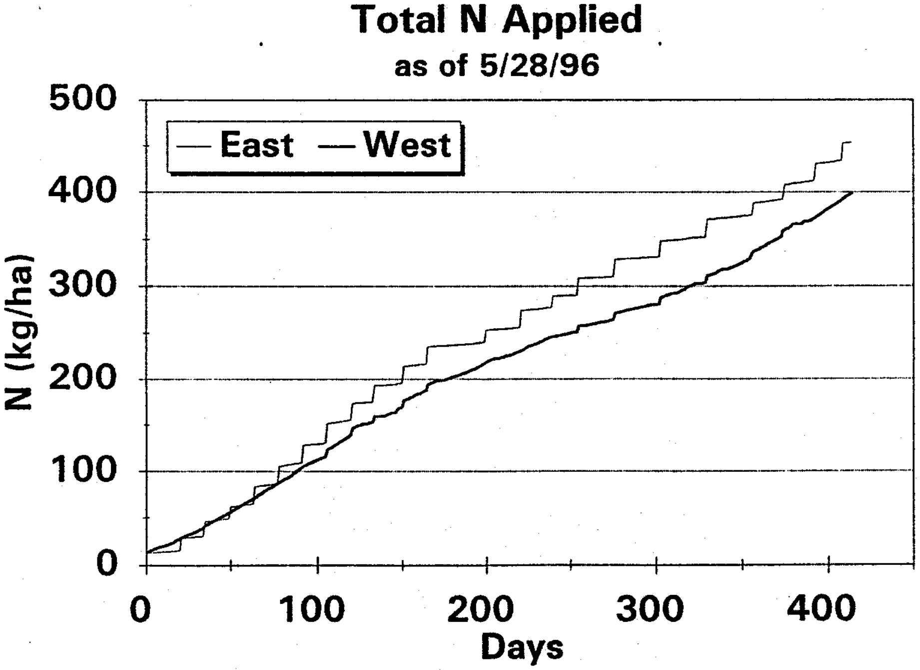

Figure 2. Nitrogen applied to each lysimeter over the period 10 April (day 0) through 28 May 1996. Potable and wastewater serve as the irrigation water on the East and West lysimeters, respectively.

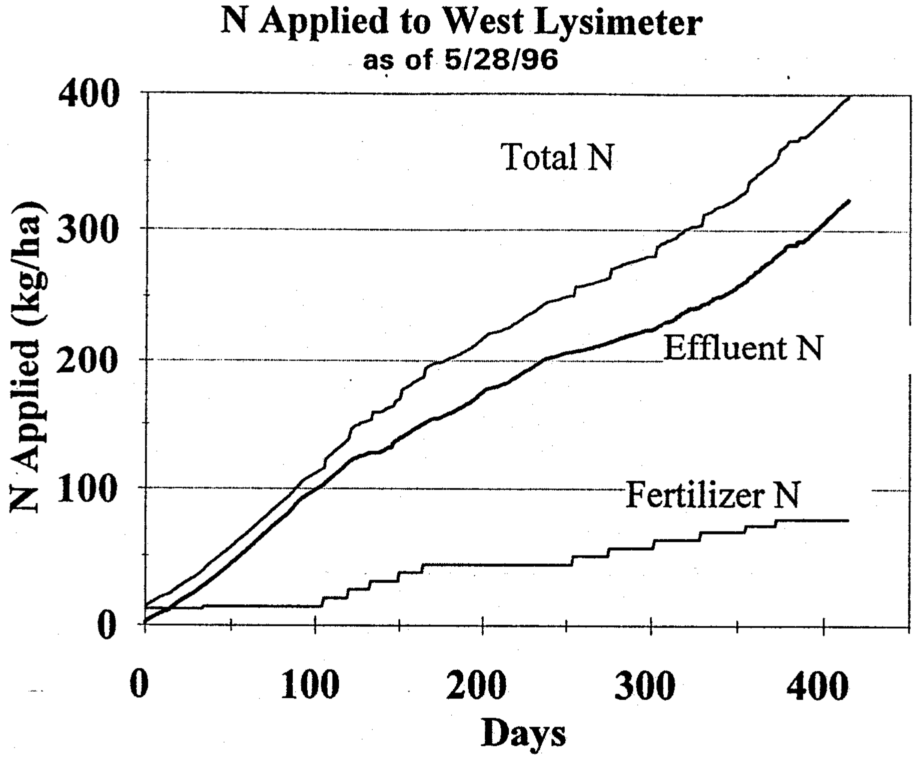

Figure 3. Quantity of nitrogen added through fertilizer and effluent (wastewater) to the West lysimeter over the period 10 April 1995 (day 0) through 28 May 1996.

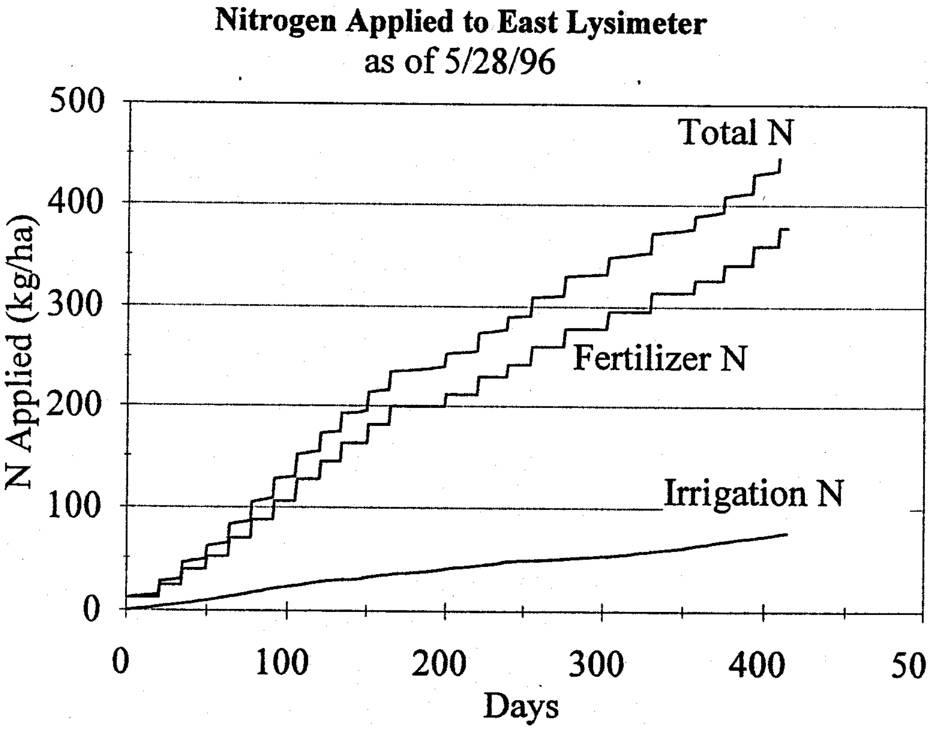

Figure 4. Quantity of nitrogen added through fertilizer and irrigation water (potable) to the East lysimeter over the period 10 April 1995 (Day 0) through 28 May 1996.

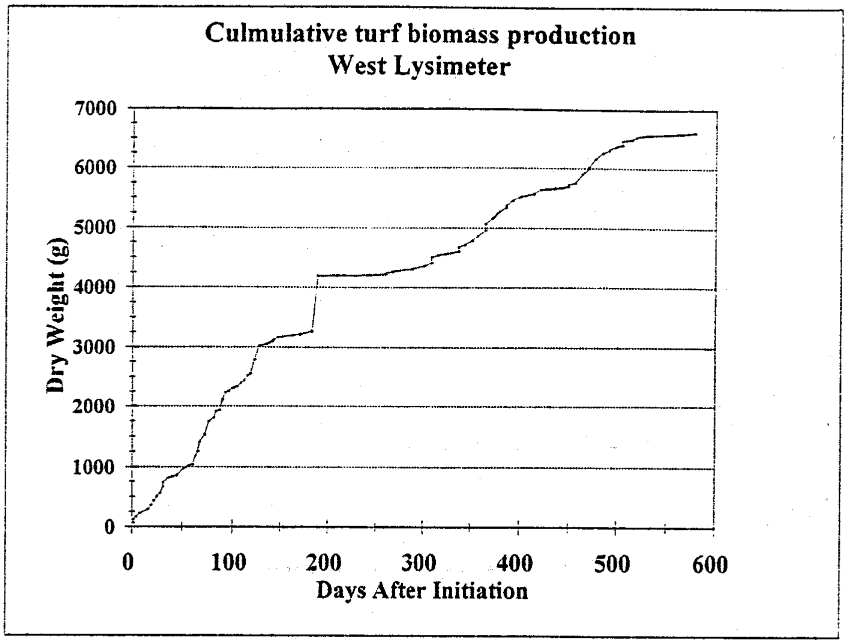

Figure 5. Cumulative turf biomass production from lysimeter turf irrigated with wastewater for the period 10 April 1995 (Day 0) and 30 September 1996.

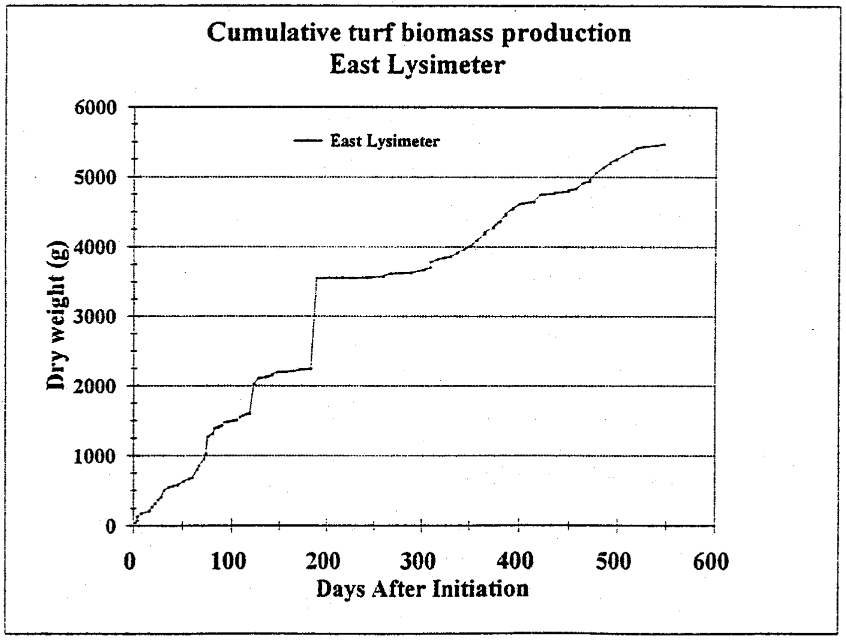

Figure 6. Cumulative turf biomass production from lysimeter turf irrigated with potable water for the period 10 April 1995 (Day 0) and 30 September 1996.

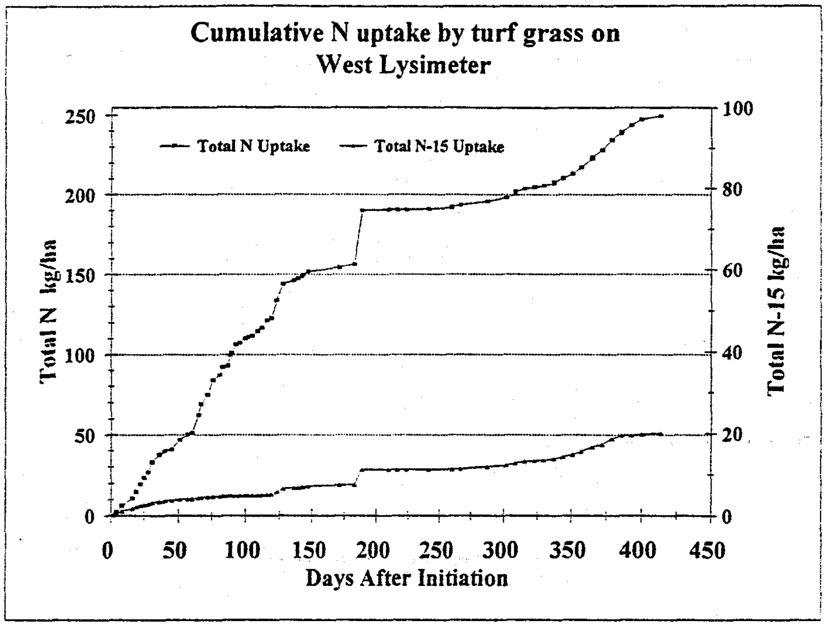

Figure 7. Cumulative uptake of total nitrogen and N-15 by lysimeter turf irrigated with wastewater for period 10 April 1995 (Day 0) through 28 May 1996.

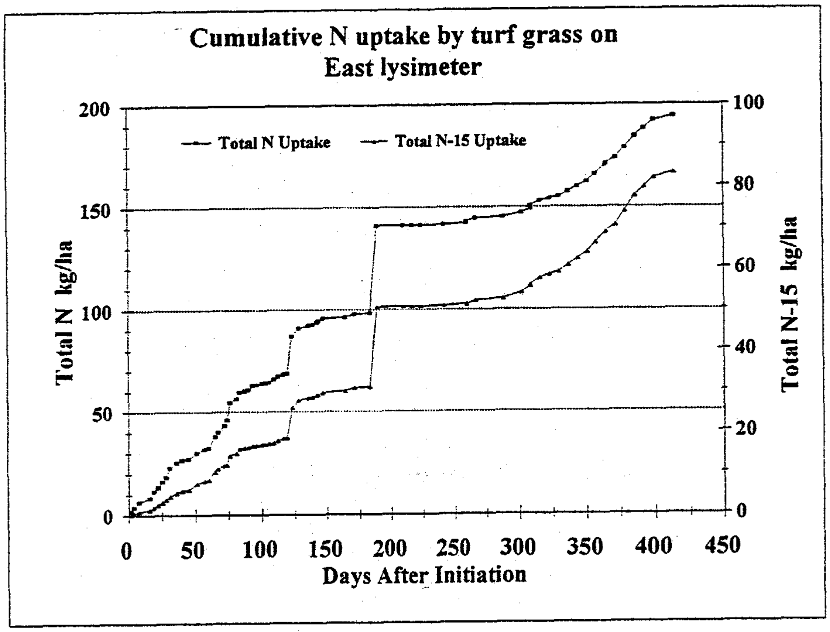

Figure 8. Cumulative uptake of total nitrogen and N-15 by lysimeter turf irrigated with potable water for period 10 April 1995 (Day 0) through 28 May 1996.

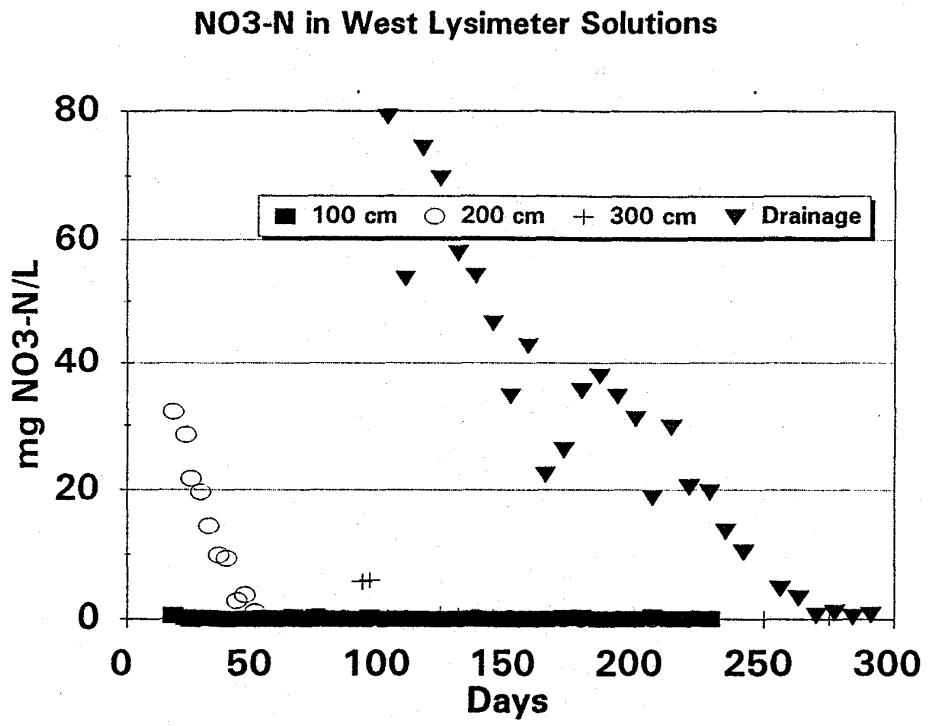

Figure 9. Nitrate nitrogen measured in soil solution samples and drainage water from the lysimeter irrigated with wastewater for the period 10 April 1995 through 29 February 1996.

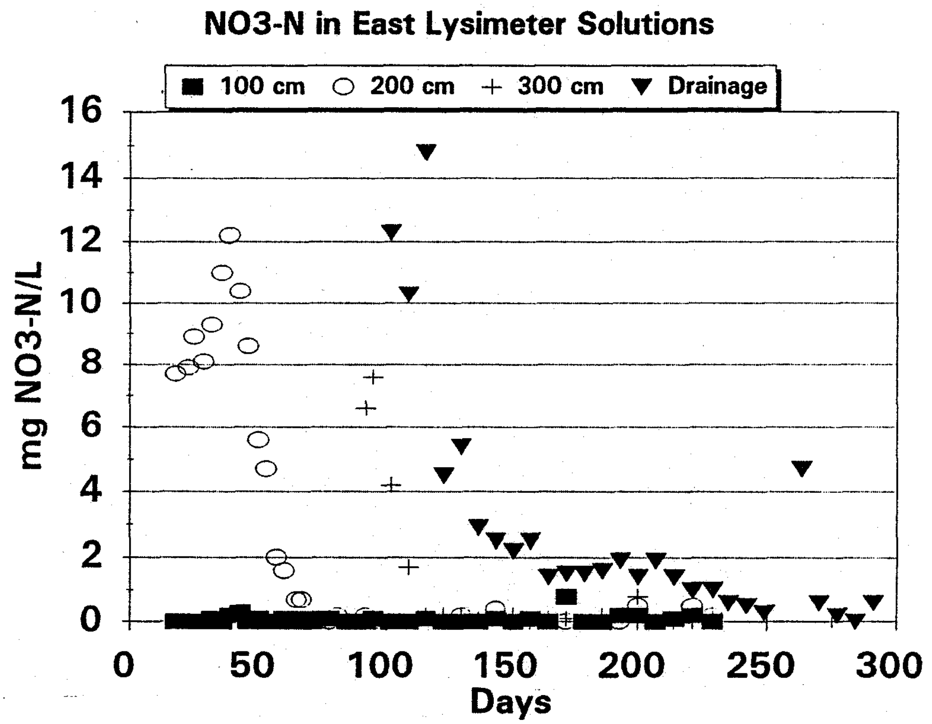

Figure 10. Nitrate nitrogen measured in soil solution samples and drainage water from the lysimeter irrigated with potable water for the period 10 April 1995 through 29 February 1996.

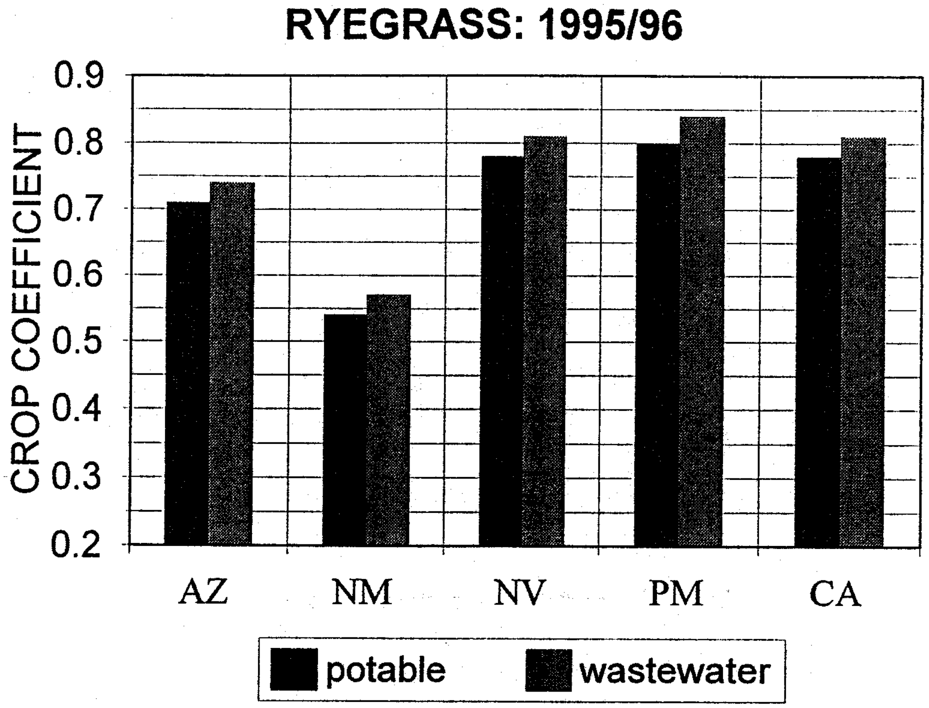

Figure 11. Seasonal (November 1995 through April 1996) crop coefficients for intermediate ryegrass irrigated with potable and wastewater. Crop coefficients are presented for five regional procedures used to estimate ETo (AZ: Arizona, NM: New Mexico, NV: Nevada, PM: Penman Monteith, CA: California).

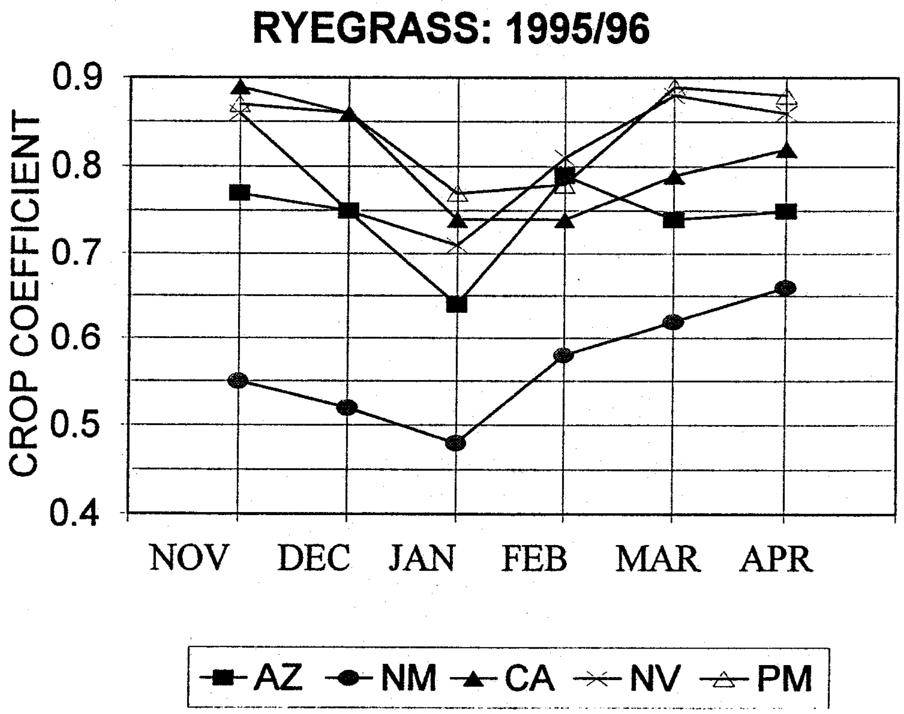

Figure 12. Monthly ryegrass Kc values obtained during the winter of 1995/96 for five regional procedures used to estimate ETo (AZ: Arizona, NM: New Mexico, NV: Nevada, PM: Penman Monteith, CA: California). Data presented are for turf irrigated with wastewater.

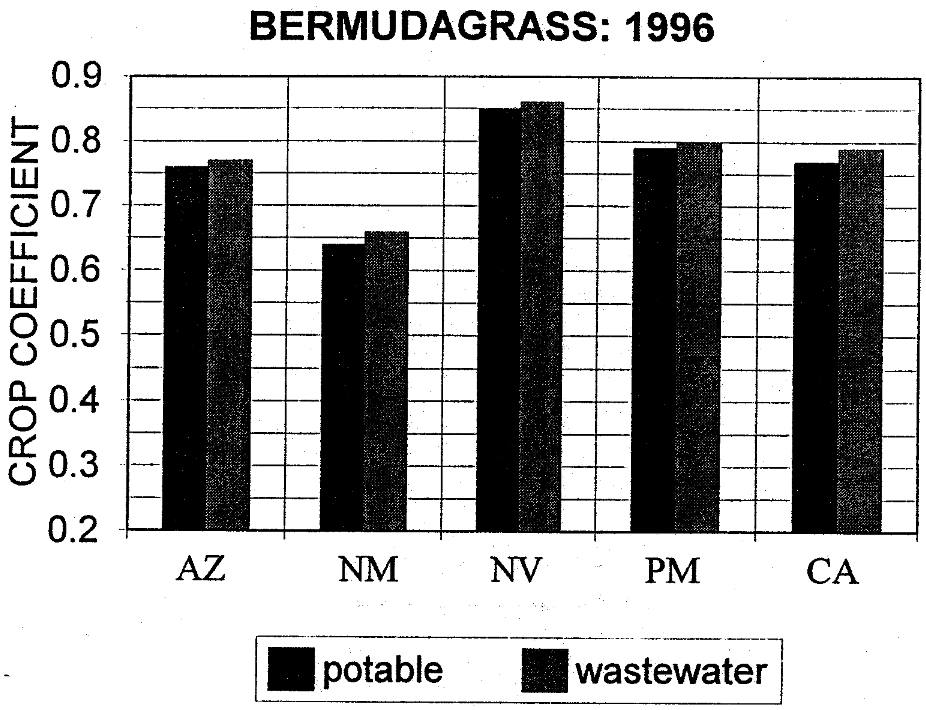

Figure 13. Seasonal (May through August 1996) crop coefficients for bermudagrass irrigated with potable and wastewater. Crop coefficients are presented for five regional procedures used to estimate ETo (AZ: Arizona, NM: New Mexico, NV: Nevada, PM: Penman Monteith, CA: California).

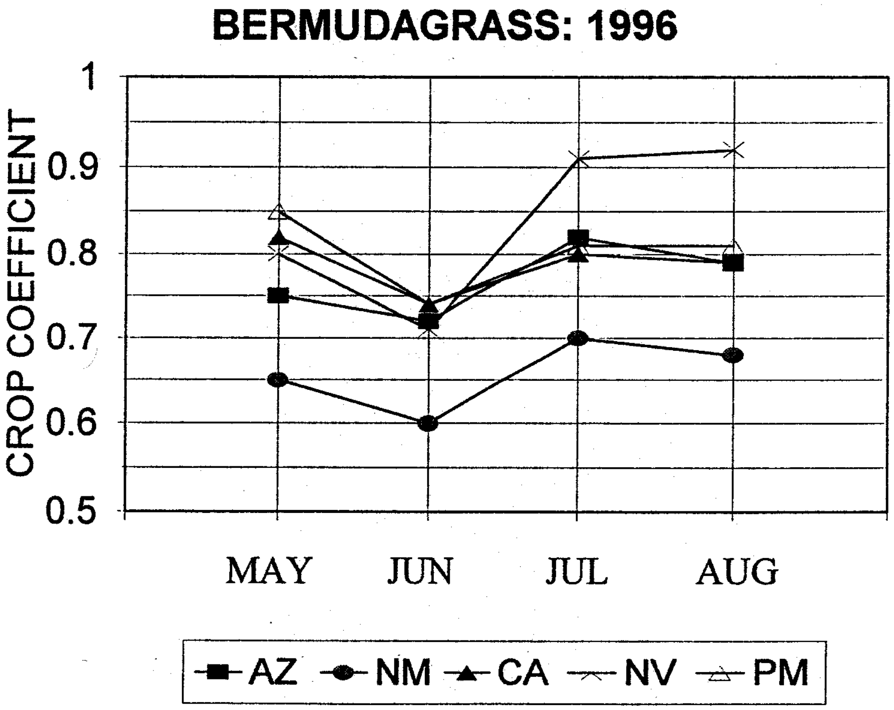

Figure 14. Monthly bermudagrass Kc values obtained during the summer of 1996 for five regional procedures used to estimate ETo (AZ: Arizona, NM: New Mexico, NV: Nevada, PM: Penman Monteith, CA: California). Data presented are for turf irrigated with wastewater.

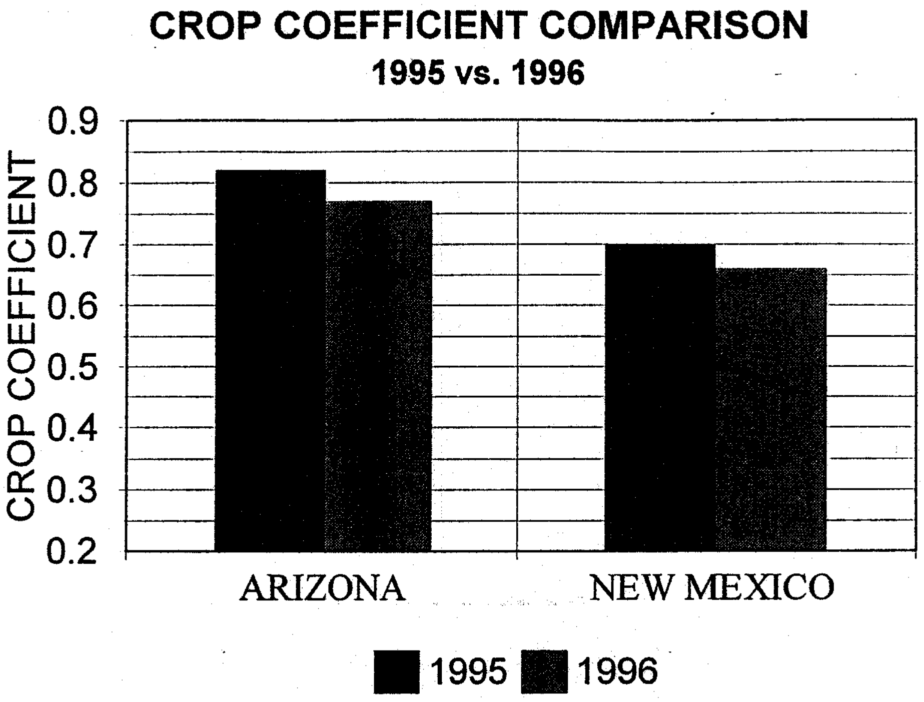

Figure 15. Seasonal bermudagrass Kc values obtained during 1995 and 1996 for the Arizona and New Mexico Penman Equations. Data presented are for turf irrigated with wastewater.