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

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EXCECUTIVE SUMMARY

Two large weighing lysimeters located at the University of Arizona Karsten Turfgrass Research Center are being used to evaluate water use and movement of nitrogen (N) fertilizer under turfgrass irrigated with potable and effluent irrigation water. Each lysimeter is 13' deep and 8' in diameter and weighs approximately 100,000 lbs. Truck scales are used to measure changes in lysimeter weight, thus allowing measurement of evapotranspiration (evaporatation from vegetation). 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.

Turf water use is determined from daily changes in lysimeter weight and related to reference evapotranspiration (ETo) as computed by automated weather stations. This relationship between actual turf water use and ETo is known as a crop coefficient (Kc) and 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 first year of study show the five methods of estimating ETo differ by as much as 20%, showing a clear need to match Kc with the method of ETo estimation. Appropriate Kc values for the five methods of estimating ETo varied from 0.74 to 0.91 during the bermudagrass season and from 0.72 to 0.90 for the winter ryegrass season.

A second portion of this study involves development of a database containing turf water use and meteorological data for use by public and private entities involved in providing turf water management information to the turf industry. Such a database would allow companies providing weather stations and/or irrigation scheduling software to develop Kc values and/or calibrate their procedures for estimating ETo. This database is presently in development and will include turf water use and most meteorological data used to estimate ETo.

Work on movement of N under the two irrigation regimes began with the bermudagrass season in April. One lysimeter was irrigated with effluent and the other with potable water. Nitrogen, applied as labled (N^{15}) ammonium sulfate, is applied to both lysimeters every two weeks. The rate of N applied to the lysimeter receiving effluent is adjusted downward to ensure both lysimeters receive similar levels of N. Results from the first 40 days of evaluation reveal no movement of labled N below the bermudagrass rootzone. Low N concentrations in soil solution extracted from 3.3' suggest very efficient N uptake by the bermudagrass. Higher N concentrations were observed in soil solution samples extracted from 6.6' and likely reflect residual N from the previous winter turf season.

Work on both turfgrass water use and N movement will continue during calendar year 1996.

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.

LYSIMETER FACILITY & OPERATION

This project is being conducted at the lysimeter facility located at the Karsten Laboratory and Desert Turfgrass Research Facility. 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 +/- 200 g (equivalent to 0.04 mm of water depth). Each lysimeter is equipped with an elaborate 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 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.

NITROGEN MANAGEMENT

Applications of labeled N (^{15}N) were initiated on 10 April 1995, approximately when the bermudagrass emerged from dormancy. The West lysimeter receives N daily through the effluent applied. Nitrogen was applied as $(NH_4)_2SO_4$ every two weeks to the East lysimeter, and as needed to the West lysimeter. The objective of the N management was to apply sufficient N for excellent turf quality and vigor, and to apply near-equal amounts to the lysimeters. Cumulative N applied is shown in Figure 1.

Nitrogen uptake has been measured for the first 40 days of labeled fertilizer application. The N uptake in the East lysimeter (Figure 2) was lower than that in the West lysimeter (Figure 3). This reflects the greater turf vigor observed in the West lysimeter early in the season. However, the difference in turf vigor and N uptake disappeared during the summer months (data not shown). In the East lysimeter (Figure 2), the majority of the N taken up early in the season was non-labeled. This may have been residual N from earlier fertilizer applications, or N mineralized from decaying ryegrass root biomass. Further studies will be needed to identify the possible sources of this N. Later in the season, we expect virtually all N uptake to be labeled (fertilizer) N. In the West lysimeter (Figure 3), very little of the labeled N was taken up, but uptake of effluent N and biomass production were high. These results support the hypothesis that effluent is an excellent source of N for bermudagrass.

Soil solutions were collected from 100 cm and 200 cm depths within each lysimeter. The NO_3-N concentrations in the 100 cm solutions were very low (Figure 4). The rooting depth for bermudagrass in the lysimeters is probably greater than 100 cm. These low solution concentrations very likely reflect efficient N uptake by the grass. The 200 cm solution concentrations (Figure 5) were somewhat higher, but show a clear trend of decreasing concentration with time. We believe the high concentrations early in the season are due either to excessive N applied to the preceding ryegrass crop, or to N mineralized from ryegrass residue. The higher concentrations in the 200 cm solutions in the West lysimeter were expected, because unlike the East lysimeter, the West lysimeter receives N at each irrigation event, including when the grass is becoming established. The average solution concentrations were much less than 10 mg NO_3-N/L. Therefore, these preliminary results indicate a low potential for groundwater contamination resulting from these turf management practices.

Nitrogen fertilizer applications were continued every two weeks until 22 September 1995. The lysimeters were overseeded with perennial ryegrass on 13 October 1995 and N applications will be resumed about 26 October. Soil solution samples will continue to be collected weekly from 100 cm, 200 cm, and 300 cm depths, and from the solution drained from the tanks. These samples will be analyzed for NO_3-N and ^{15}N. All turfgrass clippings will continue to be collected and analyzed for total N and ^{15}N.

CROP COEFFICIENT EVALUATION

Crop coefficients (Kcs) 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 (AZPE), California (CAPE), New Mexico (NMPE) and Southern Nevada (SNPE) to provide estimates of reference evapotranspiration (ETo). The fifth equation -- a Penman-Montieth Equation developed by Allen et al. (1989) -- has been evaluated extensively against lysimeters and is commonly used by the agricultural and civil engineering community.

Crop coefficient analyses are being performed for both the summer and winter turf seasons. 'Tifway' bermudagrass, established on the lysimeters in the summer of 1994, serves as the warm season turf. 'Froghair' intermediate ryegrass is overseeded on the lysimeters in October and serves as the winter turf surface.

The first full year of Kc analysis was initiated in November of 1994 when the two irrigation water treatments (effluent and potable water) were instituted on the lysimeters. In this report we will present only the results from the lysimeter irrigated with effluent since the authors believe this turf is more representative of high quality turf. Problems with the non-nitrogen fertility status of turf irrigated with potable water produced slower growing, lower quality turf which used slightly less water (5-10% less). Adjustments in the non-Nitrogen fertility regime have subsequently minimized these differences in quality, growth and water use; thus, subsequent reports will include comparisons of Kc values for similar quality grass irrigated with potable and effluent.

Bermudagrass Crop Coefficients

The 1995 summer turf season covered the period from 22 April through 26 September. Crop coefficients for each form of the Penman Equation were computed by dividing actual turf ET obtained from the lysimeters by the ETo as calculated by the appropriate equation. Two time periods were used for Kc analysis: seasonal and monthly.

Figure 6 provides the overall results of the Kc analysis for the summer turf season. The vertical bars show the total ETo for the summer turf season as computed using the five equations. The horizontal dashed line shows the actual turf ET as measured by the lysimeters. Crop coefficients appropriate for each equation are printed above the vertical bars.

All five equations generated ETo values in excess of ETa. This was an expected result since ETo is an estimate of ET from a well-watered, cool season grass maintained at a height of 8-15 cm. One would expect a tall cool season grass to use more water than a short warm season grass. However, Figure 6 clearly shows that the equations do not agree. The MPME generated the lowest ETo totals while the SNPE and NMPE produced the highest ETo totals. Seasonal Kc values range from 0.74 for the NMPE to 0.91 for the MPME, clearly showing the need to adjust Kc values for the method of ETo computation.

Figure 7 presents the monthly Kc values for each of the five Penman Equations. As was observed in Figure 1, the monthly Kc values differ for each of the methods. However, Kcs for the AZPE, CAPE, NMPE and SNPE remain fairly stable over the entire season, suggesting a single seasonal Kc value may suffice for each method during the summer months. In fact, no monthly Kc value for any of the four ETo procedures differed from the seasonal Kc value by more than 0.05. This finding of uniform monthly Kc values has important practical significance since it would allow a course superintendent to employ only one Kc value for the entire summer turf season. It is important to note that Kc obtained for the MPME did not show month-to-month stability during the bermudagrass season (Figure 7); monthly Kc adjustments would therefore be needed if using this procedure for estimating ETo.

Ryegrass Crop Coefficients

The 1995 winter turf season covered the period from 3 November 1994 through 21 April 1995. Crop coefficients for each form of the Penman Equation were computed by dividing actual turf ET obtained from the lysimeters by the ETo as calculated by the appropriate equation. Both seasonal and monthly time scales were again utilized for the Kc analysis.

The seasonal Kc analysis for the winter turf season is presented in Figure 8. The vertical bars show the total seasonal ETo as computed using the five equations. The horizontal dashed line shows actual turf ET as measured by the lysimeters. Crop coefficients appropriate for each equation are printed above the vertical bars.

As was observed with bermudagrass, the five ETo procedures generated differing levels of ETo. All procedures again generated ETo values in excess of ETa, thus producing Kc values of less than unity. Clearly, the appropriate Kc value for each method differs, ranging from 0.99 for CAPE to 0.72 for NMPE.

Crop coefficients exhibited far greater monthly variation for ryegrass than for bermudagrass (Figure 9). Monthly Kcs for the AZPE and CAPE were generally within 0.05 of the seasonal

Kc suggesting a single seasonal Kc value would be effective with these methods. However, the remaining methods of estimating ETo generated considerable month-to-month variation, declining during the cold months, then rising when warm spring weather returns.

The cause of this seasonal Kc variation with the NMPE, SNPE and MPME is due largely to the procedures these methods employ to estimate net radiation (Rn). Figure 10 shows the ratio of monthly estimated Rn by each procedure to actual measured Rn which is used by the CAPE. Note the similarity in pattern of Rn ratio and Kc (Figure 4). Only the AZPE Rn procedure shows any real seasonal stability. We believe the Rn estimation problems associated with the NMPE, SNPE and MPME stem from the fact that all three Rn procedures were developed for use with summer agricultural crops. The procedures likely are not well suited for use in the winter months. Similar month-to-month instability in Rn estimation is not evident in the summer months for these procedures (data not shown).

Discussion: Crop Coefficients

The results pertaining to Kc development clearly show the need for selecting the appropriate Kc value when using ETo to estimate turf water use. Failure to make the proper selection could lead to excessive under or over watering. For example, using the appropriate New Mexico Kc of 0.74 with the Arizona ETo procedure (correct Kc = 0.85) will underestimate water requirements of bermudagrass by 13% (0.74/0.85). Likewise, use of the appropriate Arizona Kc with the NMPE will overestimate water requirements by nearly 15% (0.85/0.74). Similar errors result from using improper Kcs during the winter turf season.

The authors believe Kcs appropriate for use with ETo procedures used by private vendors of weather stations (e.g. Rainbird, Toro, etc.) will exhibit a similar variation. Our experience to date with such vendors is limited, but the Rainbird weather station located on the Karsten facility routinely generates ETo values 10% above the AZPE values. Thus, we feel the final project goal of developing a calibration database for companies that provide weather stations and irrigation scheduling software to the turf industry is of considerable importance. This database will provide turf ET data and meteorological data which can be used to develop Kcs for existing and/or new procedures of estimating ETo. Development of this database continues to proceed in an orderly fashion. The database presently resides in a format compatible with the EXCEL spreadsheet. However, we anticipate providing this database in a simple, comma delimited ASCII form to minimize compatibility problems with current and future database/spreadsheet systems.

PROJECT SUMMARY

Project year 1995 proved to be very fruitful relative to all aspects of this project. The first full year of Kc analysis clearly shows that Kcs must be matched to the procedure used to estimate ETo. Failure to do so can result in both over and underestimates of turf water use. A second clear benefit of this project will be improved translation of regional turf water use research. Most regional studies relate treatments and results to ETo. The Kcs developed in this study will allow more effective transfer of these results to the region. The turf ET and meteorological database will also provide direct benefits to the private sector companies now providing weather stations and ETo data to the turf industry. We anticipate the database will be used by the industry to develop Kcs appropriate for their ETo procedures. Finally, we are now fully engage in the N management phase of the project with the results to date indicating high N utilization by bermudagrass.

The authors are presently looking forward to 1996 with great enthusiasm. We have now completed one full year of crop coefficient work and six months of N work. The authors believe two full years of data are necessary to give the project and its subsequent publications true scientific validity. However, the current project termination date of February 1996 must be adjusted to allow this period of data collection. The original proposed termination date assumed an earlier start to the project; however, delays associated with installing the lysimeters forced a later project starting date. We are therefore requesting an extension for this project to June of 1997. Such a termination date will provide two years of data collection on both the N management and crop coefficient portions of the study.

REFERENCES

Allen, R.G., M.E. Jensen, J.L. Wright and R.D. Burman. 1989. Operational estimates of reference evapotranspiration. Agron. J. 81:650-662.

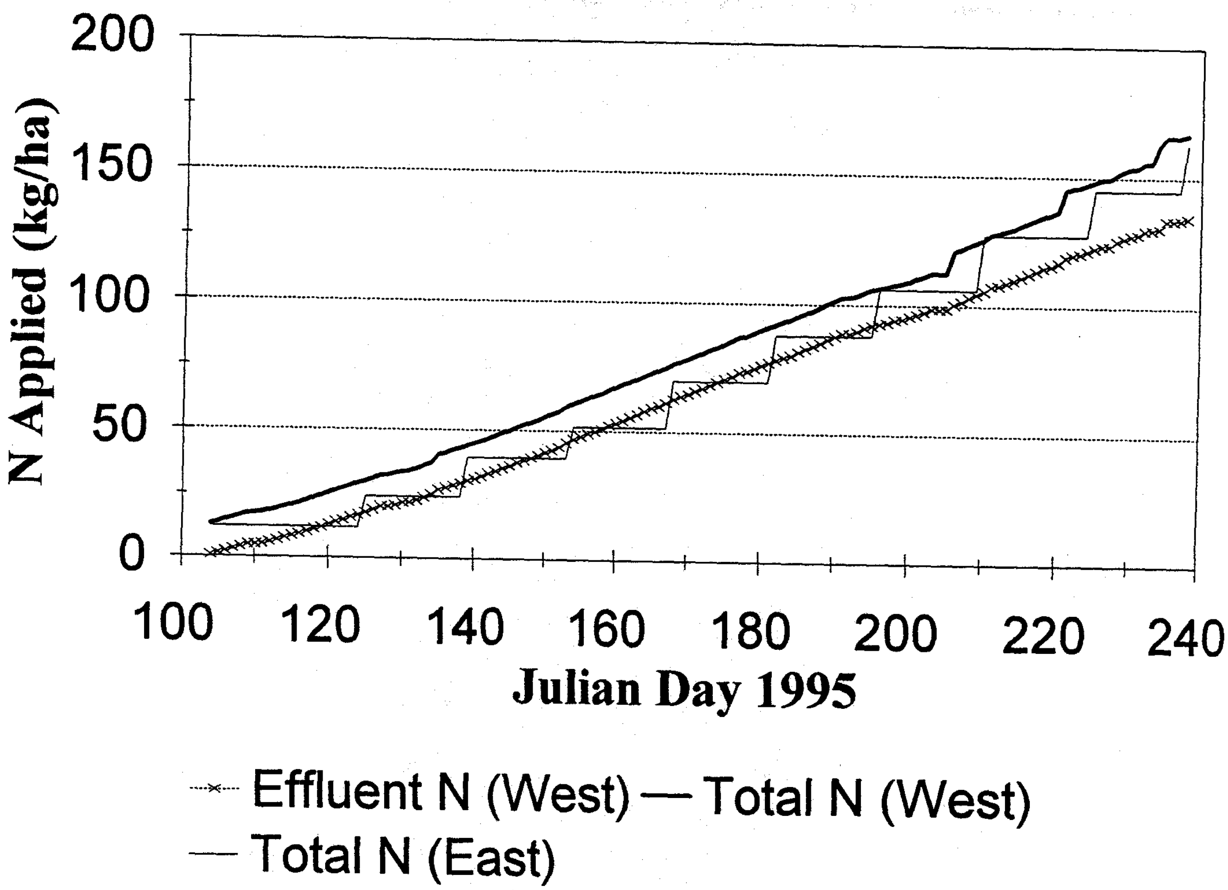

Fig. 1 Cumulative nitrogen applied to East and West lysimeters.

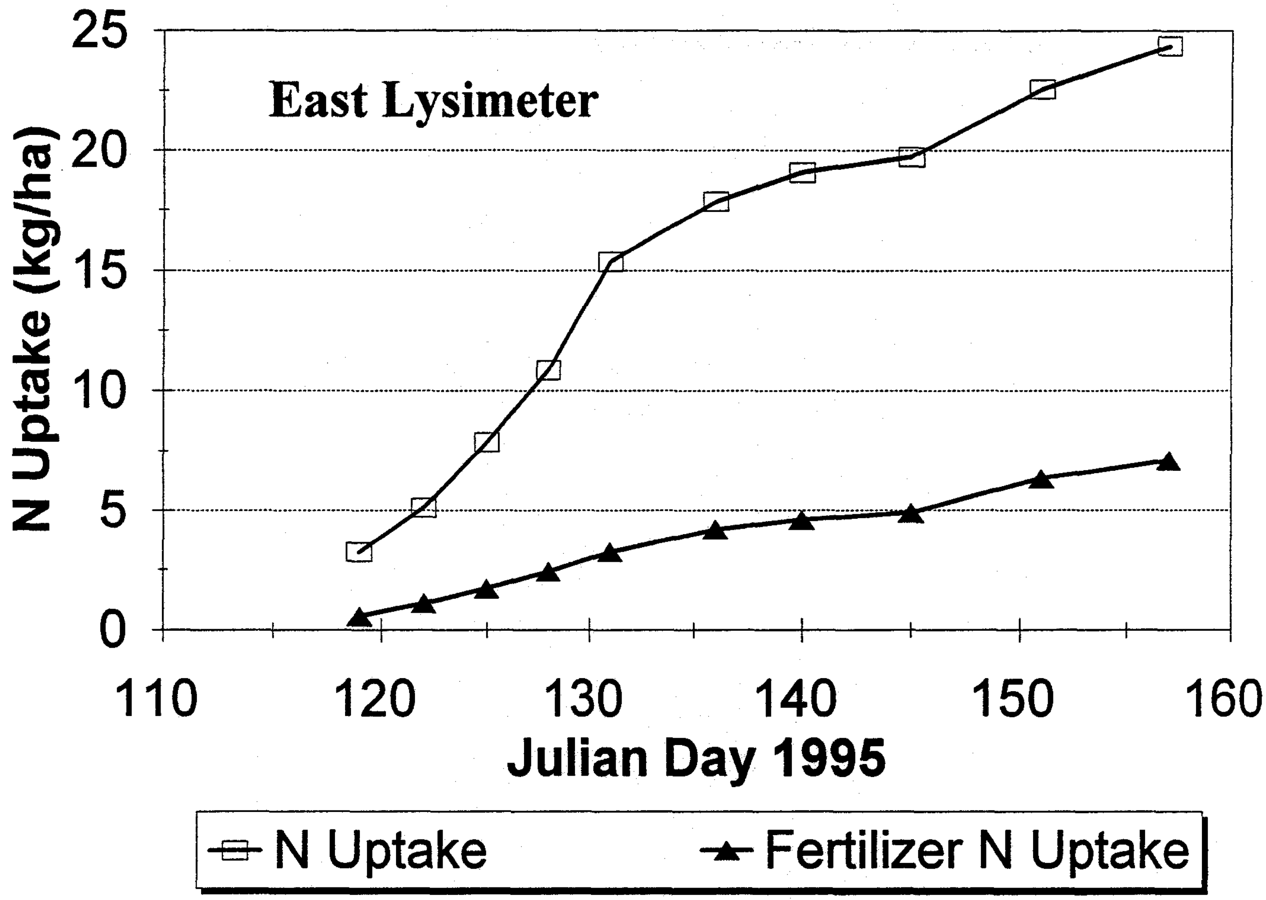

Fig. 2 Turfgrass N and ^{15}N uptake in the East lysimeter.

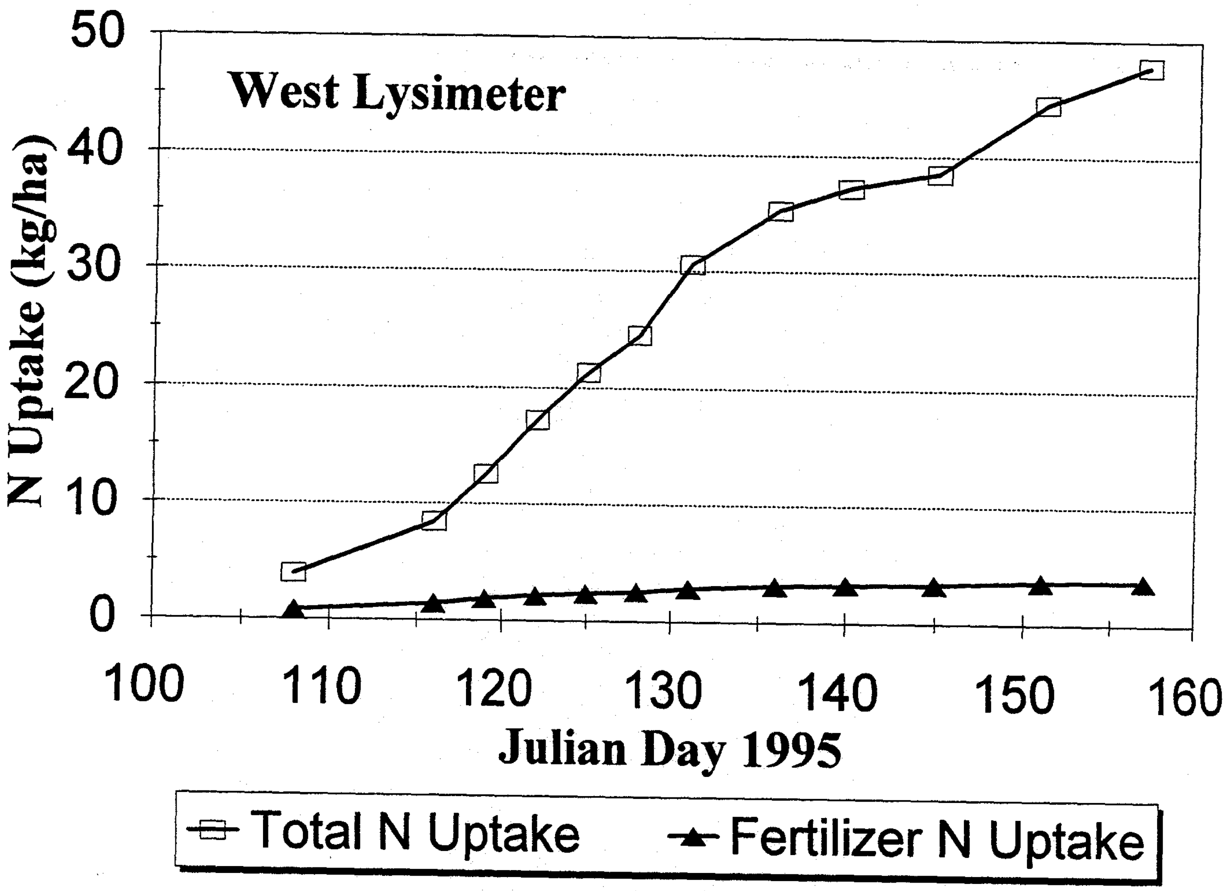

Fig. 3 Turfgrass N and ^{15}N uptake in the West lysimeter.

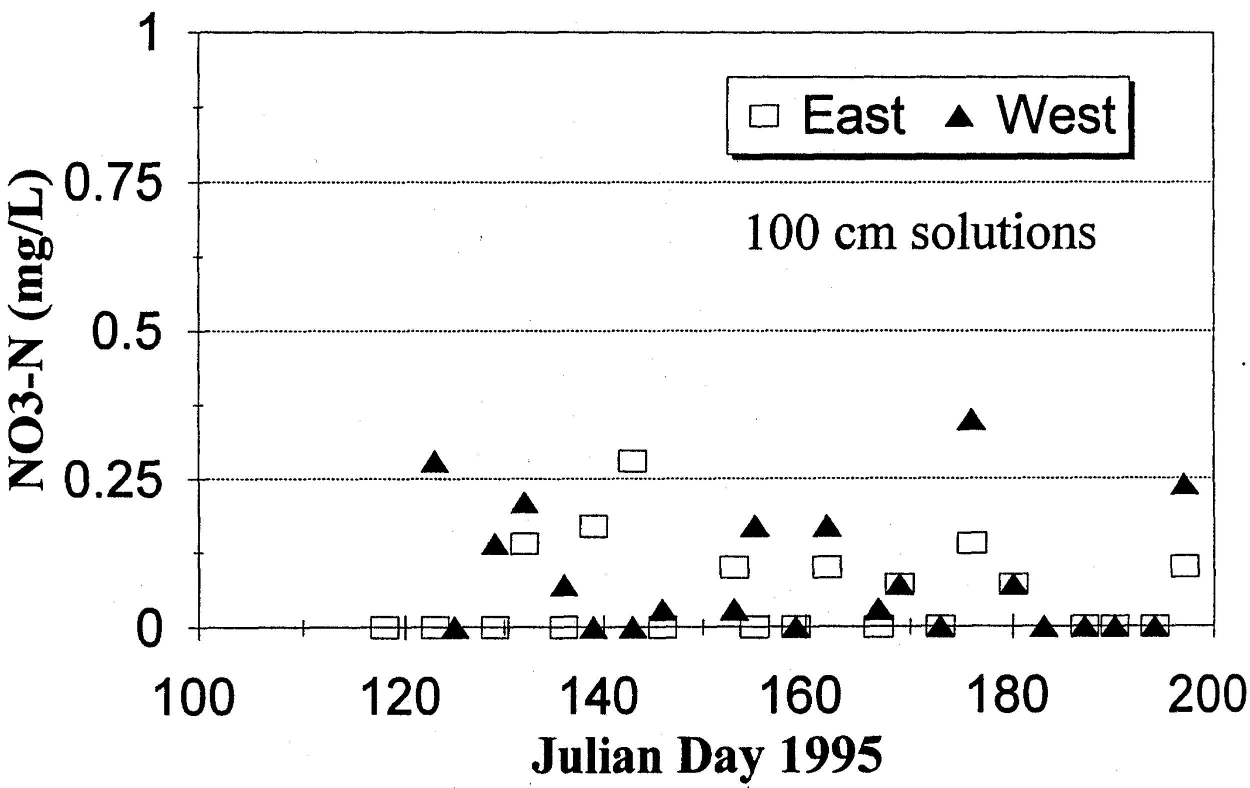

Fig. 4 Nitrate-N concentrations in soil solution samples collected at 100 cm depths in the East and West lysimeters.

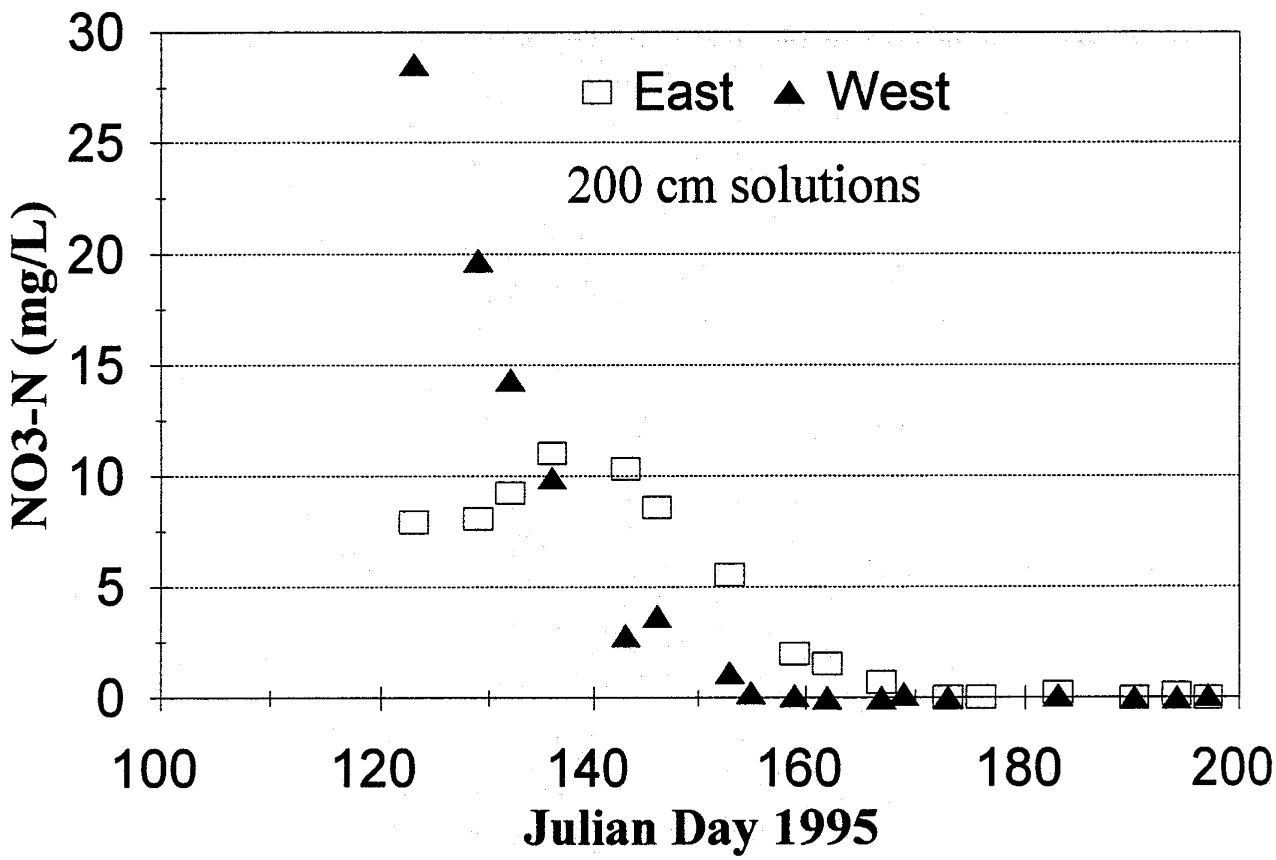

Fig. 5 Nitrate-N concentrations in soil solution samples collected at 200 cm depths in the East and West lysimeters.

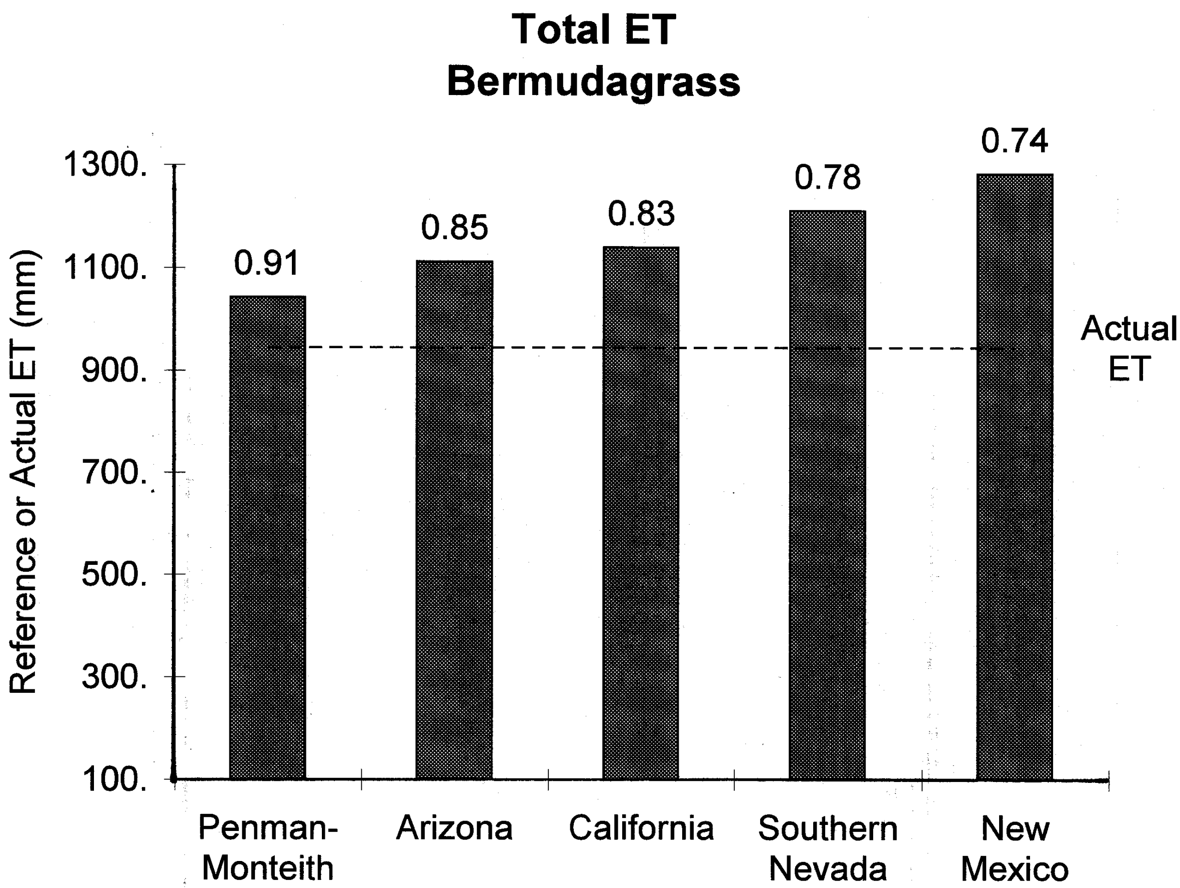

Fig. 6 Summer ETo totals obtained from the five Penman Equations under investigation (vertical bars). Actual turf ET is presented as the dashed line. The number above each bar represents the appropriate seasonal crop coefficient.

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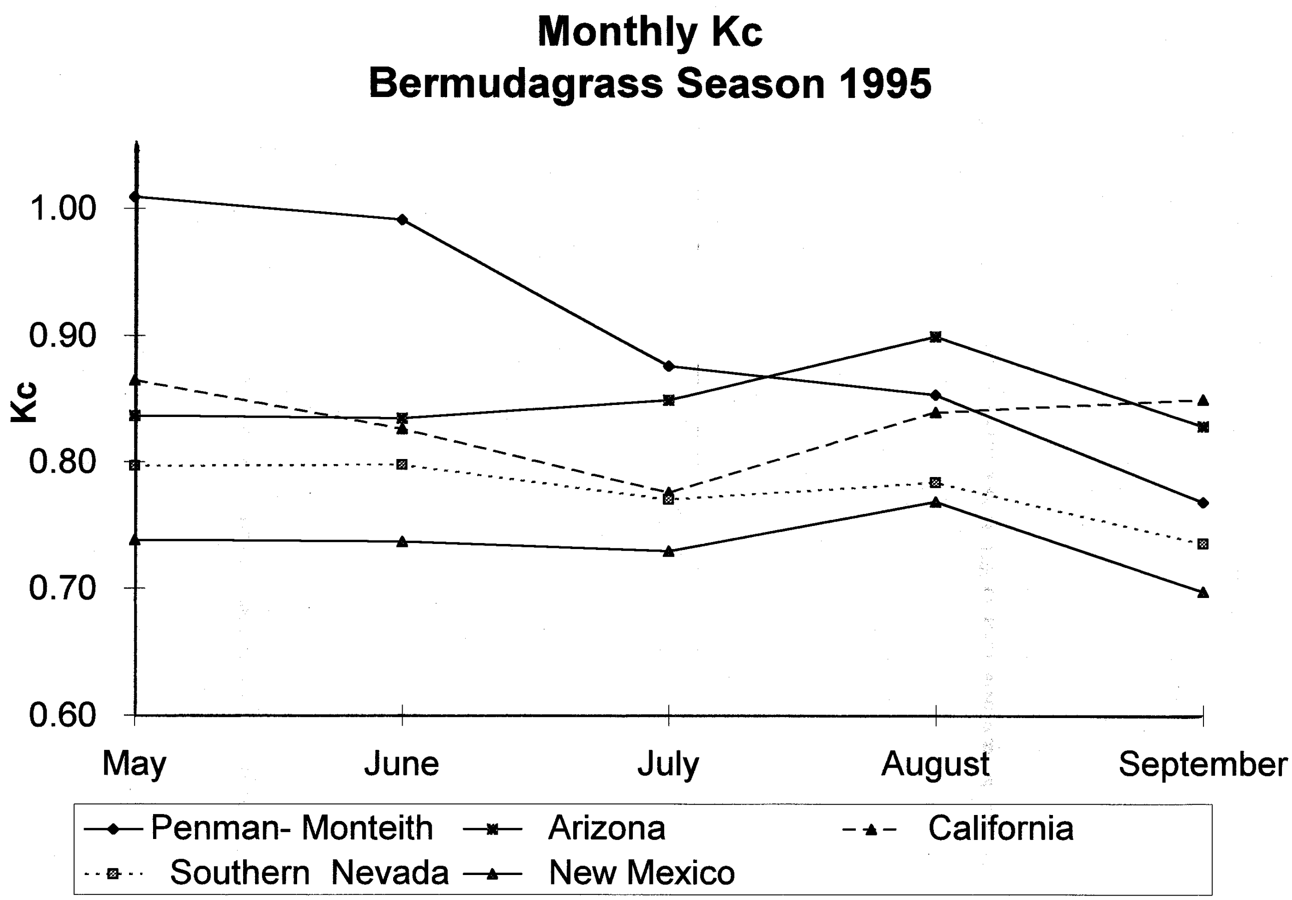

Fig. 7 Monthly bermudagrass crop coefficients for each of the five Penman Equations.

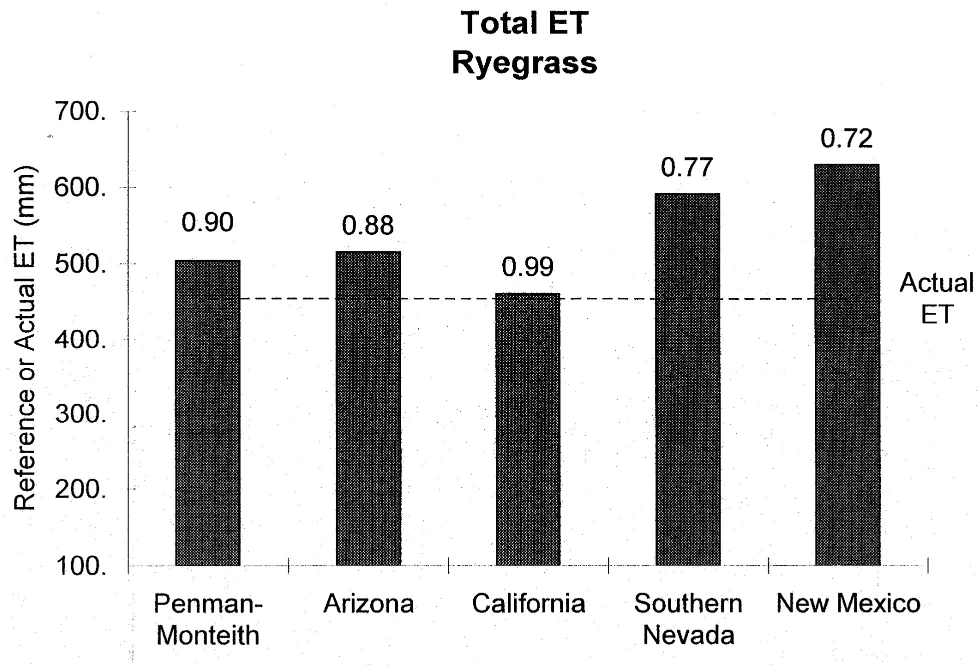

Fig. 8 Winter Eto totals obtained from the five Penman Equations under investigation (vertical bars). Actual turf ET is presented as the dashed line. The number above each bar represents the appropriate seasonal crop coefficient.

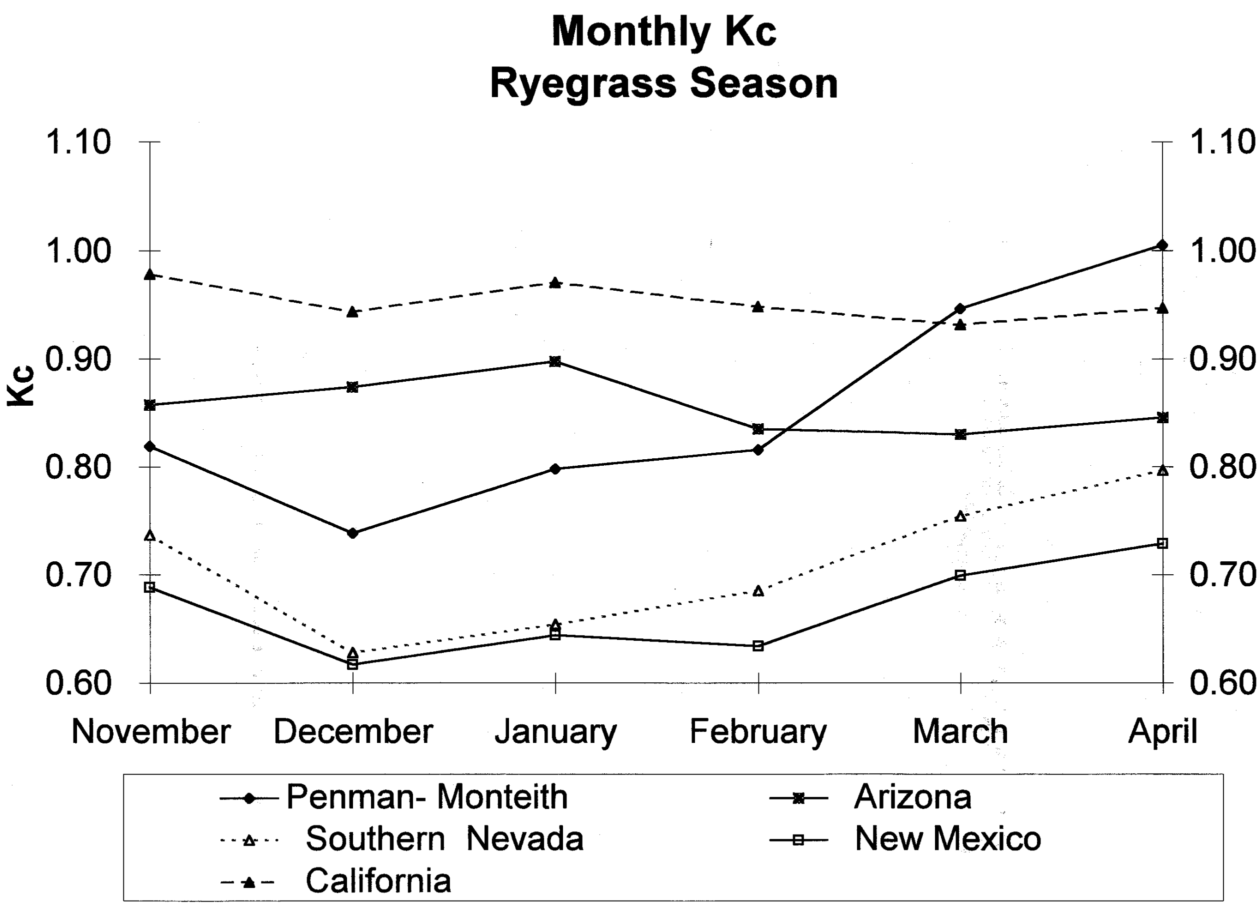

Fig. 9 Monthly ryegrass crop coefficients for each of the five Penman Equations.

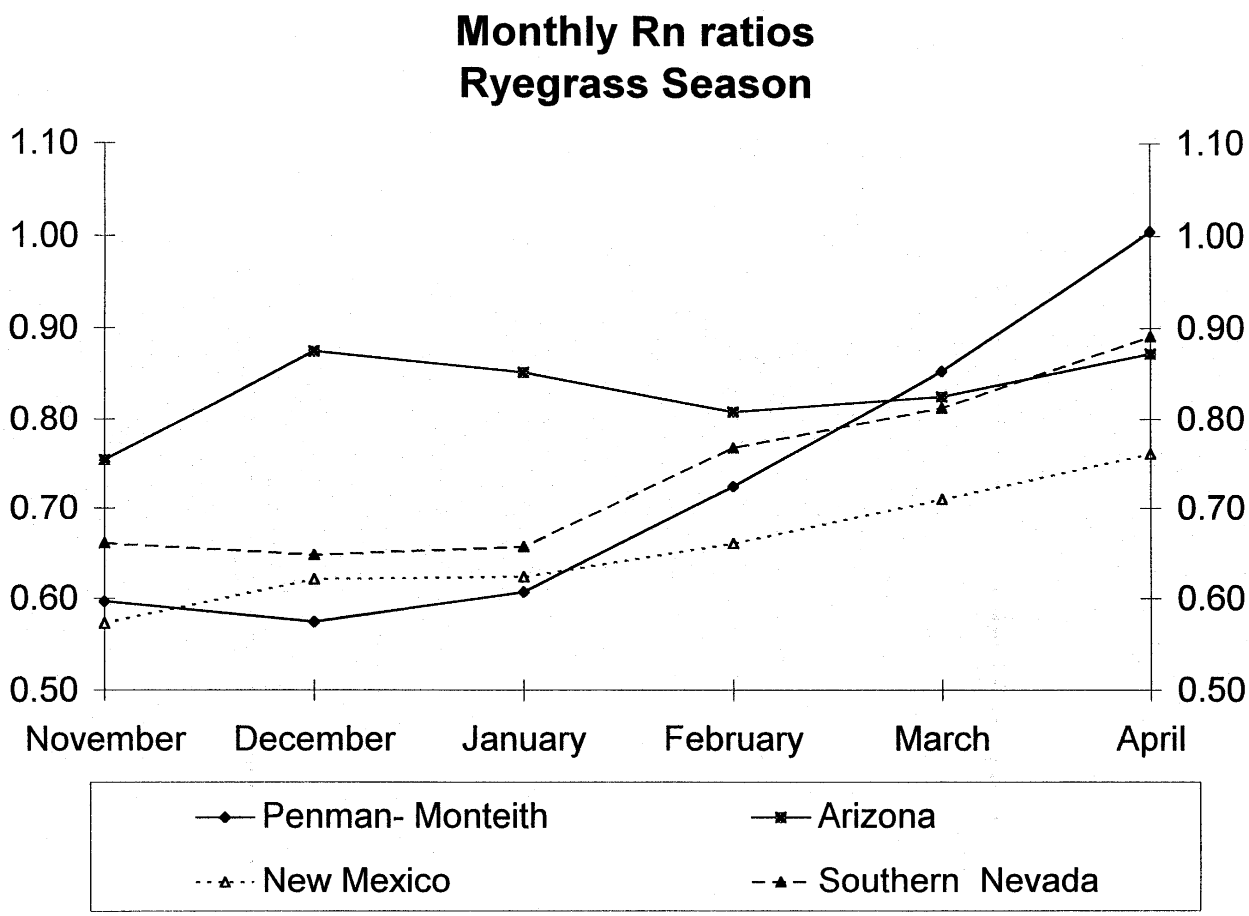

Fig. 10 Ratio of estimated net radiation (Rn) as computed using the AZPE, NMPE, SNPE and MPME procedures to measured Rn.