CHAPTER 4

Identification Of Low- And High-Water Use Kentucky Bluegrass Cultivars Using Morphological Attributes and Discriminant Analysis

ABSTRACT

In an effort to conserve limited water resources applied to irrigated turfgrass, the identification of water conserving Kentucky bluegrass *(Paa pratensis* L.) is an important objective in turfgrass breeding programs. Morphological criteria have been used successfully in warm-season turfgrass for identifying selections with low evapotranspiration (ET) rates. These studies indicate that comparative water use is a multivariate problem because ET is affected by several morphological and growth characteristics associated with components of canopy resistance to ET and leaf area. While these plant attributes are operating in combination, their effects are not independent. Therefore the efficiency of ET prediction can sometimes be improved by considering simultaneously those attributes associated with ET. The multivariate technique of discriminant analysis affords an effective method where groups are of interest, e.g., comparative water use groups in this present study. This study was conducted to determine the effectiveness of discriminant analysis in distinguishing water conserving cultivars on the basis of plant measurements including components of canopy resistance and leaf area from a population of 61 Kentucky bluegrass (KBG) cultivars. Using cluster analysis, the 61 KBG cultivars were categorized as either low- or high-water use cases based on ET rate evaluated in the growth chamber at three temperature environments (25, 30, and 35°C). Fourteen morphological and growth characteristics were assessed in the greenhouse using unmown space plants and mowed turfgrass (20cm diam. lysimeters). Based on single plant morphology, five- and seven-variable discriminant functions were identified that correctly classified cases into their actual water use groups with an estimated 70.5% actual error rate (LOER)from cross-validation using the leave-one-out method. Compared to single plant morphology, turfgrass morphology was more efficient in requiring fewer predictors (hence fewer measurements) to perform classification. Based on turfgrass morphology, two- and three-variable functions were identified that correctly classified an estimated 75.4% of the cases into their true water use groups. A 75.4% correct classification rate was the best achieved and was as good as the rate obtained using all 14 original variables in the analysis simultaneously. Leaf angle, a component of canopy resistance, was the most important discriminator of water use group, predicting actual group membership in 72.1% of the cases. Correct classification was improved only slightly over leaf angle alone by incorporating a single leaf area component such as leaf width or leaf extension rate. These results show that discriminant analysis may be an efficient and useful tool for predicting the water use patterns of new observations on the basis of a few plant measurements that are routinely assessed by breeders. Further work will be needed, however, before the technique can be considered to be practical.

INTRODUCTION

In irrigated turfgrass sites as water resources become limited and the competition for a finite water supply increases, the identification of water conserving KBG becomes an important objective in cool-season turfgrass breeding programs. The identification of turfgrass selections with a low water use pattern has been difficult because turfgrass ET is routinely assessed using weighing lysimeters which are relatively labor intense, and not well suited for mass screening. Morphological criteria have been used successfully in warm-season turfgrass in identifying selections with low water use rate (Sifer et al., 1986). The success in warm-season turfgrass has been based on the premise that those turfs with a high canopy resistance to ET and low leaf area components have lower ET (Kim and Beard, 1988a), although the relative importance of each can vary significantly between turfgrass species (Kim and Beard, 1988b). Characteristics associated with low ET include slow vertical leaf extension rate, a narrow leaf texture, high shoot and leaf density, and a more prostrate shoot and leaf orientation. These same morphological characteristics have been shown to have universal application in KBG maintained as unmown space plants and mowed turfgrass in greenhouse studies (Ebdon and Petrovic, 1995).

These studies demostrate that comparative water use in turfgrass measured under non-limiting soil moisture conditions is a multivariate problem because comparative water use is affected by several morphological and growth characteristics associated with components of canopy resistance to ET and leaf area. These characteristics operate simultaneously, but their effects in KBG are not independent (Ebdon and Petrovic, 1995). As a result, efficiency in water use prediction can be improved by considering simultaneously several plant attributes that are correlated with water use. The multivariate technique of discriminant analysis developed by Fisher (1936) provides an effective method for this purpose when groups are of interest, e.g., comparative water use groups. Discriminant analysis has been used successfully in horticulture in classifying plant material. For example, Lapins and Nash (1957) used discriminant analysis to identify peach cultivars, and Eaton and Lapins (1970) used it to distinquish between standard and compact types of apple trees. The method has seen little application because computations are complex and time-consuming. However, the use of discriminant analysis in classifying plant material has become more convenient than has previously been the case because of the increasing speed of the personal computer and the availability of statistical software that performs discriminant analysis.

This present study was conducted to determine the effectiveness of discriminant analysis in recognizing water conserving types of KBG on the basis of several plant measurements including components of canopy resistance to ET and leaf area. Plant measurements were obtained from urunown space plants and mowed turfgrass because both are relavent in evaluating turfgrass (Bourgoin and Mansat, 1977;van Wijk, 1989).

MATERIALSAND METHODS

Comparative Water Use Groups

Sixty-one KBG cultivars ~ere evaluated for ET rate under controlled conditions in three temperature environments (25,30, and 35°C) using the water balance method. The results along with methodology have been reported elsewhere (Ebdon et. aI., 1995). The 61 cultivars were categorized into comparative water use groups using hierarchical agglomerative cluster analysis on the basis of their individual ET rates measured at 25, 30, and 35°C (see Ebdon and Petrovic, 1995).Two distinct clusters (groups) were revealed in the analysis. The smaller of the two groups contained 28 members which clustered below the grand mean ET of 5.91 mm d^{-1}, and hence was labeled as low ET cases. The larger of the two groups containing 33 members clustered above the grand mean and was labeled as high ET cases. These groups are artificial in the sense that they are not representative of any natural grouping. However, the groups do indicate the true closeness of cultivars in 3-

dimensional water use space and indicate similarities between cultivars in their water use properties based on actual ET data.

The use of discriminant analysis for identification of KBG cultivars having low water use patterns based on the cultivar's morphological properties is a reasonable procedure for identification because of the relationship that exists between turfgrass morphology and comparative water use (Sherman, 1986; Ebdon and Petrovic, 1995). The success of discriminant analysis in this present study is based on the premise that cultivar groups that are dissimilar in their water use properties are likely to differ in their morphological properties and therefore classification functions can be developed that will recognize the differences in pattern between water use groups. A categorical classification variable was defined having the value '2' for high-water use cultivars and '1' for the low-water use cases. For specific case cluster membership and cultivars used in the study, see Ebdon and Petrovic (1995).

Plant Measurements

A greenhouse study to evaluate the morphological characteristics of the 61 KBG cultivars grown as unmown space plants was initiated in the early spring of 1993. Plant measurements were also obtained beginning early Dec. 1994 and ending late Jan. 1995 from mowed 20cm diam. lysimeters used for evaluation of cultivar ET. Each cultivar was replicated 6 times in the unmown space plant study and 4 times in the water use study. For specific methodology used in each study, see Ebdon and Petrovic (1995). A brief description of the 14 observations that were measured or calculated on each of the 61 KBG cultivars from unmown space plants and mowed lysimeters is given below.

Unmown space plants: leaf extension rate of the youngest leaf (budleaf) over a 24h period (mm d^{-1}); leaf width at midpoint (mm); length of the lamina measured from the collar region to the leaf tip (mm); sheath length measured from the crown to the upper portion of the sheath (mm); number of green leaves per shoot; leaf angle rating on a scale of 1 to 4, with 1 indicating a horizontal leaf and 4 indicating a vertical leaf orientation; crown type, an overall rating of the outside tillers on a scale of 1 to 4, with 1 indicating a spreading type growth habit and 4 having an erect growth habit; number of lateral shoots per plant; number of primary rhizomes per plant; shoot fresh- and shoot dry-weights at harvest (mg); shoot moisture content derived from shoot fresh- and shoot dry-weights (%); root dry weights at harvest expressed as a root density measurement (mg L^{-1}); and shoot-to-root ratio derived from shoot- and root-dry weights at harvest (mg mg^{-1}). Two shoot samples per replicate were used for leaf width, leaf length, sheath length, and leaf angle measurements, selecting the second subtending leaf from the budleaf.

Mowed lysimeters: leaf extension rate accumulated weekly above a 45mm base mowing height determined at 25, 30, and 35°C and factored to mm d^{-1}; leaf width, sheath length, number of green leaves per shoot, and leaf angle were measured as described for unmown space plants using five shoot samples per replicate; fresh weights and dry weights of five shoots per replicate (mg); shoot moisture content derived from the fresh- and dry-weights of five shoots (%); verdure at harvest (g); shoot-to-root ratio and root density measurements were determined as described for unmown space plants.

Data had been previously analyzed by analysis of variance (ANOVA) to investigate the effect of cultivar, see Ebdon and Petrovic (1995). ANOVA did not detect significant differences ($P \leq 0.05$) between low- and high-water use groups for only two variables from unmown space plants (shoot-fresh weight and shoot-dryweight) and three variables from mowed lysimeters (number of leaves per shoot, shoot moisture content, and root density).

Discriminant Analysis

A brief description of discriminant analysis will be given here. For a detailed discussion, see Johnson and Wichern (1992) and McLachlan (1992). Discriminant functions are used in deciding to which group (low- or high-water use) a cultivar belongs based on the measurements of its characteristics. Observations can be classified effectively into the groups using linear combinations of the original variables if their mean values change considerably from group to group. A discriminant function is defined as

$$d_i = c_i + k_1X_1 + k_2X_2 + \dots\dots + k_px_p \qquad \text{Eq. [1]}$$

where d_i is the discriminant score for an observation, i is 1,2,...., g number of groups, C_i is a constant, $X_1,\dots,x_p$ are mean values for p plant characters measured on an observation, and $k_1,\dots,k_p$ are the weights of the individual characters. The coefficients are chosen in such a way that the values of d are used as rules for sorting samples into groups of interest. Observations are allocated to group i for which the discriminant score (d_i) is largest. In this present problem of classifying an observation into one of two water use groups two discriminant functions are then used to make a classification.

Equivalently, an observation x is classified into group **i**, if the generalized squared distance of x to group i is the smallest. The generalized squared distance of observation x to the center (mean) of group i is given by:

$$D_i^2(x) = -2[m_i'S_p^{-1}x - 0.5m_i'S_p^{-1}m_i + \ln p_i] + x'S_p^{-1}x \qquad \text{Eq. [2]}$$

where x is a column vector of length p containing the values of the predictors for an observation, x' is the corresponding row vector of length p, m_i is a column vector of length p containing the means of the predictors calculated from the data in group i, m_i' is the corresponding row vector of length p, S_p is the pooled covariance matrix, and $\ln p_i$ is the prior probability (p_i) that an observation is in group i transformed by its natural logarithm (ln).

The term in the bracket is a linear function of x and is called the linear discriminant function for group i (see Eq. [1]). For a given x, the group with the smallest generalized squared distance has equivalently the corresponding largest discriminant score. Hence an observation is allocated into the group generating the largest discriminant score (Eq. [1]) or the corresponding smallest generalized squared distance (Eq. [2]). Note that the generalized squared distance is penalized the least by $\ln p_i$ for those observations whose prior probabilities are largest. If the prior probabilities are unknown then $p_1=p_2=\ldots=p_g=1/g$, and equal priors are assumed.

Linear discriminant analysis assumes multivariate normality and equal group covariance structure. For the unequal group covariance case the pooled covariance matrix, S_p, is substituted with the within group covariance matrix, S_i, and the term within the bracket no longer reduces to linear functions of x, hence the term quadratic discriminant analysis is used.

Fourteen plant measurements from unmown space plants and an equal number from mowed lysimeters were analyzed to identify discriminators of low- and high-water use groups. We were interested in the effectiveness of physical measurements based on unmown space plant morphology and how they compared to turfgrass morphology from mowed lysimeters in discriminating between the two water use groups. The analysis included 61 cultivars, 28 from the low-water use group and 33 from the high-water use group. In all, 854 observations (61 cv. x 14 plant variables) from each study were included in the analysis.

Discriminant analysis was performed with stepwise variable selection using SPSS (SPSS Inc., 1990) to find a subset of the 14 predictor variables making a significant *(P~0.05)* contribution in the variability of the categorical-dependent variable. All the limitations for variable selection procedures in regression analysis apply to discriminant analysis. Therefore, a subset of models of various sizes are reported here rather than a single model. MINITAB (MINITAB Inc., 1989) was then used on a chosen subset of predictor variables to develop linear discriminant functions and to perform cross-validation.

In assessing the effectiveness of discriminant functions in predicting group membership, an optimistic or apparent error rate (APER) results when the same data set that was used to derive the classification function is then used to validate the function. Cross-validation employs the holdout procedure described by Lachenbruch and Mickey (1968) to compensate for the optimistic APER. The holdout procedure or leave-one-out method (LOER) is one of several methods of cross-validation used to reduce the optimistic bias in estimating actual error rate. This procedure omits the first case (cultivar) from the analysis, develops a classification function using the 60 (n-l) remaining cases, then classifies the omitted observation. The omitted case is then returned to the data set and the holdout procedure is repeated with every case omitted and then classified. The holdout procedure is an alternative to splitting a data set into training samples and validation samples in estimating actual error rate (Johnson and Wichern, 1992). We report classification results as a percentage of total correct classification based on both LOER and APER.

Departures from the assumption of equal group covariances were detected for some models. Therefore, quadratic functions may be judged to be more appropriate than linear functions. We chose to report the percentage of total correct classification for both linear and quadratic models because good classification can sometimes be achieved even if all of the assumptions for the analysis have not been met in a specific situation. However, it is important to recognize that the classification rules are optimal and the error rates minimal under the assumptions. For those functions and corresponding classification tables that have been identified here as linear, the assumptions of linear discriminant analysis have been met.

We had no reason to believe that the prior probabilities for the low- and high-water use groups are different. This initial assumption is supported by the sample proportions of 28/61 and 33/61 for the low- and high-water use groups, respectively, which are approximately 0.50. Therefore, an equal prior probability assumption was used in the analysis.

RESULTS AND DISCUSSION

The goal of discriminant analysis in this study is to predict group membership for the purpose of screening for water conserving types. It is important to emphasize that the low- and high-water use group data in this study are from a random sample of 61 KBG cultivars representing a continuum of cultivar ET, from a low of 4.42 to a high of 8.54 mm d^{-1}, measured across a broad range of temperatures. Additionally, when evaluating error rates it is important to compare the observed misclassification rate to that expected by chance alone. For example, if there are two groups with equal prior probability the expected misclassification rate is 50%, hence a classification function with 50% correct classification is performing no better than chance.

These concepts should be kept in mind when interpreting the classification results reported here.

Classification results based on unmown space plant morphology in discriminating low- and high-water use groups are shown in Table 4.1. Based on a less bias estimate of actual error rate from cross-validation using the leave-one-out method (LOER), the best correct classification observed was 70.5% for both linear and quadratic functions using seven and five predictors, respectively. Therefore, we would expect to classify seven out of ten cases into their true group. Compared to LOER, correct classification rates based on APER are inflated because of the optimistic bias associated with this estimate of error rate (Table 4.1).

Table 4.1. Discriminant analysis correct classification rates based on variables from unmown space plants as predictors of low- and high-water use groups.

Number of predictors	Linear functions		Quadratic functions	
	LOERt	APER	LOERt	APER
		%		
7	70.5	77.1	68.9	85.2
6	65.6	78.8	67.2	83.6
5	67.2	77.1	70.5	80.3
4	67.2	70.5	63.9	70.5
14	63.9	77.1	60.7	95.1

t Estimate of actual error rate from cross-validation using the leave-one-out method.

The 14 original plant variables from unmown space plants are shown in Table 4.2, ordered by their F-statistics from a oneway ANOVA with comparative water use group used as the independent factor. Some of these predictor variables were identified by variable selection discriminant analysis as important discriminators between the low- and high-water use groups. Many of the important discriminators, such as shoot-to-root ratio, leaf angle, leaf extension rate, and tiller number, were entered early in the variable selection procedure because their mean values change considerably between the two groups, as indicated by their large F-ratios. Shoot-to-root ratio had the the largest F to enter and therefore was entered first. Root density had a significant F but was highly correlated with shoot-to-root ratio ($r=-0.45$, $P<.001$) and therefore was never entered. Other variables, such as leaf length and sheath length, were highly correlated with vertical leaf extension rate, $r=0.78$ ($P< .001$) and 0.67 ($P< .001$), respectively, and became important discriminators (or substitutes for leaf extension) when leaf extension rate was omitted from the analysis. Variables, such as shoot dry weight, crown type, and shoot fresh weight, appear to be unimportant when considered individually, but in combination with other discriminators contributed significantly in discriminating between groups.

Table 4.2. Predictor variables from unmown space plants ordered by their F-ratio from oneway ANOVA with water use group used as the independent factor.

Variable	Important discriminator	$F_{1,59}$	P-value
Shoot-to-root ratio	x	7.35	0.008
Leaf angle	x	6.33	0.014
Root density		5.97	0.018
Leaf extension rate	x	3.46	0.068
Tiller number	x	3.30	0.074
Leaf length	x	2.04	0.159
Rhizome number		1.83	0.182
Sheath length	x	1.68	0.200
Leaf width		1.61	0.210
Shoot moisture		1.24	0.269
Leaves per shoot		0.50	0.483
Shoot dry weight	x	0.06	0.807
Crown type	x	0.01	0.921
Shoot fresh weight	x	0.00	0.976

Classification results based on turfgrass morphology from mowed [illegible] are shown in Table 4.3. Discriminant functions based on one to three variables were identified by variable selection which were as good as using all 14 original variables in discriminating between low- and high-water use groups. Furthermore, we found that for these discriminant functions the common covariance matrix (Sp) was an adequate summary of the within group covariance matrices (Si) which indicated that linear discriminant analysis was appropriate. Compared to space plant morphology, turfgrass morphology was more efficient in terms of requiring fewer predictors to make a classification, without any loss of discriminatory power. For example, a linear function using leaf angle alone as the predictor afforded 72.1% correct classification based on cross-validation. This is as good or better than five to seven variable functions based on space plant morphology. A correct classification rate of 75.4% from cross-validation using two and three variable linear functions was the highest rate achieved. Classification results were similar for the one and three variable functions identified by variable selection.

Table 4.3. Discriminant analysis correct classification rates based on variables from mowed lysimeters as predictors of low- and high-water use groups.

Number of	Linear functions		Quadratic functions	
predictors	LOERt	APER	LOERt	APER
	%			
3	75.4	75.4	72.1	78.7
2	75.4	75.4	67.2	68.9
1	72.1	72.1	72.1	72.1
14	75.4	82.0	54.1	95.1

t Estimate of actual error rate from cross-validation using the leave-one-out method.

Leaf angle was the most important discriminator (based on its F-statistic) of water use groups of the 14 variables evaluated from mowed turfgrass. Leaf angle is a component of canopy resistance to ET and had the largest F-ratio (19.01) for groups, which indicated the separation between groups was largest for this variable (Table 4.4). Other important discriminators identified by variable selection discriminant analysis are related to leaf area and included variables such as leaf width and sheath length. These variables also had large F-statistics and therefore their means changed significantly between groups.

Table 4.4. Predictor variables from mowed lysimeters ordered by their F-ratio from oneway ANOVA with water use group used as the independent factor.

Variable	Important discriminator	$F_{1,59}$	P-value
Leaf angle	x	19.01	<0.001
Leaf width	x	7.38	0.009
Shoot fresh weight		6.36	0.015
Tiller number	x	6.33	0.015
Sheath length	x	5.82	0.019
Shoot dry weight		3.95	0.051
Leaf ext. rate 35°C	x	1.36	0.247
Shoot moisture		0.75	0.391
Shoot-to-root ratio		0.18	0.490
Root density		0.30	0.585
Leaf ext. rate 30°C	x	0.21	0.648
Verdure	x	0.12	0.733
Leaf ext. rate 25°C	x	0.09	0.767
Leaves per shoot		0.00	0.978

Comparative water use in turfgrass is affected by several morphological and growth characteristics which are operating in combination. In KBG, however, these characteristics associated with canopy resistance to ET and leaf area are not independent but are likely to be dependent (Ebdon and Petrovic, 1995), with important implications in dicriminant analysis. For example, Tiller number (a component of canopy resistance) had a significant F but was highly correlated with leaf angle ($r=-0.47$, $P< .001$). Because tiller number and leaf angle are interdependent, there is a potential for the duplication of information and effort when both leaf angle and tiller number are considered simultaneously as predictors of water use groups. We found that tiller number (or its equivalent, shoot density) was not important in predicting water use groups when considered in combination with leaf angle. Tiller number was only entered as a discriminator of water use groups when considered independent of leaf angle (hence when leaf angle is omitted from the analysis). Similarly, when considered individually, shoot fresh weight and shoot dry weight appear to be important base on their F-ratios, however, these variables are highly correlated with leaf width, r=0.57 ($P<$ .001) and r=0.51 ($P<$ .001), respectively, and therefore were not entered. Conversely, variables such as leaf extension rate and verdure appear to be unimportant when considered individually, however, in combination with other predictors they can be important discriminators of water use groups.

Table 4.5. Coefficients for standardized linear discriminant functions using leaf angle and leaf width from mowed lysimeters as predictors of water use group.

	Discriminant coefficients for group	
Variable	Low	High
Constant	-0.23	-0.16
Leaf angle	-0.64 (0.59***)t	0.54 (-0.25*)
Leaf width	-0.31 (0.20)	0.26 (-0.39**)

*,**,***Significant correlations at the .05, .01 and .001 levels, respectively.
t Simple correlations between original variable and the generalized squared distance for 61 observations are shown in parentheses.

Table 4.6. Summary of classification with cross-validation using leaf angle and leaf width from mowed lysimeters as predictors of water use group.

True group		Predicted group membership	
Group	Number of cases	Low	High
Low	28	19	6
High	33	9	27
Proportion correct (%):		67.9	81.8
Total correct (%):		75.4	

A linear discriminant function set obtained from standardized variables (predictor variables were standardized to a mean of 0 and a standard deviation of 1) using leaf angle and leaf width as predictors are shown in Table 4.5. The corresponding classification table for this set is shown in Table 4.6. This discriminant function set was developed based on established cultivars and its suitability for predicting the water use group of unkown observations will depend on the range of data on which the discriminant function was based. We do not claim that this specific standardization set is appropriate for any other set of conditions, however, it serves as an example. This set of linear discriminant functions is in the form given by Eq. [1]. Variables were standardized so that the relative contribution of each component variable to the total compound discriminant score is indicated by the absolute magnitude of its corresponding discriminant coefficient. Recall that an observation is classified into the group (low- or high-water use) generating the largest discriminant score. Because the discriminant coefficients for leaf angle are approximately twice the magnitude relative to leaf width (Table 4.5), the relative magnitude contributed by leaf angle to the total compound score is approximately twice as much compared to leaf width. Thus in the classification of an observation, leaf angle is given twice as much weight as leaf width (hence is twice as important).

The signs of the discriminant coefficients shown in Table 4.5 have important biological interpretations in the classification of an observation based on discriminant scores. For example, large observed values for leaf angle (e.g., a substantial vertical leaf orientation) and large observed values for leaf width (e.g., a wide leaf width) are morphological characteristics associated with high water use rates and have corresponding large positive standardized values which contribute to small scores (negative terms) for the low water use group and large scores (positive terms) for the high-water use group. Conversely, small observed values for leaf angle (e.g., a substantial horizontal leaf orientation) and small observed values for leaf width (e.g., a narrow leaf width) are morphological characteristics associated with low water use rates and have corresponding large negative standardized values which contribute to large scores (positive terms) for the low water use group and small scores (negative terms) for the high-water use group.

An equivalent interpretation in the classification of an observation is obtained using the generalized squared distance (D_i^2) given by Eq. [2]. Another way to assess the relationship between the original predictor variables and the classification of an observation is to examine the correlations between the original variables and the generalized squared distance of an observation to the center of a group (low- or high-water use). For each case the generalized squared distance is computed using Eq. [2] and the Pearson correlation between it and the original variable is obtained. The simple correlations between the original variables and the generalized squared distance to the center of each group are shown in parentheses (Table 4.5). Recall that an observation is classified into a group (low- or high-water use) if the generalized squared distance from the observation to that group center is the smallest. Close examination of the correlations indicates that narrower leaf width and more horizontal leaf orientation are associated with a smaller generalized squared distance to the morphological center of the low-water use group than the high-water use group. Conversely, a wider leaf width and a more vertical leaf orientation are associated with a smaller generalized squared distance to the morphological center of the high-water use group than the low-water use group. Thus, the classification of an observation as a low water user (based on discriminant scores or generalized squared distance), is consistent with the high canopy resistance to ET/minimal leaf area hypothesis that has been proposed in warm-season turfgrass (Kim and Beard, 1988a).

Using leaf angle and leaf width as predictors, 75.4% of the observations were correctly classified into their true groups (Table 4.6). However, a disproportionately higher error rate was observed in the classification of low-water use cases (67.9% correct classification) compared to high-water use cases (81.8% correct classification). Our objectives are to screen for water conserving patterns, so the identification of low-water use types is most important, therefore misclassifications of these are more costly. The identification of water conserving types was improved by replacing leaf width with a different component of leaf area, leaf extension rate, (Table 4.7). Overall correct classification using leaf angle and leaf extension rate as predictors remained unchanged (75.4%) compared to leaf angle and leaf width, however, correct identification of low-water use cases increased to 75.0% and fewer water conserving types were misclassified.

Table 4.7. Summary of classification with cross-validation using leaf angle and leaf extension rate from mowed lysimeters as predictors of water use group.

True group		Predicted group membership	
Group	Number of cases	Low	High
Low	28	21	8
High	33	7	25
Proportion correct (%):		75.0	75.8
Total correct (%):		75.4	

A discriminant function set that has been thoroughly tested could then be used to predict the water use patterns of new observations on the basis of a few simple plant measurements that are routinely assessed by turfgrass breeders. These results based on a random sample of 61 KBG cultivars demostrate that discriminant analysis may be an efficient and useful tool for this purpose. Further work will be needed, however, before the technique can be considered to be practical. First, the method should be reevaluated under field conditions. Secondly, visual ratings (qualitative variables) will need to be evaluated using a visual rating system similar to that utilized in assessing large collections in the field (Horst et al., 1984). The analysis can have application to other turfgrass species that share a similar relationship between morphological properties and comparative water use.

REFERENCES

Bourgoin, B., and P. Mansat. 1977. Comparisons of micro-trials and space planted nurseries with dense swords as means for evaluating turfgrass genotypes. p. 3-9. *In* J. B. Beard (ed.) Proc. 3rd Int. Turfgrass Res. Conf., Munich Germany. 11-13 July. Int. Turfgrass Soc., ASA, CSSA, SSSA, Madison WI.

Eaton, G. W., and K. O. Lapins. 1970. Identification of standard and compact apple trees by discriminant function analysis. J. Appl. Ecol. 7(2):267-272.

Ebdon, J. S., and A. M. Petrovic. 1995. Turfgrass morphological and growth characteristics of low- and high-water use Kentucky bluegrass cultivars. (submitted for publication).

Ebdon, J. S., A. M. Petrovic, and R. W. Zobel. 1995. Stability of evapotranspiration rates in Kentucky bluegrass cultivars across low- and high-evaporative environments. (submitted for publication).

Fisher, R. A. 1936. The use of multiple measuremets in taxonomic problems. Ann. Eugenics. 7:179-188.

Horst, G. L., M. C. Engelke, and W. Meyers. 1984. Assessment of visual evaluations techniques. Agron. J. 76:619-922.

Johnson, R. A., and D. W. Wichern. 1992. Applied multivariate statistical analysis. 3rd ed. Prentice-Hall, Englewood Cliffs, NJ.

Kim, K. S., and J. B. Beard. 1988a. Comparative evapotranspiration rates and associated plant morphological characteristics. Crop Sci. 28:328-331.

Kim, K. S., and J. B. Beard. 1988b. Turfgrass morphological characteristics associated with evapotranspiration rate. Texas Turfgrass Research. Texas Agric. Exp. Sta. PR-4662. p. 18-19.

Lachenbruch, P. A., and M. R. Mickey. 1968. Estimation of error rates in discriminant analysis. Technometrics. 10(1):1-11.

Lapins, K., and S. W. Nash. 1957. Discriminant function analysis in the identification of peach varieties in nursery trees. Can. J. Pl. Sci. 37:12-25.

McLachlan, G. J. 1992. Discriminant analysis and statistical pattern recognition. John Wiley and Sons, Inc., New York, NY.

MINITAB Inc. 1989. Reference manuel. Version 7. MINITAB Inc.

Sherman, R. C. 1986. Kentucky bluegrass cultivar evapotranspiration rates. Hortscience. 21(3):455-457.

Sifers, S. 1., J. B. Beard, and K. S. kim. 1986. Criteria for visual prediction of low water use rates of bermudagrass cultivars. Texas Turfgrass Research. Texas Agric. Exp. Sta. PR-4519. p. 22-23.

SPSS Inc. 1990. SPSS/PC Advanced Statistics 4.0. SPSS Inc.

van Wijk, A. J. P. 1989. The relationship between turf performance and single plant morphology data in red fescue. p. 113-115. *In* H. Takatoh (ed.) Proc. 6th Int. Turfgrass Res. Conf. , Tokyo. 31 July- 5 August. Int. Turfgrass Soc., ASA, CSSA, SSSA, Madison WI.