Daily Tall Fescue Leaf Appearance Rate in Relation to Environmental Factors

L.B. McCarty¹, J.R. Haun², and L.C. Miller³

Department of Horticulture, Clemson University, Clemson, SC 29634-0375

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Abstract. Methods for detecting and mathematically regressing daily tall fescue (*Festuca arundinacea* Schreb.) leaf appearance on environmental variables are presented. Morphological stages of leaf development were quantified and the rate of leaf appearance was linearly regressed on environmental variables. The following model was developed to predict daily tall fescue leaf appearance and was successfully tested on unrelated data: Daily leaf appearance rate = $0.016 - (2.48 \times 10^{-4} \times \text{solar radiation}) + (0.015 \times \text{precipitation 2-day lag}) + (0.117 \times \text{soil moisture 3-day lag}) + (8.79 \times 10^{-4} \times \text{maximum air temperature} \times \text{solar radiation}) - (3.61 \times 10^{-7} \times \text{maximum air temperature} \times \text{age}) + (0.00307 \times \text{minimum air temperature} \times \text{precipitation}) - (4.39 \times 10^{-4} \times \text{precipitation} \times \text{age})$, ($R^2 = 0.78$). Growers of tall fescue and researchers will benefit in the identification of environmental characteristics and cultural practices that significantly influence leaf appearance rate.

Tall fescue turf provides acceptable color and reduced maintenance requirements in South Carolina, compared with other species, such as bermudagrass [*Cynodon dactylon* (L.) Pers.].

The growth response of tall fescue maintained under turf conditions to environmental variables has not been adequately described. Understanding plant growth responses, such as leaf appearance rate, would allow cultural practices (e.g., mowing intervals) to be adjusted for environmental conditions.

Models have been used to estimate plant responses to multiple environmental variables. Bentgrass (*Agrostis palustris* Huds.) amides, glutamine, and asparagine variation can largely (57%) be accounted for by 15 measured environmental variables (Beard, 1961). Templeton et al. (1961) suggested the rate of leaf appearance of tall fescue was influenced by interactions of photoperiod, temperature, plant age, and duration of ex-

posure. Tall fescue leaf emergence occurs maximally at an optimum of $\approx 25^\circ\text{C}$ (Nelson et al., 1978) and when exposed to an 8-h photoperiod regime vs. 16 h (Templeton et al., 1961).

Tall fescue leaf appearance is critical for grass recovery under traffic or environmental stress. A study was therefore conducted to: 1) develop a nondestructive, visual procedure to measure daily tall fescue leaf appearance rate and 2) construct and test a model, on unrelated data, for predicting leaf appearance relative to environmental variables.

Established 'Kentucky 31' tall fescue turf adjacent to the Clemson Univ. weather station, Clemson, S. C., on a Cecil series (clayey, kaolinitic, thermic Typic Hapludults) was used in 1984 and 1985 to construct and test a leaf appearance prediction model. A soil test before the experiment indicated adequate levels of P, K, Mg, and Ca. Soil pH was 6.1. Nitrogen fertilizer was applied at 4.9 g N/m^2 (20N-0P-0K) in October and February. Mowing to 6.4 cm in height was performed 1 day before the experiment was started (22 Feb.) and repeated at 2-week intervals after 30 Apr. Supplemental water was not provided. Except for the modified mowing schedule, tall fescue cultural practices were similar to those typically suggested for a lawn or recreational area (Miller, 1985).

Quantifying rate of leaf appearance. Tolenaar et al. (1979) suggested that leaf appearance rate is nearly constant for a given temperature; therefore, rate of leaf appearance should be a meaningful parameter for studying the relationship between temperature and rate of development. Appearance of the youngest leaf tip in our study was visually observed between 0900 HR and 1000 HR daily. Shoots were tagged by loosely placing a cloth string attached to a numbered clip at the base of each observed plant. Observations spanned spring "green-up" (22 Feb.) through 30 Apr., at which time seedhead ini-

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¹Assistant Professor of Environmental Horticulture, 1545 Fifield Hall, Univ. of Florida, Gainesville, FL 32611.

²Professor Emeritus.

³Professor.

Fig. 1. Solar radiation (A), minimum and maximum air temperatures (B), and precipitation and estimated soil moisture (C) in 1984.

Table 1. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable tall fescue daily leaf appearance rate.

Variables		Partial regression coefficients	$P > t $		
Intercept		0.016			
Solar radiation ($\text{J} \cdot \text{m}^{-2}$)		-2.48×10^{-4}	0.0001		
Precipitation (cm) 2-day lag		1.50×10^{-2}	0.0005		
ESM ² 3-day lag		1.17×10^{-1}	0.0001		
Maximum air temp ($^{\circ}\text{C}$) $\times$ solar radiation		8.79×10^{-6}	0.0001		
Maximum air temp ($^{\circ}\text{C}$) $\times$ age ^y		-3.61×10^{-5}	0.0001		
Minimum air temp ($^{\circ}\text{C}$) $\times$ precipitation		3.07×10^{-3}	0.0001		
Precipitation $\times$ age		-4.39×10^{-4}	0.0036		
Source	df	MS	F	$P > F$	R^2
Regression	7	0.00720	25.59	0.0001	0.76
Error	57	0.00028			
Total	64				
Variables		Partial regression coefficients	$P > t $		

ESM = Estimated soil moisture (%), Thornthwaite-Mather method (1957).

²Age = days from mowing.

unrolled; those unrolling were scored on the basis of a scale previously described for wheat (*Triticum aestivum*) (Haun, 1973) and peaches (*Prunus persica*) (Haun and Coston, 1983). Each new complete leaf represented a unit of development, visually subdivided into 10 stages (O to 1.0, in 0.1 increments), during leaf emergence and/or unrolling. Stage O indicated first visible leaf emergence. Stages 0.1 through 0.4 represented leaf extension only. The 0.5 stage indicated initial leaf tip unrolling, while subsequent stages represented progressive tip unrolling and additional leaf extension. Stage 1.0 included one completely unrolled leaf plus the next emerging leaf tip. Daily growth rate was obtained by averaging the growth rates of 20 tagged shoots and was computed by the equation (Haun and Coston, 1983):

$$R = \frac{\Sigma a - \Sigma b}{Nt},$$

where: R = daily index of leaf appearance, a = current total number of leaves and stage of unrolling leaf, b = previous day's total, N = total number of observations, and t = number of days between observations (daily; i.e., 1 day, in our study).

Measurements continued on the leaf until it completely unrolled, at which time measurements continued on the next successive appearing leaf. This span of growth measurement provided a continuous succession of points to monitor the middle stages of development of each leaf. These successive daily observations were nondestructive.

Environmental data. Daily environmental data recorded during the experiment included: maximum and minimum air temperature ($^{\circ}\text{C}$) recorded weekly to the nearest 0.25°C using a hygrothermograph, soil temperature ($^{\circ}\text{C}$) at a 10.2-cm depth, solar radiation ($\text{J} \cdot \text{M}^{-2}$) recorded weekly using a Belfort pyreheliograph (Belfort Instrument Co., Baltimore), and precipitation (cm). Soil moisture (%) was computed by the Palmer-Havens (1958) adaptation of the Thornthwaite-Mather method (1957).

Environmental variables during the 1984 experiment are presented (Fig. 1). Features during this period included: 1) total precipitation of 11.8 cm, 2) 5 days with a minimum below 0°C and a maximum low of -5°C , and 3) 12 days with a maximum $\geq 27^{\circ}\text{C}$.

Statistical analysis. Average leaf appearance rate was regressed on the following independent variables: maximum and minimum air temperature ($^{\circ}\text{C}$), mean soil temperature ($^{\circ}\text{C}$) at a 10.2-cm depth, precipitation (cm), age (in days of leaf development) from mowing, solar radiation ($\text{J} \cdot \text{m}^{-2}$), and soil moisture, (%). Lags of 1 to 3 days for temperature and moisture data were also included as independent variables. Lags were used because plant responses are not necessarily best correlated with the environment occurring the same day as observations, but instead may be influenced by that of several previous days (Haun, 1982). Additional variables to account for interactive relationships were formed by selected two-factor cross products.

tiation was apparent. Spring green-up is the appropriate initial point for observations (Danneberger et al., 1987). Each observation involved a notation of leaves completely

Fig. 2. Actual leaf appearance rates in 1984 (A) and 1985 (B) and leaf appearance rates calculated by 1984 prediction equation (Table 1). Data values represent the means of 20 observations.

Stepwise regression analyses of independent variables were performed with a computer program designed by the SAS Institute (Barr et al., 1979). In this program, leaf appearance was regressed on each independent variable. The variable producing the highest R^2 was selected for the first step. In the next step, this variable was paired with all others to obtain the highest R^2 . These two were then combined with all remaining variables until an arbitrary limit of 15 was reached. In selecting the best-fit equation, if the addition of a new variable caused the significance of a previously selected one to fall below a given point, the previous variable was rejected. Criteria used in selection of the best step for the leaf appearance equation were significant Student-Newman-Keuls t values. Where temperature, precipitation (mainly as soil moisture), and plant age are known to be related to growth, but exact quantification of their relationship is unknown, this analysis of stepwise multiple regression was made to obtain a useful set of coefficients of variables. Many regression models have been criticized for lack of tests on independent data (Laird and Cady, 1969); therefore, the model developed in 1984 was evaluated not only from significant statistical indications but also from a test of the growth equation on 1985 environmental data.

Leaf appearance peaked between 20 and 40 days after mowing in 1984 and 20 days after mowing in 1985 (Fig. 2). Leaf appearance generally declined when seed-

heads were first visible. Leaf appearance responded to environmental variables as: leaf appearance rate = $0.016 - (2.48 \times 10^{-4} \times \text{solar radiation}) + (0.015 \times \text{precipitation 2-day lag}) + (0.117 \times \text{soil moisture 3-day lag}) + (8.79 \times 10^{-6} \times \text{maximum air temperature} \times \text{solar radiation}) - (3.61 \times 10^{-5} \times \text{maximum air temperature} \times \text{age}) + (0.00307 \times \text{minimum air temperature} \times \text{precipitation}) - (4.39 \times 10^{-4} \times \text{precipitation} \times \text{age})$. The model accounted for 76% of observed variation and all estimated coefficients were statistically significant at $P = 0.01$ (Table 1). Other variables measured (i.e., soil temperature) affected leaf growth, but were not included in the equation because they did not significantly ($P < 0.05$) increase correlation. For simplicity and to facilitate its application, the leaf appearance equation included as few variables as possible.

Calculated values were compared with actual 1984 data from which the leaf appearance model was derived (Fig. 2A). Statistics of fit were significant for the analysis of tall fescue multiple regression when applied to data on which the equation was based (Table 1). Comparison of the 1985 tall fescue leaf appearance with that predicted by the 1984 model is shown (Fig. 2B). The coefficient of determination (R^2) was 78%. The correlation between 1985 actual and predicted leaf appearance, using the 1984 model, indicates potential usefulness of the model for identification of environmental variables pro-

moting or limiting tall fescue leaf development (e.g., the value for a given variable could be varied with all other values held constant to evaluate its effect on growth rate).

This system of observation and analysis provided a means for: 1) a visual method of measuring changes in the rate of daily leaf appearance and 2) a mathematical model for daily plant responses to environmental variables, such as temperature and soil moisture, under natural conditions.

We describe the initial steps for researchers and growers toward mathematically predicting tall fescue turf growth under specific environmental conditions. Additional data are needed to test the model in other locations and times of the year. Improved leaf-appearance-predicting models could also be developed for specific cultivars and other variables influencing growth. For example, pesticides have been shown to reduce grass photosynthesis, which could be important during stressful growth periods. Other dependent variables, such as harvested grass regrowth, could also be measured. Busey (1985) suggested a model that incorporated time and N fertilization as independent variables when determining if sod regrowth of stripped bermudagrass was strong enough for commercial harvesting.

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