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INVESTIGATIONS ON STATISTICAL ANALYSIS OF TURFGRASS RATING DATA, LOCALIZED DRY SPOTS OF GREENS, AND NITROGEN APPLICATION TECHNIQUES FOR TURF

By

Douglas Edward Karcher

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ABSTRACT

INVESTIGATIONS ON STATISTICAL ANALYSIS OF TURFGRASS RATING DATA, LOCALIZED DRY SPOTS OF GREENS, AND NITROGEN APPLICATION TECHNIQUES FOR TURF

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Three separate turfgrass research topics were addressed: 1) statistical analysis of visual rating data, 2) localized dry spots (LDS) on putting greens, and 3) nitrogen fertilization using high pressure water injection cultivation (WIC) on putting green turf. 1) Visual ratings are often used by researchers to assess turfgrass quality. The resultant data are ordinal and often violate assumptions necessary for analysis using ANOVA. Valid analysis of ordinal data is possible with the proportional odds model (POM) and gives the researcher nearly the same amount of information on treatment effects as ANOVA. A Rating Data Analysis File Package was developed that allows researchers to analyze rating data with the POM, without needing to program statistical software.
2) Consistent control of LDS is difficult. The effects of flutolanil (a fungicide), a soil wetting agent, and WIC on LDS control, and the cause of LDS were investigated. All treatments showed some control of LDS in 1998 or 1999, but results were variable. Where characteristic LDS occurred, soil at the center of the dry spot, and at a 1 cm depth, was most non-wettable. Slides buried into the soil (1 cm beneath thatch) at the edges of the dry spots had the greatest amount

of fungal hyphae, consistent with the hypothesis that fungi may be involved in development of LDS. 3) Subsurface nitrogen fertilization has increased nitrogen use efficiency by crops in the food and forage industries. However, the equipment needed for subsurface fertilization in turf was unavailable until the recent development of WIC. Studies were conducted to compare putting green turf responses between surface applications nitrogen and nitrogen injected via WIC to 7.5 and 15 cm. An additional study was conducted to evaluate the effects of several WIC nitrogen application methods on surface uniformity, since nitrogen injection with traditional nozzles sometimes causes unacceptable striping of putting green turf. Subsurface placement of nitrogen increased clipping yields and nitrogen content in leaf tissues in 1997, and improved visual color and general turf quality in 1997 and 1998 compared to surface applications. An application of WIC on turf receiving surface applications of nitrogen did not significantly affect any turf evaluation. Injecting nitrogen with a Toro HydroJect 3000® at a 7.5 cm by 2.5 cm spacing and with the roller washers turned on significantly reduced turf striping following application compared to other nitrogen injection techniques.

To all of the wonderful people at Michigan State University who enriched my graduate education beyond all expectations

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CHAPTER ONE

THE PROPORTIONAL ODDS MODEL: A STATISTICALLY SOUND METHOD TO ANALYZE TURFGRASS RATING DATA

ABSTRACT

A common objective of many turfgrass experiments is to evaluate the effects of various treatments on turf quality. Analysis of variance (ANOVA) has traditionally been used to analyze quality rating data. However, many data sets resulting from turf quality ratings have ordinal outcomes, defined as the ranking of a set of observed values. These data violate assumptions required for valid statistical inference from ANOVA since they are not continuous. The development of the proportional odds model (POM) allows for valid statistical inference on treatment effects from ordinal rating data. The POM also estimates treatment parameters and standard errors, making treatment separation tests and contrasts possible. These options were not available with the traditional statistical tests appropriate for ordinal data. Unfortunately, to use the POM to its full potential a researcher had to be an experienced statistical software programmer, making it unusable for many. The objective of the following work was to develop a Rating Data Analysis File Package (RDAFP) that (i) analyzes ordinal rating data in a statistically valid manner using the POM, (ii) outputs nearly the same amount of information on treatment effects as ANOVA, and (iii) has an intuitively simple user-interface, from data entry to the production of output. An example quality rating data set from a 4 x 2 factorial randomized

complete block design was used to demonstrate how the RDAFP analyzes data with the POM and outputs probability distribution charts into MS Excel. Complete analysis of the quality rating data with the POM, comparison of the results to ANOVA, and the production of probability distribution charts were possible with minimal SAS programming knowledge needed.

INTRODUCTION

The majority of turfgrass research is funded by groups interested in improving golf course, lawn care, or athletic field conditions. Therefore, an objective of many turfgrass experiments is to examine the effects of treatments on the functional or aesthetic quality of turf. This objective cannot be addressed without an evaluation of turfgrass quality by the researcher. Historically, quality evaluations have been done by visually rating plots on a scale of 1 to 9, where 1 = dead or brown turf, 6 = minimum acceptable quality (varying depending on the intended use of the turf), and 9 = ideal turf (dark green, dense, and uniform). The 1 to 9 scale was probably first used because of its practicality. Nine rating categories were usually adequate to distinguish quality differences observed among the turf plots, statistical calculations with values from 1 to 9 were relatively simple, and the results presented to the non-scientific community were comprehensible.

Quality rating data have different characteristics from data such as clipping yields that are obtained from an objective measuring device. Rating data resulting from the 1 to 9 scale will only have nine possible values (1, 2, ..., 8, 9). Seventeen values are possible if half steps are used (1, 1.5, ..., 8.5, 9). A typical quality rating may result in less than five unique observed values, whereas a clipping yield measurements usually result in a unique observed value for each experimental unit.

Another property of quality rating values is that they are arbitrary, since the values assigned to turfgrass plots are not from a standardized scale. An

alternate, but equally effective quality rating could be accomplished by using a scale of "A" to "I" where "A" represented ideal turf, "I" represented dead turf and "B through H" represented declining levels of turf quality intermediate to ideal and dead. However, a scale of this sort certainly could not be used to evaluate clipping yields. Clipping yields are measured with a standardized scale. For example, an observed clipping yield of 17.6 grams can be precisely comprehended by any turf researcher. It is obvious that quality rating data are of a different type than clipping yield data.

Classical statistical texts define the type of data resulting from quality ratings as *ordinal* (Freund and Wilson, 1993). Freund and Wilson define ordinal data as, "... a ranking or ordering of a set of observed values. Usually these ranks are assigned integer values starting with '1' for the lowest value, although other representations may be used." In contrast, clipping yield data is *continuous*, meaning that it can take on an infinite number of values within an interval (Freund and Wilson, 1993). Of course, an infinite number of values is limited by the precision of the measuring device.

Analysis of variance is a popular statistical tool because of the relatively large amount of information obtained from the data compared to other statistical analyses. Global hypothesis testing, treatment mean estimation, and treatment mean separation tests can all be accomplished using ANOVA techniques. In contrast, traditional statistical tests appropriate for ordinal data (Kruskal-Wallis test, Friedman test, or Spearman correlation) only test the global hypothesis of treatment equality. The relative weakness of these tests, as well as the better

comprehension of ANOVA calculations by most turf researchers may account for the frequent use of ANOVA for rating data.

Analysis of variance is only valid on continuous data, and only if the data: 1) result from a linear combination of the treatment effects and random error, 2) error values are random and from a Gaussian distribution with mean = 0 and variance = σ^2, and 3) data values are from independent and random samples (Freund and Wilson, 1993). In addition to violating the continuous data stipulation, rating data often violate the second assumption of ANOVA. Since visual quality ratings usually lead to few unique outcomes (typical rating data may have a minimum value of "5" and maximum value of "8"), the error values do not approximate a Gaussian distribution well. Furthermore, the analysis used to analyze rating data should accommodate whatever rating scale is used by the researcher. It would be impossible to use ANOVA if an "A" to "I" scale was used to rate quality. Despite these statistical flaws, ANOVA has been used to analyze turf rating data for decades.

McCullagh and Nelder (1980) described POMs capable of predicting ordinal responses from independent variables. These models yield nearly the same amount of treatment information as ANOVA. However, calculations of treatment effects and standard errors are complex, and typically require programming of statistical software.

Recently, Schabenberger et al. (2000) authored SAS® macros that produce global hypothesis tests, treatment comparisons, and contrasts that resemble ANOVA output. The complex SAS environment and macro

programming language may deter many turf researchers from using the macro. The development of a simplified user-interface for this SAS macro may result in more turf researchers using it to analyze rating data.

The objective of the following work was to develop a Rating Data Analysis File Package (RDAFP) that (i) analyzes ordinal rating data in a statistically valid manner using the POM, (ii) outputs nearly the same amount of information on treatment effects as ANOVA, and (iii) has an intuitively simple user-interface, from data entry to the production of output.

STATISTICAL METHODS

Ordinal data are traditionally analyzed by non-parametric methods that only test global hypotheses of treatment equality. Logistic regression models, first used in the 1940's to analyze bioassay data (McCullagh and Nelder, 1989) , estimate the probability of a response based on predictor variables. Because the model estimates probabilities rather than mean rating values, it is applicable regardless of the rating scale used by the researcher. Logistic regression models have gained popularity in the last 20 years, paralleling the refinement of mathematical techniques used in their calculation. Kleinbaum (1994) presents an overview of logistic regression models with applied examples in a format palatable to the non-statistician.

McCullagh (1980) described the POM, specialized for the analysis of ordinal data. The POM involves parallel logistic regressions that estimate the probabilities of an observation to fall into the ordered response categories, based

on the values of independent predictor variables. The RDAFP discussed later uses the POM to analyze rating data.

The POM estimates a value, ranging from $-\infty$ to ∞, for each parameter in the model. For rating data, the model parameters consist of the independent treatment variables, their interactions, and all observed rating categories. For example, a completely randomized design with treatment factors A (with 2 levels) and B (with 3 levels), and observed rating values of "5", "6", "7", and "8" would have values estimated for the following parameters: α_1, α_2, β_1, β_2, β_3, $\alpha_1\beta_1$, $\alpha_1\beta_2$, $\alpha_1\beta_3$, $\alpha_2\beta_1$, $\alpha_2\beta_2$, $\alpha_2\beta_3$, π_5, π_6, π_7, and π_8. Most software packages will estimate treatment and category effects as differences from a reference level. Therefore, the parameter estimates for the first treatment levels (α_1, β_1, and $\alpha_1\beta_1$) and the highest ranking rating category level (π_8) will be zero.

Parameter estimates are calculated by maximum likelihood techniques (Shenton and Bowman, 1977). Maximum likelihood calculations result in parameter estimates that best predict the observed values in the data set. Calculations involve iterative, re-weighted, differentiation of likelihood functions and become very complex with few model parameters. However, with the development of powerful PC processors, maximum likelihood calculations have become commonplace.

A latent variable, *Z*, represents a linear combination of the parameter estimates for the treatment and rating category combination of interest. For example, if a researcher was interested in the probability of a turf plot receiving level 1 of factor A and level 3 of factor B being rated *at best* a 7, then $Z = \alpha_1 + \beta_3$

+ $\alpha_1\beta_3 + \pi_7$. Since the parameter estimates range from $-\infty$ to ∞, *Z* must also share this range. However, probabilities are constrained between zero and one.

A logit-link function is used to transform *Z* values into probability predictions by the following equation: $1 / (1 + e^{-Z})$, where *e* is Euler's number (2.178). This function has a range of zero to one, regardless of the value of *Z*. Plugging the sum of the treatment parameter estimates of interest into the logit-link function will result in a cumulative probability, the probability to be rated, at best, in a given category. Individual category probabilities are calculated by differencing cumulative probabilities for two adjacent rating categories. For example, the probability of the treatment described above to be rated *exactly* a "7" is calculated by:

$$\{ [1 / (1 + e^{-(\alpha 1 + \beta 3 + \alpha 1 \beta 3 + \pi 7)})] - [1 / (1 + e^{-(\alpha 1 + \beta 3 + \alpha 1 \beta 3 + \pi 6)})] \}$$

A variance-covariance matrix for the parameter estimates can be produced by maximum likelihood calculations in computer software programs. From this matrix and the parameter estimates, statistical tests can be performed on the equality between any combination of treatment levels. These tests give information similar to the mean comparison tests and pre-planned contrasts often used with ANOVA.

RATING DATA ANALYSIS FILE PACKAGE

Excel version 95 or later (Microsoft, 1995) and SAS release 6.12 (SAS Institute, 1996) must be installed on the user's PC to use the file package described in this paper. The files needed to analyze, output, and graph rating

data are bundled in an installation program called "RDAFP.exe". This program can be downloaded from "Rating Data Analysis File Package" web page at the URL, http://www.msu.edu/~karcherd/ratings (Karcher, 2000).

Running "RDAFP.exe" will create a directory called "Ordinal Analysis" on the C drive of the user's PC. The files, "PropOddsModel.sas" (Schabenberger et al., 2000), "turfrate.sas" (Appendix A), "Rating Charts.xlt", and "readme.txt", are all placed in the "Ordinal Analysis" directory. Additionally, a shortcut to "Rating Charts.xlt" is placed on the PC Desktop during installation.

"Rating Charts.xlt" is an MS Excel template that produces probability distribution charts from data output by SAS. The "readme.txt" file is a text file containing detailed instructions for RDAFP and covers installation through interpretation of results. The "turfrate.sas" file (Appendix A) was created by the author to run the Schabenberger et al. (2000) macro from easy to use web based forms and the downloaded MS Excel template.

Once the installation program is completed, a data file needs to be created. Although data files can be created in either MS Excel or SAS, using MS Excel simplifies the analysis process. If the data file is created in MS Excel, variable names must be in the first row of the spreadsheet and the data values must begin in the second row (Figure 1). There cannot be any blank rows within the data when using MS Excel. Additionally, an MS Excel data file must be saved in an Excel 95 file format (Figure 1). Finally, the MS Excel file must be closed during analysis since the data cannot be imported into SAS if the file is left open.

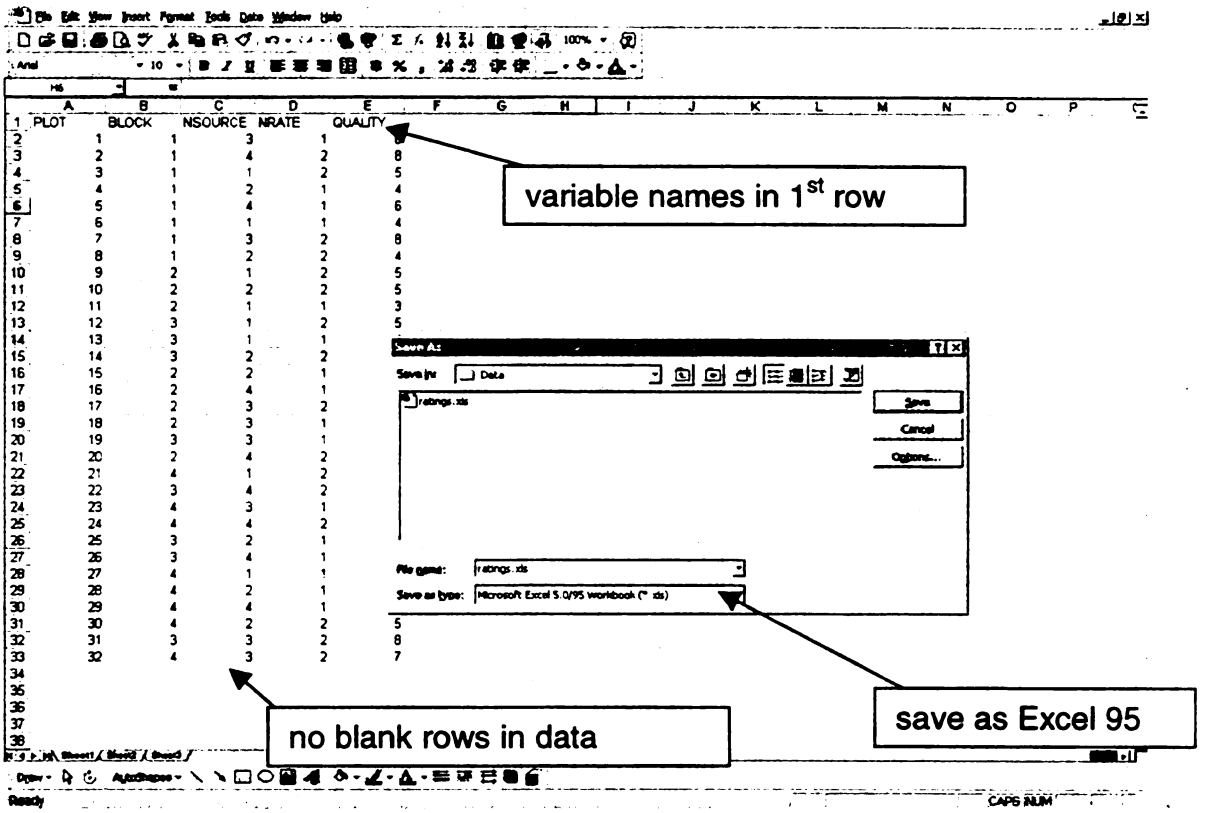

Figure 1. Rating data file created in MS Excel.

The SAS code needed to analyze and generate probability charts from the rating data can be generated by the RDAFP web page (Karcher, 2000). This is a form based web page where the user answers a few questions regarding the experimental design and treatment structure of the study that generated the rating data. After answering all questions, clicking the "Generate SAS Code" button will generate code in a separate window titled, "SAS Code for Ordinal Data Analysis" that is ready for pasting into the Program Editor window of SAS.

Copying the text from the web window into SAS is relatively simple: 1) activate the output window by clicking it with the mouse pointer, 2) drag over the code with the mouse to select, 3) press Ctrl+C to copy all of the code, 4) activate

the Program Editor window of SAS by clicking it with the mouse pointer, and 5) press Ctrl+V to paste the code into the Program Editor window of SAS.

If probability distribution charts created in MS Excel are desired, "Shortcut to Rating Charts" should be opened from the PC's Desktop prior to executing the SAS code. The SAS code is executed by activating the Program Editor window in SAS and pressing the F8 key.

EXAMPLE USAGE

Experimental Design

The data used in this example are from a quality rating taken on a nitrogen fertilization study. The objective of the study was to compare the effects of nitrogen application method and rate on the quality of a 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.) putting green. The application methods included nitrogen injection using high pressure water injection cultivation (WIC) (Murphy and Rieke, 1994) and traditional surface applications. The study was 4 x 2 factorial with four replications in a randomized complete block design. The first factor was application method, having four levels: 1) surface sprayed N, no WIC, 2) surface sprayed N, followed by WIC, 3) N applied via WIC to a 7.5 cm depth, and 4) N applied via WIC to a 15 cm depth. The second factor was N rate, having two levels: 1) 2.4 and 2) 4.8 g N m^{-2} $application^{-1}$.

Generating SAS Code

Figure 2 shows the RDAFP web page for downloading the file package and generating SAS code for analysis. Step #1 on the page instructs the user to

click the installation icon with the mouse pointer and download the file package. After downloading and running the installation program, the form on the web page can be used to generate SAS code.

Steps #2 through #6 on the form **must** be completed in order to generate the proper SAS code. Step #2 defines the path on the researcher's PC to the MS Excel file containing the rating data, which in this case was "C:\DATA FILES\RATINGS.xls" (Figure 1). Step #3 defines the treatment factors as they are named in the MS Excel data file. The treatment factors in the data file created for this study were named NSOURCE and NRATE (Figure 1). Step #4 defines the blocking factor, if present, as it is named in the MS Excel data file, which was BLOCK in this case (Figure 1). Step #5 defines the response variable, as named in the MS Excel data file. The response variable was named QUALITY in this situation (Figure 1).

Step #6 gives the user an opportunity to label the observed data values from the rating. Possible labels for a typical quality rating scale are (1=dead, 2=mostly dead, 3=severely flawed, 4=flawed, 5=slightly flawed, 6=acceptable, 7=good, 8=excellent, 9=ideal). For this study, "3", "4", "5", "6", "7", and "8" were the only observed quality rating values. They were labeled here as "SEVFLAWED", "FLAWED", "SLIFLAWED", "ACCEPTABLE", "GOOD", AND "EXCELLENT". Labels should not contain any spaces or special characters and be relatively short in order to accommodate output. Labels provide the researcher with an opportunity to describe the basis for rating the turf and are typically more informative than arbitrary numbers.

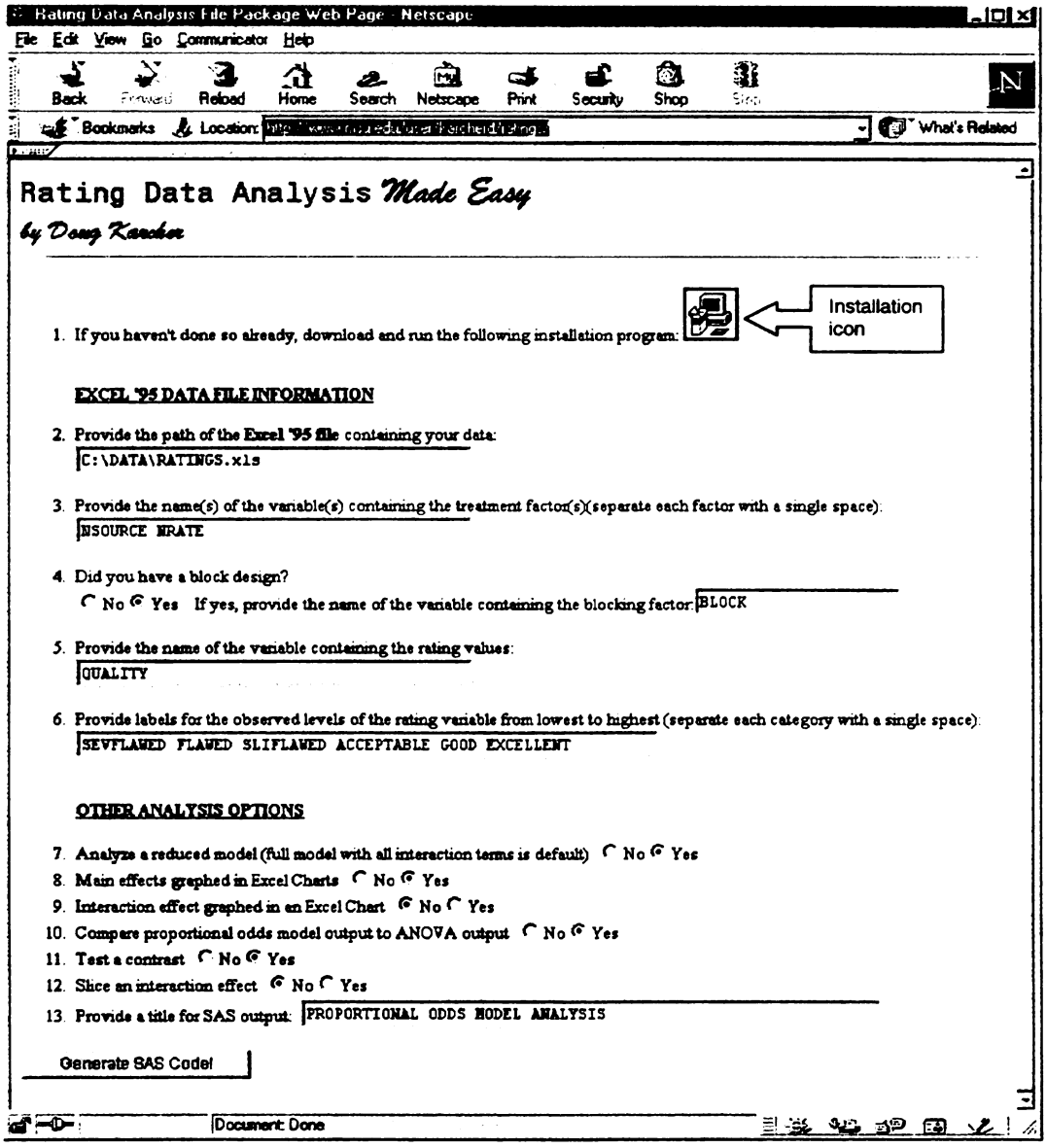

Figure 2. SAS code generating form, completed with information from nitrogen application method study. This form is from the "Rating Data Analysis" web page at "http://www.msu.edu/~karcherd/ratings".

Steps #7 through #13 are extra analysis options. Step #7 gives an option to the user to define a reduced model. By default, a full model is used that contains all treatment factors and all possible interactions. When the number of treatment factors and observed rating categories is large relative to the number

of observations in the data set, a full model might result in errors during maximum likelihood calculations. The following message (Figure 3) appears in the Log window of SAS when maximum likelihood errors occur:

```
WARNING: There is possibly a quasicomplete separation in the sample points.  The
         maximum likelihood estimate may not exist.
WARNING: The LOGISTIC procedure continues in spite of the above warning. Results
         shown are based on the last maximum likelihood iteration. Validity of the
                model fit is questionable.
```

Figure 3. Warning message that appears in the Log window of SAS when errors occur during maximum likelihood calculation.

Checking "Yes" in Step #7 will cause a text prompt to appear upon clicking the "Generate SAS Code" button (Figure 4). The user may define a reduced model in this text prompt if maximum likelihood errors occur when analyzing the full model.

The example data set had 32 observations and 24 (4 BLOCK, 4 NSOURCE, 2 NRATE, 8 NSOURCE x NRATE, and 6 QUALITY) parameter estimates in the full model. The full model resulted in maximum likelihood errors, causing the error message in Figure 3 to be printed in the Log window of SAS. Therefore, a reduced model was used by dropping the NSOURCE X NRATE interaction term from the full model (Figure 4). No error messages resulted from analyzing the reduced model.

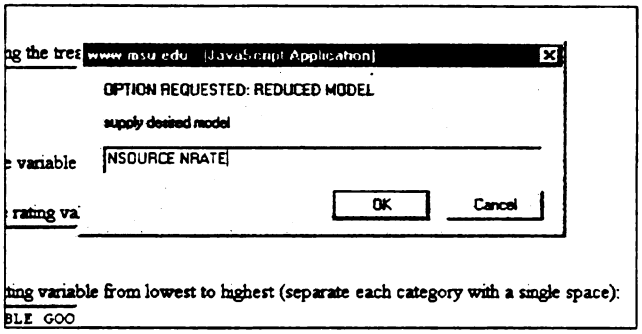

Figure 4. Textbox used to supply a reduced model. In this case, the NSOURCE x NRATE interaction term has been dropped from the full model.

Step #8 defines if probability distributions for treatment main effects are to be graphed using the "Rating Charts" template in MS Excel. The default is "Yes" and the template must be opened prior to executing code in SAS if "Yes" is checked. Step #9 defines if probability distributions for an interaction term are to be graphed in the "Rating Charts" template. The default for this option is "No". Interaction distributions can only be graphed after main effects analysis has been executed in SAS. Following main effects analysis, if "Yes" is checked in Step #9, a text prompt will appear for the user to define the interaction term for which probability distributions are to be graphed in MS Excel.

Step #10 allows the user to compare results produced by POM analysis with results obtained from ANOVA. The default for Step #10 is "No". Checking Step #10 will produce side-by-side tests of fixed effects and mean separation tests from the POM and ANOVA.

Steps #11 and #12 give the user an opportunity to test treatment contrasts and slice interaction terms by user-defined effects. These are the only options that require SAS programming knowledge by the user. Checking these steps will

produce text prompts where the user must provide the proper "contrast" or "slice" statement, using syntax identical to that of SAS's glm procedure.

Clicking the "Generate SAS Code" button with the mouse pointer will generate a new window that contains SAS code (Figure 5). The code shown in Figure 5 is for the reduced model. This code must be pasted into the SAS Program Editor window before POM analysis can take place. This is accomplished by: 1) selecting the code below the horizontal rule with the mouse, 2) pressing Ctrl+C to copy the code, 3) clicking inside the Program Editor window of SAS with the mouse pointer, and 4) pressing Ctrl+V to paste the code. After pasting the code into the SAS Program Editor window, pressing the F8 key will execute the "turfrate.sas" macro that uses the POM and all other files in the RDAFP to generate output.

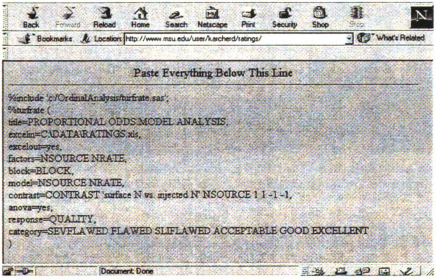

Figure 5. Output generated from the "Rating Data Analysis" web page form. This code can simply be pasted into SAS v. 6.12 for expedient analysis using the POM.

Summary of Output

Executing the code in Figure 5 produced the output shown in Figure 6 through Figure 10. Figure 6 shows the comparison of fixed effects tests between the POM and ANOVA. The output shows the degrees of freedom and computed chi-square and F values used to determine the respective *P*-values for each statistical test. In this example, nitrogen application method and nitrogen rate significantly affected turf quality. The two statistical analyses produced remarkably similar *P*-values for NSOURCE ($P = 0.0001$) and NRATE ($P = 0.0003$) effects.

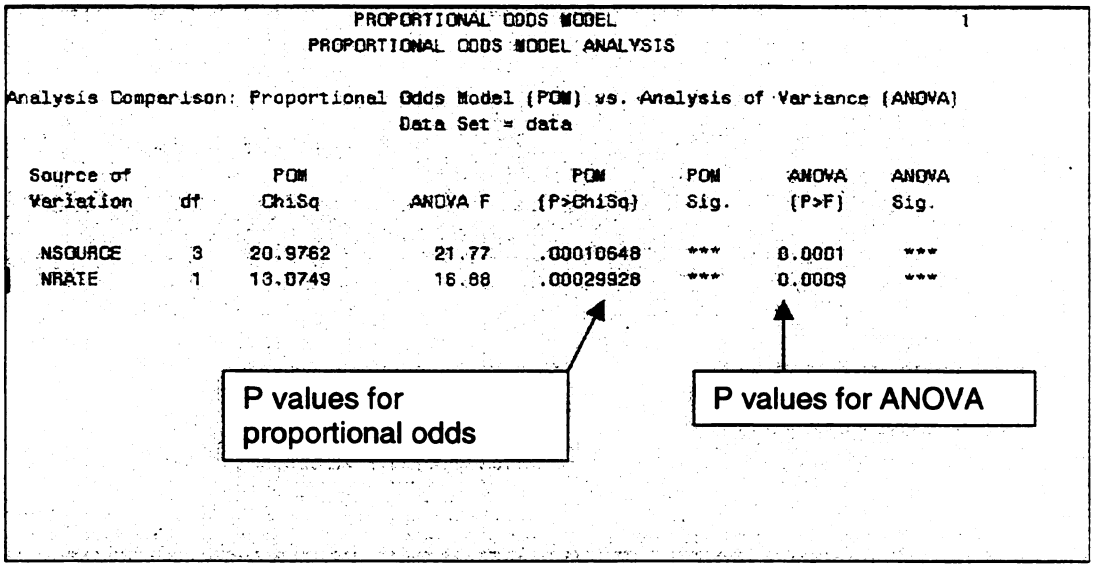

Figure 6. Tests of fixed effects produced by RDAFP. Both application method (NSOURCE) and nitrogen rate (NRATE) effects were highly significant when analyzed by the POM and ANOVA.

Predicted probabilities for each treatment level to be rated into each quality category and a comparison of mean separation tests between the POM and ANOVA for NSOURCE are shown in Figure 7. Treatment #3, which corresponded to nitrogen injected to a 7.5 cm depth, had the highest probability

(41%) to be rated as excellent. Conversely, Treatment #2, which corresponded to surface applications of nitrogen plus WIC, had the highest probability (6%) to be rated as severely flawed. From the treatment separation tests following analysis by the POM , treatments #3 and #4 (followed by A's) were significantly different from treatments #1 and #2 (followed by B's). Examination of the category probabilities for the treatment levels reveals that treatments #3 and #4 produced significantly higher quality than treatments #1 and #2. Similar results were calculated by a post ANOVA LSD test.

PROPORTIONAL ODDS MODEL
PROPORTIONAL ODDS MODEL ANALYSIS

Predicted Category Probabilities (P = RATING CATEGORY)
for NSOURCE effects

OBS	NSOURCE	SEVFLAWED	FLAWED	SLIFLAWED	ACCEPTABLE	GOOD
1	3	0.000024	0.00129	0.02001	0.04531	0.52714
2	4	0.000125	0.00659	0.08417	0.16792	0.61393
3	1	0.026858	0.66843	0.36577	0.02706	0.01177
4	2	0.057575	0.71054	0.21401	0.01235	0.00525

OBS	EXCELLENT	POM LS Mean	ANOVA LS Mean	POM Mean Groups	ANOVA Mean Groups
1	0.40623	-4.67000	7.25000000	A	A
2	0.11727	-3.03108	6.50000000	A	A
3	0.00061	2.34905	4.75000000	B	B
4	0.00027	3.16295	4.25000000	B	B

Figure 7. Probability of each NSOURCE treatment to be rated into each quality rating category, as well as mean separation tests from the POM and ANOVA.

Category probabilities are easier to compare among treatments using a probability distribution chart. The probability distribution chart shown in Figure 8 was created automatically in the "Rating Charts.xlt" MS Excel template.

Treatments with larger white bars were poorer in quality than treatments with larger dark gray and black bars. Figure 8 demonstrates that analysis by the POM yields a greater amount of information regarding treatment effects than the arbitrary mean rating values produced by ANOVA.

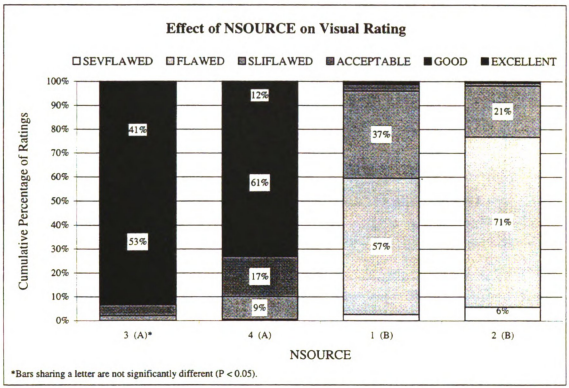

Figure 8. Probability distribution chart created automatically by RDAFP. Cumulative probabilities are shown on the y-axis, whereas individual category probabilities (greater than 5%) are labeled within each bar section.

Treatments #1 and #2 corresponded to turf receiving surface applications of nitrogen, whereas treatments #3 and #4 correspond to turf injected with nitrogen. A contrast testing equality between the treatment groups would test the effects of injecting nitrogen vs. surface applications of nitrogen on turf quality. A hypothesis test comparing treatments #1 and #2 vs. #3 and #4 was accomplished by checking "Yes" in Step #7 on the RDAFP web page and

inputting the appropriate contrast statement (Figure 9). The contrast statement in the textbox has identical syntax to the contrast statement used in SAS's proc glm (minus a semi-colon).

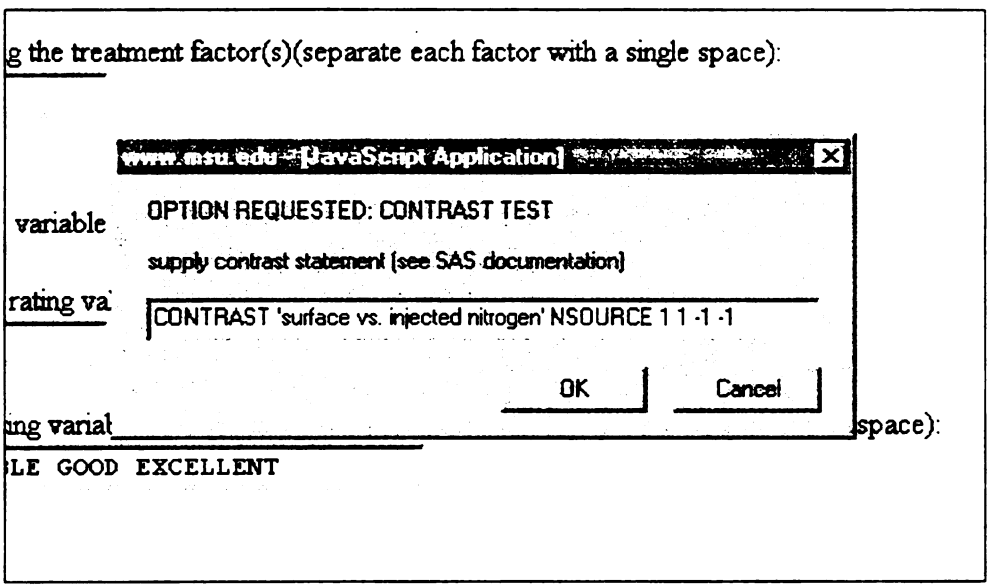

Figure 9. Textbox generated from checking the contrast option on the RDAFP web page. Textbox input has identical syntax to the contrast statement used in proc glm of SAS.

Figure 10 shows the output resulting from the above contrast statement. Whether nitrogen was applied on the surface or injected significantly affected turf quality ($P < 0.001$). Caution must be exercised when interpreting contrast results. A *positive* chi-square value means that treatments corresponding to *negative* coefficients in the contrast statement had higher ratings. This results because probabilities calculated from the logit-link function increase as Z values decrease. In this example, the negative coefficients correspond to treatments #3 and #4, which correspond to injected nitrogen. Since the chi-square value was positive (20.59), these treatments had significantly higher ratings.

PROPORTIONAL ODDS MODEL ANALYSIS

Test of Contrasts
Data Set = data

OBS	Source of Variation	Chi-Square Value	Degrees of Freedom	P > Chi-Square
1	SURFACE N VS. INJECTED N	20.5878	1	.0000056959

Figure 10. Contrast test from the RDAFP. Here, treatments receiving surface nitrogen were significantly different ($P < 0.001$) than turf injected with nitrogen.

CONCLUSIONS

Analysis of turfgrass quality data with the RDAFP was a simple process. The data file was created in MS Excel and the SAS code needed to run the RDAFP was generated from an intuitive web based form. After generating SAS code from the web and pasting it into the SAS Program Editor window, pressing the F8 key executed the "turfrate.sas" macro. This macro accessed the other files in the RDAFP to import the data from an MS Excel data file, analyze the data using the POM, perform treatment separation tests, and output probability distributions to the "Rating Charts" template in MS Excel. This occurred without the need to program any SAS code. The only SAS knowledge needed was how to paste code into the Program Editor window, and then press the F8 key to execute the pasted code.

The RDAFP has potential to be a valid, user-friendly data analysis tool for researchers in other agricultural sciences when data is acquired from subjective, qualitative rankings. Examples include, but are not restricted to, disease ratings

on potatoes, insect damage ratings on tree leaves, and color brilliance ratings on flowers. Several applications of the RDAFP also exist in the non-agricultural sciences.

During the initial phase of the RDAFP creation, version 6.12 was the latest release of SAS. Since then, versions 7.0 and 8.0 have been released, each containing procedures (tlogisitic and genmod) capable of proportional odds model analysis. An updated version of the RDAFP is under development that will work with these procedures in the later versions of SAS.

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CHAPTER TWO

INVESTIGATING CAUSES AND CURES FOR LOCALIZED DRY SPOTS ON CREEPING BENTGRASS PUTTING GREENS

ABSTRACT

Localized dry spots (LDS) on creeping bentgrass (*Agrostis palustris* Huds.) putting greens are characterized by irregular patches of wilting turf that resist wetting by irrigation or rainfall. Turf managers around the world have attempted to control LDS, rarely with long term success. Previous research has demonstrated the causal agent of LDS to be of fungal origin, possibly a basidiomycete fairy-ring causing pathogen. Water injection cultivation (WIC), a non-ionic surfactant blend soil wetting agent (SWA), and flutolanil fungicide have all shown limited control of LDS. Combinations of these treatments may provide enhanced control of LDS. Additionally, if the causal agent of LDS is identified, better strategies to control this problem may be developed. The objectives of this research were (i) to evaluate the effects and interactions of WIC, SWA, and flutolanil on the control of LDS on a sand based creeping bentgrass putting green, and (ii) to more thoroughly define the spatial distribution of the most affected area by LDS and (iii) to further evaluate the relationship of fungal biomass and LDS activity. A preventative LDS study was conducted in 1998 and 1999 on a creeping bentgrass putting green with a coarse-textured root zone. Treatments were arranged in a 2 x 2 x 2 factorial, with the factors consisting of: WIC (tri-weekly or none), SWA (1.3 ml m^{-2} tri-weekly or none), and flutolanil (0.9 g a.i. m^{-2} tri-weekly or none). Treatment effects on turf quality, wilt, soil moisture,

and water drop penetration times varied between years. Wilting was reduced with WIC in 1999, while flutolanil improved general turf quality during summer stress periods in 1998. Flutolanil and SWA improved turf quality when applied as curative treatments in 1998. The depth and surface distribution of water repellant characteristics in randomly selected LDS patches were evaluated by direct visualization using stereophotmicrography to locate where LDS symptoms were most prominent. These studies indicated that water drop penetration times were greatest at the inside and edge of dry spots, just beneath the thatch layer. Buried slides examined by quantitative brightfield microscopy and computer assisted image analysis revealed a significantly greater amount of growing hyphae at the edges of the dry spots, consistent with the proposal that the cause of LDS may be of fungal origin.

INTRODUCTION

Localized dry spots (LDS) routinely confound turfgrass management because of unpredictable occurrence and difficulty of control. Localized dry spots are defined as dry spots of turf and soil surrounded by more moist turf conditions, which resist rewetting by normal irrigation or rainfall (Beard, 1982). Most turf areas afflicted with LDS share common characteristics (Henry and Paul, 1978; Wilkinson and Miller, 1978) including: 1) coarse-textured soils, 2) only the surface centimeters of the soil are hydrophobic, and 3) water repellent coatings on soil particles. Since the United States Golf Association introduced putting green specifications (USGA, 1960), most new greens have been constructed with sand based root zones, increasing the incidence of LDS (Karnok et al., 1993). Continued use of sand topdressing as a putting green management practice also contributes to the LDS problem.

Localized dry spot is not confined to any single geographic region. In a survey by York (1993) 86% of the greenskeepers in the United Kingdom encountered LDS on their golf courses and 61% had LDS problems for at least five years. In addition to reducing available water, LDS may contribute to other poor soil physical properties. Dry putting green soils in Michigan became hard and reduced the penetration of cultivation units (Rieke, 1974). Creeping bentgrass putting greens (*Agrostis palustris* Huds.) with LDS in Ohio had 20% lower infiltration rates than did healthy areas (Wilkinson and Miller, 1978).

Once LDS occurs on turf, complete eradication is difficult in a short period of time. Only 3% of those experiencing LDS in the York (1993) survey achieved

complete control with wetting agent applications. Hydrophobic soils in northern Michigan were improved only temporarily with application of high rates of a wetting agent (Rieke and Beard, 1975). Management practices that completely prevent LDS have not been firmly established. A survey of 10 Georgia golf course superintendents experiencing LDS on creeping bentgrass putting greens showed no correlation between standard management practices and LDS severity (Tucker et al., 1990). Additionally, the survey showed no relationship between LDS severity and chemical soil tests.

A specific causal agent of LDS has not been discovered, but the literature suggests it may be of fungal origin (Bond and Harris, 1964). Organic coatings on sand particles taken from LDS areas in Ohio had the presence of fungal mycelia. The coatings were determined to be primarily fulvic acid compounds (Miller and Wilkinson, 1977). Some basidiomycete fungi that cause fairy rings are known to induce hydrophobic conditions that stress turf within the rings. (Smith et al., 1988). Soil samples taken from within several fairy rings caused by *Marasmius oreades* on golf course fairways in Norway had significantly low moisture content (Smith, 1975). Similarly, inner zones of *M. oreades* fairy rings on Kentucky bluegrass (*Poa pratensis* L.) turf in Saskatoon, Canada had significantly low soil moisture contents (Smith and Rupps, 1978).

We hypothesize that the presence of fungi may contribute to LDS formation by depositing organic coatings on sand particles. Flutolanil (Prostar® fungicide manufactured by AgrEvo, Montvale, NJ) controls many fairy ring causing fungi (Elliot and Hickman, 1998) and may be effective in preventing LDS.

Two other management practices that have reduced LDS severity are water injection cultivation (WIC) with a Toro HydroJect 3000® (Karcher, 1997) and the application of an effective soil wetting agent (SWA) (Gelernter and Stowell, 1998). Additionally, if we can identify the properties of the causal agent of LDS and locate its growing front, better recommendations for effective control are possible. The objectives of this research were (i) to evaluate the effects and interactions of flutolanil, WIC, and SWA wetting agent applications on the control of LDS on a sand based creeping bentgrass putting green, (ii) locate the zone of maximum soil hydrophobicity in characteristic LDS, and (iii) further examine the role of soil fungi in development of LDS.

MATERIALS AND METHODS

Experimental Area

Three separate experiments were designed to address research objectives: A preventative study to compare the effects of WIC, SWA, and flutolanil on the prevention of LDS, a curative study to compare the above effects on curing turf that was severely afflicted with LDS, and an isolation study to determine the precise location of activity and identify the characteristics of the LDS causal agent.

Plots were established for the preventative study on a 'Penncross' creeping bentgrass putting green with a modified sand root zone (96% sand, 3% silt, and 1% sand) in early April 1998. Plots were mowed at 4.0 mm five days per week throughout the study. Nitrogen was applied at 30 g m^{-2} $year^{-1}$ and irrigation

was applied only at severe drought to provide reasonable growth, but to encourage the onset of LDS. Other nutrients were applied according to soil test recommendations. In April 1999 the experiment was repeated on a 'Penncross' creeping bentgrass putting green with a modified loamy sand soil (modified fine-loamy, mixed, mesic, Typic Hapludalf). The experiment was repeated in this area because it had frequent occurrences of LDS in 1998.

For the isolation experiment, three individual patches showing pronounced LDS symptoms adjacent to the preventative study were selected in 1998. Plots were mowed five times per week at a 5.0 mm height and fertilized with 20 g N m^{-2} $year^{-1}$. Formation of LDS occurred despite this area being irrigated daily at rates approximating evapotranspiration water loss.

All experimental areas were topdressed lightly with 100% sand approximately every six weeks. The topdressing sand layer depth remained less than 1.0 cm throughout the experiments. Each fall, all plots were core cultivated at a 7.5 by 5.0 cm spacing to an approximate depth of 8 cm using 1.0 cm diameter hollow tines. Cores were brushed, returning the soil to the plot area, and the remaining thatch was removed. Fungicides were applied on a curative basis.

Treatment Design

PREVENTATIVE STUDY

The preventative study had three treatment factors: WIC, SWA, and flutolanil. Each factor had two levels, applied or not applied, yielding eight treatment combinations (2 x 2 x 2 factorial). In both years, treatments were

applied on 21-day intervals beginning in late April and ending in mid October. Plots were drenched with 2.5 cm of water several hours prior to all treatments, in accordance with the flutolanil label. Water injection cultivation treatments were made first with a Toro HydroJect 3000® set at the closest hole spacing (7.5 by 2.5 cm). Flutolanil and SWA were applied next at rates of 0.9 g a.i. m^{-2} (WP) and 1.3 ml m^{-2}, respectively, with a CO_2 powered plot sprayer. Following treatments, plots were irrigated with 1 cm of water. Treatments were replicated 3 times in a randomized complete block design.

CURATIVE STUDY

In August 1998, a turf area adjacent to the preventative LDS study, but with separate irrigation control, had severe wilt symptoms with random dry patches characteristic of LDS. A curative study was established with treatments identical to the preventative study on this area. Treatments were applied tri-weekly from August to October in 1998 for this study.

ISOLATION STUDY

The treatment factors in the isolation study consisted of surface location and depth, relative to the dry spots. Surface location was classified as the center, edge, or outside of the dry spot. The edge of the dry spot was identified as the border between turf with visual wilting symptoms from LDS and turf with no visible LDS symptoms. Sampling of the outside of the dry patch was made 15 cm from the outside perimeter. Depth was classified in one cm increments from just beneath the thatch layer to a 5 cm depth. Location and depth factors were

arranged in a randomized complete block design (blocked by dry spots) with three replications.

Treatment Evaluations

PREVENTATIVE AND CURATIVE STUDIES

Treatments in the preventative and curative studies were evaluated for turf quality and soil moisture content. Additionally, wilt and soil wettability were evaluated in the preventative study. Quality and wilt were evaluated weekly, and when symptoms were visible, respectively. The rating scale for quality was from 1 to 9 (1=dead, 2=mostly dead, 3=severely flawed, 4=flawed, 5=slightly flawed, 6=acceptable, 7=good, 8=excellent, 9=ideal), and for wilt was from 1 to 5 (1=no wilt, 2=slight wilt, 3=moderate wilt, 4=significant wilt, 5=severe wilt). Wilt ratings were typically done in the late afternoon when wilt symptoms were easiest to detect. Volumetric soil moisture to a 15 cm depth was measured weekly on three randomly selected locations per plot with a Trime®-FM portable time domain reflectometry unit (manufactured by IMKO, Ettlingen, Germany). Soil wettability was evaluated monthly by water drop penetration times. Three randomly selected soil cores per plot were pulled and sectioned by depth into five one cm increments. Within 48 hours of sampling, cores were sliced in half vertically with a razor blade. A 100 µl water droplet was then placed on the flat surface of each core section and the time elapsed until the droplet had completely penetrated the soil surface was recorded.

ISOLATION STUDY

Treatment evaluations for the isolation study were designed to precisely locate where the LDS causal agent affected soil wettability. Water drop penetration times were measured on samples from the inside, edge, and outside of three separate dry patches using the methods described above. Rossi-Cholodny buried slides (Johnson and Curl, 1972) were inserted just beneath the thatch layer at the inside, edge, and outside of three individual dry patches and incubated for 21 days. The use of buried slides allowed for precise spatial analysis of alive, active fungi capable of colonizing the slide. Following incubation, slides were carefully extracted and stained with lactophenol-aniline blue-acid fuchsin. An AusJenaval brightfield microscope (25x objective) and Panasonic WV185 Neuvicon camera were used to output fungal images to a video monitor so that hyphae could be traced onto transparency overlays. All of the hyphae occurring on a one-cm^2 portion of the slide that was adjacent to the soil immediately below the thatch layer were recorded. The hyphae were digitized and analyzed by the cumulative hyphal length feature of the Image Tool option in the CMEIAS software package (Liu et al., 2000).

Statistical Analysis

Quality and wilt rating were analyzed using the proportional odds model that is incorporated into the Rating Data Analysis File Package (Karcher, 2000). Treatment separation was done with pairwise chi-square tests of the treatment least squared estimates. Probability distributions were constructed to represent the odds of a treatment level to be rated in a particular category. These

distributions were constructed by inserting the appropriate combination of least square estimates into the logit-link function.

Soil moisture, soil wettability, and hyphal length data were analyzed with ANOVA. If treatment effects were significant, means were separated using LSD at the 0.05 probability level. Where repeated measures were made on the same experimental units, time was analyzed as a sub-plot factor of the experiment. The best fitting covariance model among compound symmetry, first order auto-regressive, and spatial exponential was used to fit correlations among time points. The best fitting covariance model was determined by the highest Akaike's Information Criteron value (Littell et al., 1996). A log transform was used to normalize the water drop penetration data, which originally were highly right skewed because of several values near zero.

RESULTS AND DISCUSSION

Preventative Study

ANOVA results and the main effects of WIC, SWA, and flutolanil on turf quality, wilt, and soil moisture are summarized in Table 1. The main effects of WIC, SWA, and flutolanil on turf quality were not significant in either year. However, there was a significant flutolanil x time interaction in 1998 and a significant SWA x flutolanil interaction in 1999.

The flutolanil x time interaction resulted from a significant flutolanil effect on 5 out of the 20 rating dates in 1998 (Figure 11). On 7 May flutolanil slightly decreased the probability to be rated high in quality, but on 17 July, 11 August,

18 August, and 18 September flutolanil significantly increased the probability to be rated high in quality. The dates when flutolanil significantly increased quality were dates when the plots, averaged over all treatments, were rated significantly low in quality (Figure 12). In 1999, the probability of plots to be rated high in quality decreased when flutolanil and SWA were both applied compared to the application of either alone (Figure 13).

These results suggest that flutolanil may be effective in increasing turf quality when environmental conditions are particularly stressful. On 11 August and 18 September, 1998, the experimental area was drought stressed, resulting in low overall quality. However, flutolanil significantly improved turf quality on these rating dates. These results are to be expected if drought symptoms in turf are partially caused by a fungal species susceptible to flutolanil. Adams (1989) found that flutolanil had a high degree of fungicidal activity against *Marasmius oreades*, a fungus known to cause fairy ring often expressing hydrophobic soil conditions (Bayliss, 1911; Smith, 1975; Smith and Rupps, 1978).

The flutolanil x SWA interaction suggests that these products may be slightly phytotoxic when applied together at the highest labeled rate of each. Flutolanil has been reported to cause phytotoxicity when mixed with other products (Gelernter and Stowell, 1997).

Table 1. Effects of WIC, SWA, and flutolanil on quality, wilt, and soil moisture of a creeping bentgrass putting green.

Effect	1998 df	Quality Parameter	df	Wilt Parameter	df	Soil Moisture	1999 df	Quality Parameter	df	Wilt Parameter	df	Soil Moisture
		likelihood estimate		likelihood estimate		$m^3\ m^{-3}$		likelihood estimate		likelihood estimate		$m^3\ m^{-3}$
WIC												
None		-1.22 A†		5.22 A		26.6 A		-1.03 A		-0.95 A		26.6 A
Tri-Weekly		-0.92 A		2.11 A		26.2 A		-0.60 A		0.15 B		27.3 A
SWA												
None		-0.89 A		3.50 A		26.4 A		-0.84 A		-0.28 A		26.5 A
1.3 ml m^{-2}		-1.24 A		3.83 A		26.5 A		-0.79 A		-0.52 A		27.4 A
Flutolanil												
None		-0.80 A		3.76 A		26.5 A		-0.84 A		-0.57 A		26.6 A
0.9 g a.i. m^{-2}		-1.34 A		3.57 A		26.4 A		-0.78 A		-0.23 A		27.3 A
						ANOVA						
Source of variation												
Block	2	***	2	***	2	**	2	***	2	***	2	**
WIC (w)	1	NS	1	NS	1	NS	1	NS	1	*	1	NS
SWA (s)	1	NS	1	NS	1	NS	1	NS	1	NS	1	NS
w x s	1	NS	1	NS	1	NS	1	NS	1	NS	1	NS
Flutolanil (f)	1	NS	1	NS	1	NS	1	NS	1	NS	1	NS
w x f	1	NS	1	NS	1	NS	1	NS	1	NS	1	NS
s x f	1	NS	1	NS	1	NS	1	**	1	NS	1	NS
w x s x f	1	NS	1	NS	1	NS	1	NS	1	NS	1	NS
Time (t)	19	***	1	NS	16	***	13	***	2	***	4	***
w x t	19	NS	1	NS	16	***	13	NS	2	NS	4	NS
s x t	19	NS	1	NS	16	NS	13	NS	2	NS	4	NS
w x s x t	19	NS	1	NS	16	NS	13	NS	2	NS	4	NS
f x t	19	*	1	NS	16	NS	13	NS	2	NS	4	NS
w x f x t	19	NS	1	NS	16	NS	13	NS	2	NS	4	NS
s x f x t	19	NS	1	NS	16	NS	13	NS	2	NS	4	NS
w x s x f x t	19	NS	1	NS	16	NS	13	NS	2	NS	4	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Within effects, means sharing a letter are not significantly different

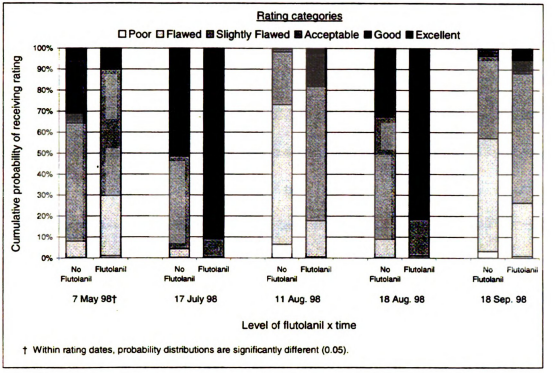

Figure 11. Quality rating probability distributions as affected by flutolanil x time. Preventative Study, 1998.

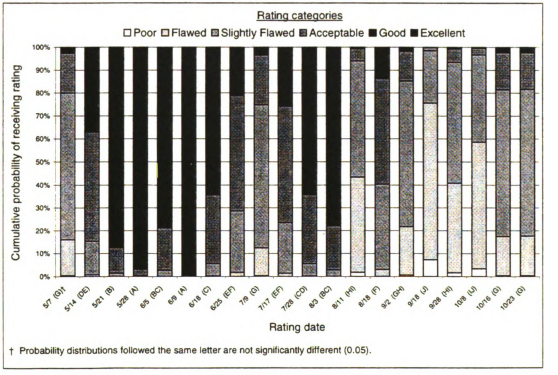

Figure 12. Quality rating probability distributions as affected by time. Preventative Study, 1998.

The experimental area wilted enough for ratings on only two dates in 1998 and three dates in 1999. The lack of LDS formation on the experimental area was probably due to the irrigation practices used to accommodate treatment application. A tri-weekly application of 3.5 cm of water during the study may have inhibited the onset of LDS, since a reported precursor to LDS formation is a thorough drying down of the soil (Paul and Henry, 1973). When the experimental area dried down, it usually did so in a uniform fashion rather than by forming random dry spots characteristic of LDS. The only significant treatment effect on wilt was WIC in 1999 (Figure 14). Averaged over all rating dates in 1999, WIC treated turf had significantly lower probability to be rated high in wilt than untreated turf. This result is consistent with results from previous WIC experiments (Karcher, 1997). The 20 MPa water blasts from the HydroJect® unit may partially remove hydrophobic coatings on sand particles. Additionally, isolated channels created by the cultivation blast (Murphy and Rieke, 1994) may allow for deeper rooting and subsequently, more total water available in the root zone for WIC treated turf.

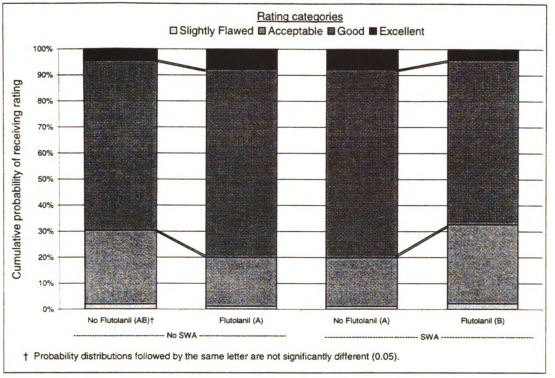

Figure 13. Quality rating probability distributions as affected by SWA x flutolanil. Preventative study, 1999.

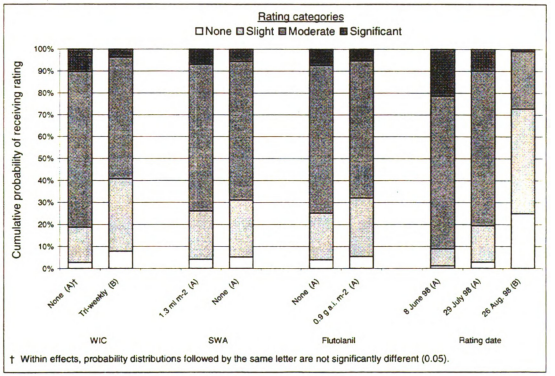

Figure 14. Wilt rating probability distributions as affected by WIC, SWA, flutolanil, and time. Preventative LDS study, 1999.

Volumetric soil moisture was measured on 17 dates in 1998, but only 5 dates in 1999 due to broken time domain reflectometry equipment. Time and WIC x time effects were significant in 1998, whereas only time effects were significant in 1999. There were significant differences between WIC treatments on 5 of the 17 dates soil moisture was measured in 1998 (Table 2). Turf cultivated by water injection had significantly greater soil moisture content on 20 May and 9 June, but significantly lower soil moisture content on the three significant evaluation dates in August. These data are surprising when considering the wilt reducing effect of WIC seen in 1999. These data suggest that the reduction in wilt with WIC treatment is probably not caused by the simple addition of water to the root zone. The HydroJect® adds approximately 1.5 mm water to the turf at the closest hole spacing and with the roller washers off.

Table 2. Interaction effects of WIC and evaluation date on volumetric soil moisture. Preventative study, 1998.

	Soil Moisture				
WIC Treatement	20 May. 98	9 Jun. 98	3 Aug. 98	6 Aug. 98	12 Aug. 98
	$m^3\ m^{-3}$				
None	31.3 †	34.4	16.4	20.6	23.7
Tri-Weekly	33.5	37.0	10.4	16.9	21.1

† Within columns, means are significantly different at the 0.05 probability level.

Water drop penetration times were recorded only in September in 1998 and monthly from June through September in 1999 (Table 3). Mishandled samples from June through August in 1998 had to be discarded. Depth was the only significant main effect in both years. Significant interaction effects included

WIC x depth in 1998, and flutolanil x depth, depth x time, WIC x flutolanil x time, and WIC x SWA x flutolanil x time in 1999.

In 1998, the 3 and 4 cm depths had significantly longer penetration times than depths 1, 2, and 5. Although the log(s) penetration times were statistically significant, there were no practical differences in the untransformed means among treatments. In 1999, the soil samples were significantly less wettable near the surface and became more wettable with depth. However, all soil depths showed some degree of non-wettability in both years. The 1999 data are fairly consistent with those of Wilkinson and Miller (1978), who found that hydrophobic conditions in sand based putting greens were restricted to the upper 2 cm of soil. However, the 1998 data do not show this trend. Wilkinson and Miller evaluated turf showing characteristic LDS symptoms, whereas the turf in this study dried down uniformly. Uniform dry down conditions may result in hydrophobic soil at depths greater than 2 cm. Bond (1968) reported hydrophobic conditions in sands at depths of up to 0.5 meter.

Where no WIC applications were made in 1998, the 3 and 4 cm depths were significantly less wettable than the 1 and 2 cm depth (Table 4). However, there were no differences in wettability among depths where WIC was applied. The 20 MPa blast of the WIC unit probably mixed the soil so that there were no differences in penetration times among soil depths. Previous studies have shown that WIC significantly mixes soil layers in putting green (Karcher, 1997).

Table 3. Effects of WIC, SWA, flutolanil, and sample depth on water drop penetration time.

Effect	Water drop penetration time					
	——— 1998 ———			——— 1999 ———		
	df	s	log(s)†	df	s	log(s)
WIC						
None		5.7	0.22 A		30.2	2.69 A
Tri-Weekly		11.3	0.21 A		34.4	2.89 A
SWA						
None		5.2	0.16 A		32.8	2.78 A
1.3 ml m^{-2}		11.8	0.28 A		31.8	2.80 A
Flutolanil						
None		14.1	0.30 A		34.3	2.92 A
0.9 g a.i. m^{-2}		2.9	0.13 A		30.3	2.66 A
Depth						
1		9.5	0.10 B		56.1	3.71 A
2		9.7	0.13 B		48.7	3.46 A
3		10.0	0.32 A		32.3	2.92 B
4		10.8	0.35 A		15.2	2.17 C
5		2.6	0.18 B		9.2	1.70 D
			ANOVA			
Source of variation						
Block	2		NS	2		NS
WIC (w)	1		NS	1		NS
SWA (s)	1		NS	1		NS
w x s	1		NS	1		NS
Flutolanil (f)	1		NS	1		NS
w x f	1		NS	1		NS
s x f	1		NS	1		NS
w x s x f	1		NS	1		NS
Depth (d)	4		**	4		***
w x d	4		*	4		NS
s x d	4		NS	4		NS
w x s x d	4		NS	4		NS
f x d	4		NS	4		*
w x f x d	4		NS	4		NS
s x f x d	4		NS	4		NS
w x s x f x d	4		NS	4		NS
Time (t)	---		---	3		***
w x t	---		---	3		NS
s x t	---		---	3		NS
w x s x t	---		---	3		NS
f x t	---		---	3		NS
w x f x t	---		---	3		***
s x f x t	---		---	3		NS
w x s x f x t	---		---	3		*
d x t	---		---	12		**
w x d x t	---		---	12		NS
s x d x t	---		---	12		NS
w x s x d x t	---		---	12		NS
f x d x t	---		---	12		NS
w x f x d x t	---		---	12		NS
s x f x d x t	---		---	12		NS
w x s x f x d x t	---		---	12		NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Data were normalized by a log(seconds) transformation for statistical analysis.

When no flutolanil was applied in 1999, soil became significantly more wettable with depth, except from 4 to 5 cm (Table 5). Flutolanil application increased the wettability of the 1 cm depth to where it was equal to the 2 cm depth. The 1999 data suggest that flutolanil application improves soil wettability near the turf surface, which would be expected if hydrophobic soil conditions were partially caused by a fungus susceptible to flutolanil.

The other high order interactions with time imply that the effects of depth, WIC x flutolanil, and WIC x SWA x flutolanil were inconsistent from month to month.

Table 4. Water drop penetration times as affected by WIC x depth interaction. Preventative study, 1998.

	Depth (cm)				
WIC Treatement	1	2	3	4	5
	log(s)				
None	0.02	0.05	0.36	0.43	0.23
Tri-Weekly	0.17	0.21	0.28	0.27	0.13

† Within columns LSD = 0.28, within rows LSD = 0.18, both at the 0.05 probability level.

Table 5. Water drop penetration times as affected by flutolanil x depth interaction. Preventative study, 1999.

	Depth (cm)				
Flutolanil Treatment	1	2	3	4	5
	log(s)				
None	3.97	3.46	2.81	2.03	1.63
0.9 g a.i. m^{-2}	3.45	3.47	3.02	2.31	1.76

† Within columns LSD = 0.56, within rows LSD = 0.49, both at the 0.05 probability level.

Curative Study

For the 1998 curative study, ANOVA results and the main effects of WIC, flutolanil, and SWA on turf quality and soil moisture are summarized in Table 6.

The main effects of SWA and flutolanil on turf quality were significant in the curative study. There was also a WIC x SWA interaction with regard to quality. Time was the only significant effect with regard to soil moisture in the curative study.

Averaged over all rating dates, both SWA and flutolanil application significantly increased the probability of the turf to be rated high in quality compared to application of neither (Figure 15). There are no data in the refereed literature pertaining to initiating treatments on turfs that are already severely affected with LDS. These results indicate that turf affected by LDS can be improved by curative applications of SWA or flutolanil.

When plots received no WIC treatment in the curative study, quality probability distributions were not affected by the addition of SWA (Figure 16). However, plots receiving WIC treatment had a significantly greater probability of being rated high in quality when SWA was also applied. The creation of channels by WIC probably allowed better penetration of the wetting agent through the thatch layer into hydrophobic soil areas. This may have made soil more wettable and improved turf quality when WIC preceded SWA applications. Wilkinson and Miller (1978) showed that a combination of core cultivation plus wetting agent significantly improved turf quality over either alone.

Table 6. ANOVA and main effects of WIC, SWA, and flutolanil on turf quality and soil moisture. Curative study, 1998.

Effect	df	Quality Parameter	df	Soil Moisture
		likelihood estimate		$m^3\ m^{-3}$
WIC				
None		0.75 A†		28.8 A
Tri-Weekly		0.73 A		29.2 A
SWA				
None		1.33 B		29.0 A
1.3 ml m^{-2}		0.15 A		29.0 A
Flutolanil				
None		1.09 B		29.3 A
0.9 g a.i. m^{-2}		0.38 A		28.8 A
			ANOVA	
Source of variation				
Block	2	***	2	NS
WIC (w)	1	NS	1	NS
SWA (s)	1	***	1	NS
w x s	1	**	1	NS
Flutolanil (f)	1	*	1	NS
w x f	1	NS	1	NS
s x f	1	NS	1	NS
w x s x f	1	NS	1	NS
Time (t)	7	**	2	***
w x t	7	NS	2	NS
s x t	7	NS	2	NS
w x s x t	7	NS	2	NS
f x t	7	NS	2	NS
w x f x t	7	NS	2	NS
s x f x t	7	NS	2	NS
w x s x f x t	7	NS	2	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Within effects, means sharing a letter are not significantly different.

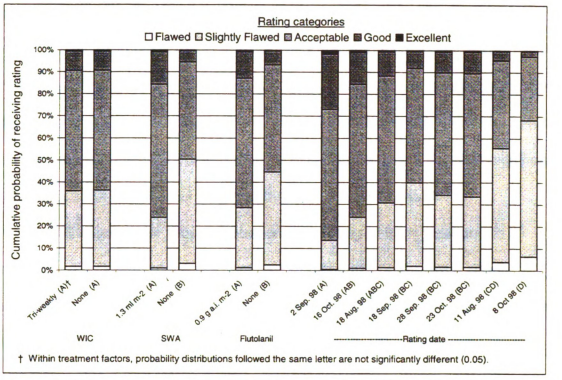

Figure 15. Quality rating probability distributions as affected by WIC, SWA, flutolanil, and rating date. Curative study, 1998.

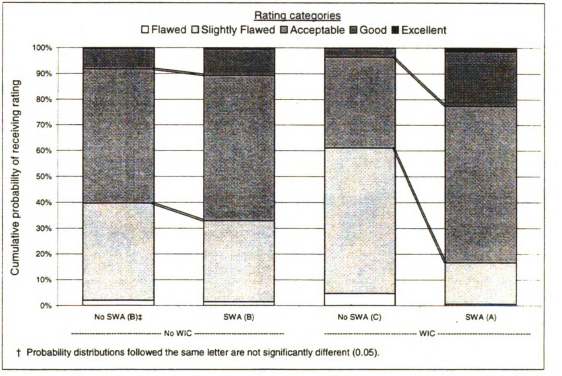

Figure 16. Quality rating probability distributions as affected by WIC x SWA. Curative study, 1998.

Isolation Study

Water drop penetration time and cumulative hyphal length ANOVAs and main effect means are summarized in Table 7. Location and depth main effects, as well as the location x depth effect, were all significant with regard to water drop penetration time. Location relative to the center of the dry spot significantly affected cumulative hyphal length at the 0.06 probability level.

Individual water drop penetration times ranged from 1 second to 21 minutes. The inside of the dry spot had significantly longer water drop penetration times than the edge and outside. Additionally, the edge of the patch was significantly less wettable than outside (Figure 17). There is no mention in the refereed literature of evaluating differences in water drop penetration time among locations, relative to the center of a dry patch.

The 1 and 2 cm depths were less wettable than all other depths, whereas the 3 cm depth was intermediate, and the 4 and 5 cm depths were most wettable. These results are similar to those reported previously (Wilkinson and Miller, 1978; Tucker et al., 1990), where the upper few cm of the soil were the most hydrophobic in sand based putting greens. The significant location x depth interaction indicated that significant differences among locations only occurred at depths of 1, 2, and 3 cm (Table 9).

Table 7. Water drop penetration times and cumulative hyphae length as affected by surface location and depth relative to LDS. Isolation study, 1998.

Effect	df	Water drop penetration time	df	Cumulative hyphal length
		s log(s)		μm hyphae cm^{-2}
Location				
edge	56	2.5 B†		10295 A‡
inside	284	3.5 A		3067 B
outside	3	0.8 C		7841 A
Depth (cm)				
1	416	4.4 A		--
2	128	3.6 A		--
3	24	2.4 B		--
4	3	0.6 C		--
5	2	0.3 C		--
	ANOVA			
Source of variation				
Block	2	**	2	NS
Location (l)	2	***	1	§
Depth (d)	4	***	--	--
l x d	8	***	--	--

§, **, *** Significant at the 0.1, 0.05, and 0.001 probability levels, respectively.

† Within effects, means sharing a letter are not significantly different ($P \leq 0.05$).

‡ Means sharing a letter are not significant at the 0.10 probability level.

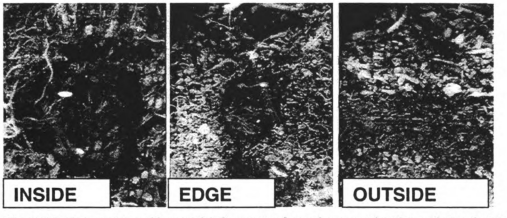

Figure 17. Images taken 30 seconds after water drop placement just beneath the thatch layer at the inside, edge, and outside of a dry patch.

Stained hyphae from the edge of a dry spot are shown in Figure 18. The edge of the dry spot had significantly ($P = 0.06$) greater fungal biomass (measured as the cumulative hyphal length) than the inside or outside. This is further evidence that LDS may be caused by a fungal organism. If the causal agent of LDS is of fungal origin, growth initiates at a central point and continues radially outward, with the highest concentration of active viable fungi biomass at the growing edge of a dry spot. This growth pattern is similar to many pathogenic fungal species that are known to cause fairy ring and patch diseases (Smiley et al., 1992). Although previous research has associated various fungal species with LDS (Miller and Wilkinson, 1978; York and Baldwin, 1992), no fungal species have been identified that are specific to LDS.

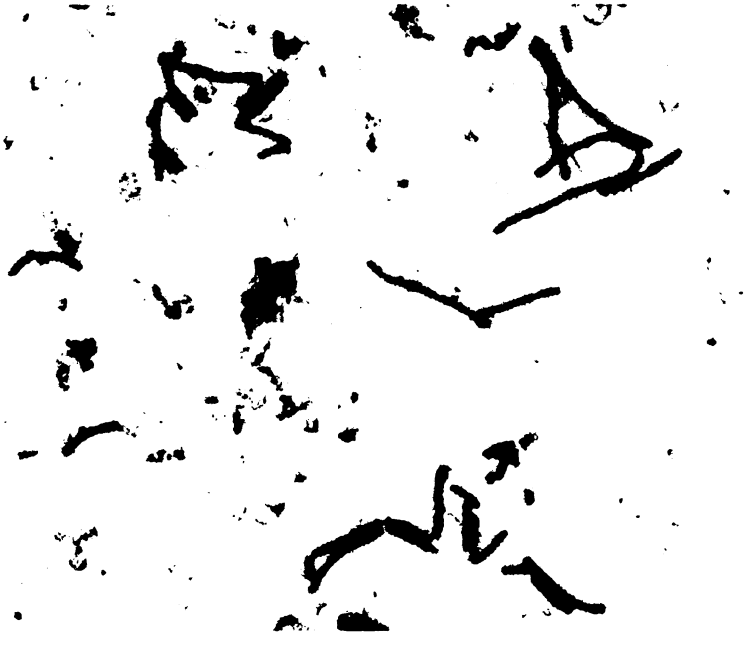

Figure 18. Stained hyphae from a section of a buried slide at the edge of a dry patch, immediately beneath the thatch layer. Image is magnified 250 times.

Table 9. Effects of location x depth on water drop penetration time. Isolation study, 1998.

	Location relative to patch		
Depth (cm)	Inside	Edge	Outside
	log(s)		
1	6.9†	4.7	1.5
2	5.7	3.7	1.5
3	2.8	3.2	1.0
4	1.1	0.8	0.0
5	1.0	0.0	0.0

† Within columns LSD = 1.4, within rows LSD = 1.2, both at the 0.05 probability level.

CONCLUSIONS

Results from the preventative study indicated that LDS occurrence and control were highly variable, as treatment effects were inconsistent between years. However, WIC, SWA, and flutolanil all showed some potential to alleviate LDS symptoms. Water injection cultivation seemed to decrease visual wilting symptoms, whereas flutolanil increased visual quality during general summer stress conditions. Soil moisture analyses established that the effect of WIC on wilt reduction was not simply by wetting the soil. Flutolanil and SWA appear to provide some curative control of LDS, however combining both at the highest labeled rate of each may result in phytotoxicity.

The causal agent of typical LDS symptoms appeared to affect the soil immediately beneath the thatch, although hydrophobic soil was measured at greater depths when dry down was uniform. A significantly greater accumulation of hyphae was measured at the edges of the dry spots than the inside. This is evidence that the causal agent of LDS may be of fungal origin.

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CHAPTER THREE

THE EFFECTS OF NITROGEN PLACEMENT AND WATER INJECTION CULTIVATION ON CREEPING BENTGRASS PUTTING GREENS

ABSTRACT

Nitrogen is usually the most limiting nutrient in turfgrass growth. Food and forage crops have benefited from receiving subsurface nitrogen fertilization. Subsurface fertilization in turfgrass had not been feasible until the development of high pressure water injection cultivation (WIC). Previous research showed that applying nitrogen with WIC increased turf color ratings, clipping yields, and nitrogen content compared to surface fertilization, but the effects of nitrogen placement and cultivation were confounded. In addition, turf injected with nitrogen exhibited occasional dark green striping that would be unacceptable in a putting green situation. The objectives of this research were to evaluate (i) the separate effects of nitrogen application method and WIC on growth, nitrogen content in the plant tissue, turf color, and turf quality and (ii) the effects of several alternative methods of injecting nitrogen on uniformity of color response. In a nitrogen injection – management practice study, four combinations of nitrogen injection, WIC, and surface fertilization were applied at 2.4 and 4.8 g N m^{-2} $application^{-1}$. In 1997, nitrogen injection increased turf color and quality ratings, clipping yields and leaf nitrogen content, but in 1998 only increased turfgrass color. In both years, WIC alone had no significant effect on any turfgrass evaluations. In an application uniformity study, an application method providing

both injection and surface application of nitrogen provided superior color, quality, and uniformity of putting green turf. If injecting nitrogen improves turf responses compared to surface applications, less overall nitrogen may be needed to maintain a healthy turf stand.

INTRODUCTION

Nitrogen is usually the limiting nutrient for turfgrass growth. It is an essential component of chlorophyll, other proteins, genetic material, and many other plant substances. Turfgrass plants normally contain more nitrogen, 3 to 5 percent, than any other mineral nutrient. Responses to nitrogen by turf include darker green color and increased growth and density. Too much nitrogen can be detrimental by enhancing some diseases or causing osmotic burn (Emmons, 1995).

Turfgrass fertilization is traditionally accomplished through surface applications. This is primarily due to the unavailability of equipment capable of placing fertilizers below the soil surface without causing significant turf disruption. Subsurface applications of nitrogen increase plant nitrogen use efficiency in the food and forage crop industries (Mengal et al., 1982; Stecker et al. 1993).

Rapid suburban growth and golf course construction has increased nitrogen fertilizer use in the turfgrass industry during recent decades. More efficient nitrogen application methods on turfgrass, and the subsequent conservation of nitrogen in the turfgrass industry, could save energy and reduce risks of environmental pollution.

The introduction of water injection cultivation (WIC) (Murphy and Rieke, 1994) to the turfgrass management marketplace makes possible subsurface placement of soluble materials in established turf. Although WIC was introduced purely as a tool for soil cultivation, previous studies have concluded that injecting soluble nutrients with WIC may be beneficial to turf (Miller, 1994).

Most literature available on fertilizer placement in turfgrass concerns turfgrass establishment, i.e. fertilizer placement effects on seed germination or sod establishment (Jackson and Burton, 1962; King and Skogley, 1969; King and Beard, 1972) This work has shown minimal differences in turfgrass establishment with regard to fertilizer placement. In contrast, Murphy and Zaurov (1994) observed in a greenhouse study that perennial ryegrass (*Lolium perenne* L.) receiving subsurface nitrogen injections (urea) had higher clipping yields, greater root mass, higher nitrogen accumulation in plant tissues, and higher water use rate efficiency than turfgrass receiving surface applications of nitrogen.

Studies examining the effects of injecting nitrogen with WIC on fairway and putting green turfs were conducted in 1994 (Karcher, 1997). Treatments included three rates of urea, either injected or surface applied. Plots injected with urea had consistently higher clipping yields, nitrogen content in plant tissues, and color ratings than plots receiving surface applications. One possible explanation for these differences could have been as a result of ammonia volatilization from surface applications, even though plots were irrigated shortly after application. This hypothesis was tested by repeating the study in 1995 using ammonium nitrate as the nitrogen source, which is much less susceptible to volatilization than urea. Results from the 1995 study were very similar to those recorded in 1994. Clipping yields, nitrogen content in plant tissues and color ratings were all increased by injecting ammonium nitrate. Plots injected with nitrogen had a longer duration of a dark green turf response than plots receiving

surface applications during both years. Additionally, turf injected with nitrogen was less susceptible to moisture stress than turf receiving surface applications.

These results suggest that by injecting nitrogen, a turfgrass manager may be able to use less total nitrogen and increase water use efficiency when compared to making surface applications. Plots receiving surface applications of nitrogen in these studies were not subjected to WIC treatment with water alone. Therefore, the effects of placement of nitrogen beneath the surface, and soil aerification from WIC could not be separated.

In previous studies involving application of nitrogen with WIC, the turf exhibited striping due to the nozzle alignment of the WIC unit on some dates. Striping was most evident on closely mowed putting green turf, 5 to 14 days following application. Turf striping occasionally reduced surface uniformity on putting green turf to a level likely considered unacceptable by most turf managers.

A group of studies were initiated in 1997 to compare the effects of surface application and subsurface injection of nitrogen. The overall objective of these studies was to determine if nitrogen application via injection is a practical and improved means of fertilizing turfgrass. More specifically, they were to compare injection and surface application of nitrogen by evaluating: (i) the separate effects of nitrogen application method and WIC on growth, nitrogen content in the plant tissue, turf color, and turf quality in **a nitrogen injection – management practice study** and (ii) the effects of several alternative methods of injecting

nitrogen on uniformity of turf color and quality in an **application uniformity study**.

MATERIALS AND METHODS

Nitrogen Injection - Management Practice Study

Experimental Area

The nitrogen injection - management practice study was initiated in May 1997 at the Hancock Turfgrass Research Center (East Lansing, MI) on a one year old 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.) putting green established on a root zone meeting USGA specifications (96% sand, 3% silt, 1% clay) (Hummel, 1993). The experimental area was mowed at 4 mm and maintained under typical putting green management practices. Pesticides were applied on a curative basis and phosphorus and potassium were applied as recommended from soil test values. Light sand topdressing applications were made monthly with sand matching the texture of the root zone. Irrigation was applied to approximate water loss due to average daily evapotranspiration.

Treatment Structure

This study contained two treatment factors, management practice and nitrogen rate. There were four management practices: 1) surface applied nitrogen without supplemental WIC, 2) surface applied nitrogen with supplemental WIC using a standard, #53 nozzle (approximately 15 cm injection depth), 3) nitrogen injected using a #56 nozzle (approximately 7.5 cm injection depth), and 4) nitrogen injected using a #53 nozzle. There were two nitrogen

rates: 1) 2.4 g m^{-2} application^{-1} and 2) 4.8 g m^{-2} application^{-1}. Combining the two factors yielded eight individual treatments (Table 9). This treatment arrangement allowed specific and separate analyses of the effects of nitrogen placement and WIC. The effects of nitrogen placement were tested by contrasting treatments #1, #2, #3, and #4 vs. #5, #6, #7, and #8. The effects of WIC were tested by contrasting treatments #1 and #2 vs. #3 and #4.

Table 9. Summary of treatments comprising the nitrogen injection - management practice study.

Treatment No.	Management Practice	Nitrogen Rate
		g m^{-2} application^{-1}
1.	N applied on surface with no WIC	2.4
2.	N applied on surface with no WIC	4.8
3.	N applied on surface plus WIC	2.4
4.	N applied on surface plus WIC	4.8
5.	N injected with #56 nozzle	2.4
6.	N injected with #56 nozzle	4.8
7.	N injected with #53 nozzle	2.4
8.	N injected with #53 nozzle	4.8

The nitrogen source for all applications was ammonium nitrate. Nitrogen applications were made once a month throughout the growing season. Fertilizer injections and WIC were done with a HydroJect 3000® provided by the Toro Co. of Minneapolis. Nitrogen injections were achieved by pumping dissolved ammonium nitrate solution from a mounted tank to the intake line of the HydroJect. The HydroJect was operated at the closest hole spacing (approximately 7.5 cm x 2.5 cm). Surface applications were made using a CO_2 powered sprayer designed specifically for small plot applications. Approximately 5 mm of water were applied to the experimental area immediately following nitrogen applications. On plots receiving surface applications of nitrogen plus WIC, WIC was applied immediately following irrigation. Treatments were

replicated four times in a randomized complete block design. Individual plot sizes were 3.6 by 1.7 m.

Since the experimental area was extremely nitrogen deficient at the beginning of the study, 38 g m^{-2} nitrogen was applied in 1997, whereas 24 g m^{-2} was applied in 1998. Treatments were applied on 2 May, 28 May, 27 Jun., 31 July, 25 Aug., 25 Sep., and 12 Nov in 1997 and 9 May, 5 Jun, 10 July, 9 Aug., and 15 Sep. in 1998. The November 1997 application was a double rate late fall application.

TREATMENT EVALUATIONS

Clippings were collected by mowing two passes lengthwise on each plot with a greens mower once a week from May through October. Clippings were dried at 60° C and weighed to determine yield. Clipping yields were evaluated on 22 dates in 1997 and 18 dates in 1998.

Plant tissue nitrogen content was determined from the dried clippings using a Karsten Model 591 NIRS analyzer (Karsten Inc., Phoenix, AZ). Leaf nitrogen content was evaluated on 15 dates in 1997 and 18 dates in 1998.

Turfgrass quality and color ratings were taken weekly throughout the growing season. The rating scale for quality was from 1 to 9 (1=dead, 2=mostly dead, 3=severely flawed, 4=flawed, 5=slightly flawed, 6=acceptable, 7=good, 8=excellent, 9=ideal) and for color was from 1 to 9 (1=tan, 2=greenish yellow, 3=yellowish green, 4=light green, 5=medium light green, 6=medium green, 7=medium dark green, 8=dark green, 9=extremely dark green). Turf quality and color were evaluated on 21 dates in 1997 and 17 dates in 1998.

Application Uniformity Study

Experimental Area

The application uniformity study was conducted in June through October in 1997, and September through October in 1998 at the Hancock Turfgrass Research Center on a 14-year old annual bluegrass (*Poa annua* L. *reptans*) turf established on a fine-loamy, mixed, mesic Typic Hapludalf (68% sand, 19% silt, 13% clay). The experimental area was mowed at 4 mm and managed under typical putting green management practices. Pesticides were applied on a curative basis and phosphorus and potassium were applied as recommended from soil test values. Light sand topdressing applications were made monthly (96% sand, 3% silt, 1% clay) and irrigation was applied to approximate water loss due to average daily evapotranspiration.

Treatment Structure

Seven nitrogen application methods are evaluated in the 1997 study, whereas nine were evaluated in 1998 (Table 10). Alternative application treatments were chosen based on their potential to reduce the appearance of green stripes following nitrogen injection. Nitrogen injections were made with a HydroJect 3000. Nitrogen injections were achieved by pumping dissolved ammonium nitrate from a mounted tank to the intake line of the HydroJect. The HydroJect was operated at the closest hole spacing (approximately 7.5 cm x 2.5 cm).

Treatments #4 and #5 used experimental nozzles manufactured by the Toro Co., with 2 orifices and 3 orifices, respectively. The orifices on these

nozzles were arranged to affect the largest volume of soil possible. Treatments #6 and #8 involved turning on the roller washers of the HydroJect, which resulted in approximately half of the nitrogen being applied on the turf surface. This was determined by comparing the volume of water entering the roller washer to the volume of water entering the HydroJect. The normal function of the roller washers is to clean the rollers on which the unit rides during WIC.

The application rate for all treatments was 4.8 g N m^{-2}. Treatments were replicated four times in a completely randomized design. In 1997, treatments were applied on 25 June, 15 Aug., and 25 Sep. The direction of nitrogen injection was alternated 180 degrees between consecutive application dates. Treatments were applied only on 10 Sep. in 1998. In both years, nitrogen was applied on the experimental area at 3.6 g m^{-2} every six weeks, from early May until one month prior to treatment applications.

Table 10. Treatments comprising the application uniformity study.

Treatment No.	Application Method
1.	Surface application
2.	Injected with #53 nozzle (approximately 15 cm depth)
3.	Injected with #56 nozzle (approximately 7.5 cm depth)
4.	Injected with 2 orifice prototype nozzle
5.	Injected with 3 orifice prototype nozzle
6.	Injected with #53 nozzle while surface roller washers on (using nitrogen solution)
7.	Injected with #53 nozzle at half rate making two passes in perpendicular directions
8.	Injected with #56 nozzle while surface roller washers on (using nitrogen solution)†
9.	Injected with #56 nozzle at half rate making two passes in perpendicular directions†

† Treatments were only applied in 1998 study.

Visual quality, color, and stripe ratings were taken weekly following treatment applications. Quality and color ratings were taken in the same manner described in the nitrogen injection - management practice study. A scale of 1 to 5 was used to evaluate turfgrass striping with 1 representing no discernible

striping, 2 representing barely discernible striping, 3 representing fairly discernible striping, 4 representing easily detected striping, and 5 representing obvious striping with sharp contrasting stripe borders. Ratings were taken on 13 dates in 1997 and 6 dates in 1998.

Statistical Analyses

Visual rating data for both studies were analyzed using the proportional odds model that is incorporated into the Rating Data Analysis File Package (Karcher, 2000). Treatment separation was done with pairwise chi-square tests of the treatment parameter estimates. Probability distributions were constructed to represent the odds of a treatment level to be rated in a particular category. These distributions were constructed by inserting the appropriate combination of parameter estimates into the logit-link function.

For the application uniformity study, maximum likelihood calculation errors occurred using the full model. This was due to a relatively large ratio of model parameters to experimental units. Therefore, a reduced model was used by dropping the application method x rating date interaction term from the model, and subsequently, only estimates of main effects were possible.

All other data were analyzed with ANOVA. If treatment effects were significant, means were separated using LSD at the 0.05 probability level. Where repeated measures were made on the same experimental units, time was analyzed as a sub-plot factor of the experiment. The best fitting covariance model among compound symmetry, first order auto-regressive, and spatial exponential was used to fit correlations among time points. The best fitting

covariance model was determined by the highest Akaike's Information Criteron value (Littell et al., 1996).

RESULTS AND DISCUSSION

Nitrogen Injection – Management Practice Study

Treatment main effects, nitrogen placement contrasts, and ANOVA results are summarized in Table 11 (1997) and Table 12 (1998). The higher nitrogen rate significantly increased the probability of the turf to be rated high in color and quality, clipping yields, and leaf nitrogen content in both years. Management practices effects were significant for all evaluations in 1997, but only color and quality in 1998. The management practice x nitrogen rate interaction was significant for all evaluations in 1997 and 1998, with the exception of leaf nitrogen content in 1997. The nitrogen placement contrast was significant for all evaluations in 1997, but only turfgrass color in 1998. Significant interactions involving rating date resulted from the lack of treatment effects on a few rating dates throughout the year. However, within years, treatment separation was consistent on rating dates when treatment effects were significant.

Color Ratings

Fertilizing turf with the high nitrogen rate increased the probability of being rated as medium green or better by approximately 85% over the low rate in both years (Figure 19 and Figure 20). Much previous research has demonstrated that creeping bentgrass has a dark color response to increased rates of nitrogen (Landschoot and McNitt, 1997; Powell et al., 1967, Brauen et al., 1975).

Table 11. Treatment main effects, and nitrogen placement contrast for turf quality, color, clipping yields, and nitrogen content. 1997.

Effect	df	Color Parameter	df	Quality Parameter	df	Clipping Yield	df	Nitrogen Content
		estimate		estimate		$g\ m^{-2}\ day^{-1}$		%
Management practices								
surface N, no WIC		0.98 D†		3.00 D		2.84 B		4.02 B
surface N, + WIC		0.31 C		2.08 C		2.69 B		4.04 B
injected N to 7.5 cm		-5.00 A		-1.72 A		4.40 A		4.41 A
injected N to 15 cm		-3.92 B		-1.17 B		4.26 A		4.42 A
Nitrogen rate								
2.4 $g\ m^{-2}\ app^{-1}$		0.66 B		2.67 B		2.83 B		3.96 B
4.8 $g\ m^{-2}\ app^{-1}$		-4.47 A		-1.57 A		4.27 A		4.48 A
Nitrogen placement contrast								
surface		0.65 B		2.54 B		2.76 B		4.03 B
injected		-4.46 A		-1.44 A		4.33 A		4.41 A
				ANOVA				
Source of variation								
Block	3	***	3	***	3	**	3	*
Management practice (mp)	3	***	3	***	3	***	3	***
Nitrogen rate (nr)	1	***	1	***	1	***	1	***
mp x nr	3	***	3	***	3	***	3	NS
Date (d)	20	***	20	***	21	***	14	***
mp x d	60	***	60	***	63	***	42	***
nr x d	20	***	20	***	21	***	14	***
mp x nr x d	60	***	60	***	63	***	42	**

† Within effects, means sharing a letter are not significantly different.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 12. Treatment main effects, and nitrogen placement contrast for turf quality, color, clipping yields, and nitrogen content. 1998.

Effect	df	Color Parameter	df	Quality Parameter	df	Clipping Yield	df	Nitrogen Content
		estimate		estimate		g m^{-2} day^{-1}		%
Management practices								
surface N, no WIC		0.16 C†		0.12 C		5.24 A		4.57 A
surface N, + WIC		-0.71 B		-1.51 A		5.24 A		4.57 A
injected N to 7.5 cm		-1.57 A		-1.12 AB		4.98 A		4.53 A
injected N to 15 cm		-0.74 B		-0.88 B		5.10 A		4.51 A
Nitrogen rate								
2.4 g m^{-2} app^{-1}		1.02 B		0.76 B		4.18 B		4.38 B
4.8 g m^{-2} app^{-1}		-2.46 A		-2.46 A		6.10 A		4.72 A
Nitrogen placement contrast								
surface		-0.28 B		-0.70 A		5.24 A		4.57 A
injected		-1.16 A		-1.00 A		5.04 A		4.52 A
				ANOVA				
Source of variation								
Block	3	NS	3	**	3	***	3	NS
Management practice (mp)	3	***	3	***	3	NS	3	NS
Nitrogen rate (nr)	1	***	1	***	1	***	1	***
mp x nr	3	***	3	***	3	***	3	*
Date (d)	16	***	16	***	17	***	17	***
mp x d	48	***	48	***	51	NS	51	NS
nr x d	16	***	16	***	17	***	17	***
mp x nr x d	48	NS	48	*	51	*	51	NS

† Within effects, means sharing a letter are not significantly different.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

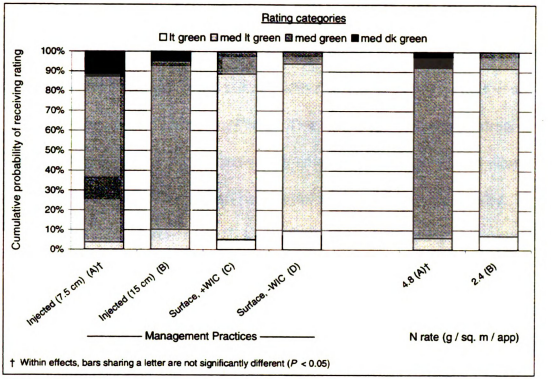


Figure 19. Color rating probability distributions for management practice and nitrogen rate main effects. 1997.

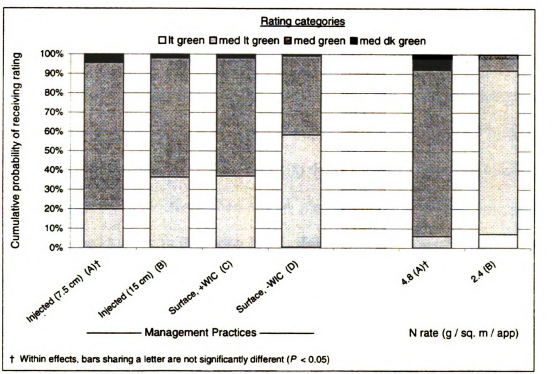


Figure 20. Color rating probability distributions for management practice and nitrogen rate main effects. 1998.

In both years, turf injected with nitrogen to a 7.5 cm depth had the highest probability to be rated dark in color, followed by turf injected with nitrogen to a 15 cm depth, turf fertilized on the surface with nitrogen plus WIC, and turf fertilized on the surface without additional WIC. The differences among treatments were greatest in 1997. There is an extremely small amount of published work regarding the effects of nitrogen placement in turf on color and quality. In previous studies, Karcher (1997) found that injecting creeping bentgrass putting green turf with urea or ammonium nitrate resulted in darker green turf compared to surface applications. Injection to 7.5 cm probably concentrated the nitrogen solution in closer proximity to the majority of the creeping bentgrass roots, allowing for greater cumulative uptake compared to surface applications or injection to a 15 cm depth. Previous rooting studies on creeping bentgrass turf have determined the majority of the root mass is within 10 cm of the turf surface (Cooper et al., 1998). Surface applications may have resulted in more microbial immobilization compared to nitrogen injection since microbial populations are greater near the turf surface than at soil depths of 7.5 cm or more. Thatch was found to contain up to 1600, 600, and 100 times as many bacteria, fungi, and actimomycetes, respectively than soil on a creeping bentgrass putting green with a sand based root zone (Mancino et al., 1993). Harper et al. (1996) discovered that a significant amount of nitrogen applied to a perennial ryegrass pasture was immobilized by microbes, and remobilized at insufficient rates to avoid nitrogen stress by the grass.

The significant management practice x nitrogen rate interaction in 1997 resulted from nitrogen injected to a 7.5 cm depth increasing turf color compared to the 15 cm depth at the low nitrogen rate, but not at the high rate (Figure 21). These results suggest that nitrogen placement to an optimum depth is more critical when fertilizing at relatively low rates. The significant management practice x nitrogen rate interaction in 1998 resulted from WIC significantly increasing turf color on turf receiving surface fertilization at the low nitrogen rate, but not at the high rate (Figure 22).

QUALITY RATINGS

Turf fertilized with the high nitrogen rate increased the probability of being rated as acceptable or better by approximately 55% in 1997 (Figure 23) and 85% in 1998 (Figure 24) over the low nitrogen rate. Similar results were reported in previous studies examining the effects of nitrogen on creeping bentgrass quality (Waddington et al., 1978; Christians et al., 1981).

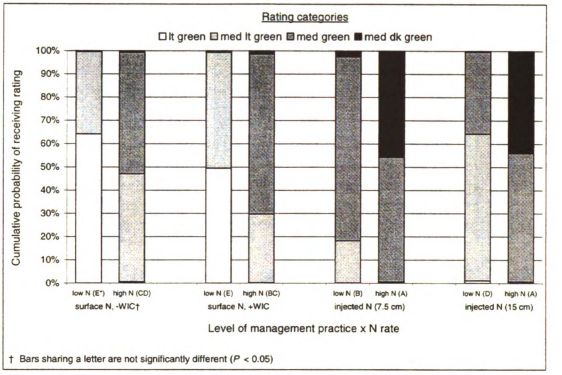


Figure 21. Color rating probability distributions for the management practice x nitrogen rate interaction. 1997.

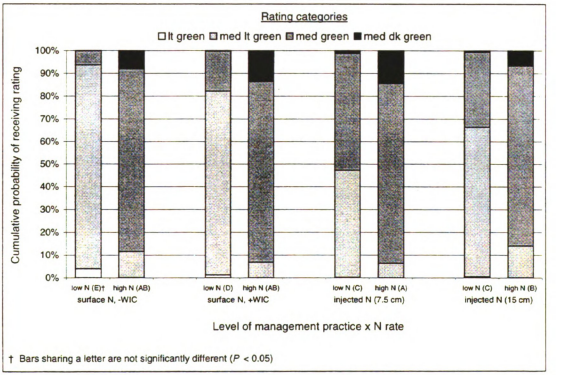


Figure 22. Color rating probability distributions for the management practice x nitrogen rate interaction. 1998.

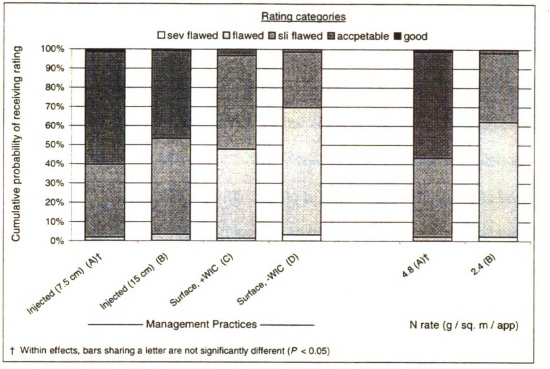


Figure 23. Quality rating probability distributions for management practice and nitrogen rate main effects. 1997.

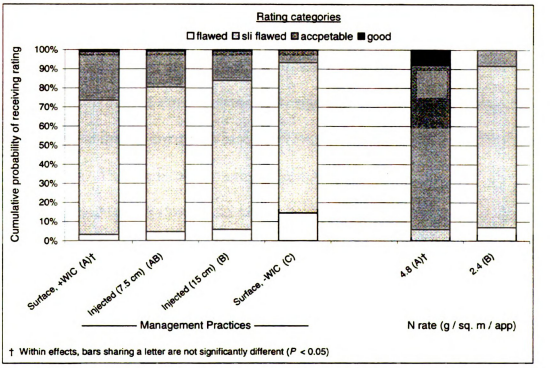


Figure 24 Quality rating probability distributions for management practice and nitrogen rate main effects. 1998.

In 1997, turf injected with nitrogen to a 7.5 cm depth had the highest probability to be rated high in quality, followed by turf injected with nitrogen to a 15 cm depth, turf fertilized on the surface with nitrogen plus WIC, and turf fertilized on the surface without additional WIC. Each management practice was significantly different from the others. More cumulative uptake of nitrogen in 1997 of turf receiving injected nitrogen to a 7.5 cm depth could likely have produced more chlorophyll and increased turf density, improving turf quality. However, in 1998, surface application of nitrogen plus WIC had quality equal to the 7.5 cm injection treatment. Although turf injected with nitrogen had better color than turf receiving surface applications, striping on several dates resulted in equal quality among the application methods. Previous studies have shown variable differences in quality between application methods due to striping of the turf caused by injecting nitrogen (Karcher, 1997).

The significant management practice x nitrogen rate interaction in 1997 resulted from the 7.5 cm injection depth significantly increasing turf quality compared to the 15 cm depth at the low nitrogen rate, but not at the high rate (Figure 25). The significant management practice x nitrogen rate interaction in 1998 resulted from turf fertilized on the surface with nitrogen having quality equal to both injected nitrogen treatments at the high nitrogen rate, but significantly lower quality at the low nitrogen rate (Figure 26). These results suggest with extended use at low nitrogen rates, injecting nitrogen to a 7.5 cm depth may result in optimal quality, whereas at high nitrogen rates application method has little effect on turf quality.

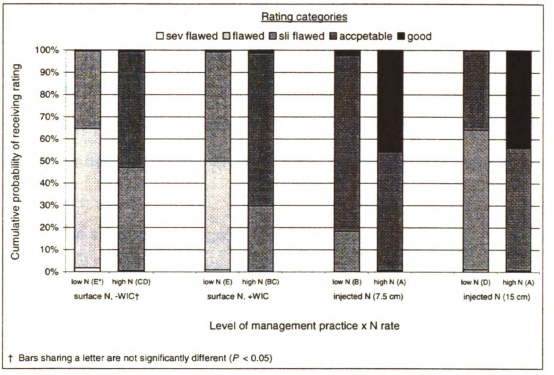


Figure 25. Quality rating probability distributions for the management practice x nitrogen rate interaction. 1997.

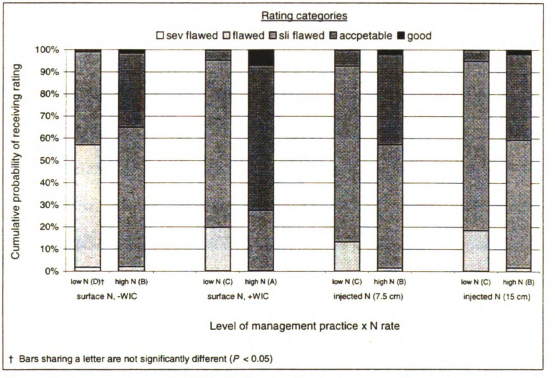


Figure 26. Quality rating probability distributions for the management practice x nitrogen rate interaction. 1998.

CLIPPING YIELDS

Turf fertilized at the high nitrogen rate had 1.4 and 1.9 g m^{-2} day^{-1} more clippings than the low rate in 1997 and 1998, respectively. A significant production of creeping bentgrass leaf tissue in response to increasing nitrogen levels has been previously reported (Carroll and Petrovic, 1991; Sheldrick et al., 1990).

The significant management practice effect on clipping yields was due to nitrogen placement rather than WIC (Table 11). In 1997, turf receiving subsurface nitrogen placement averaged 1.6 g m^{-2} day^{-1} more clippings than turf fertilized on the surface. However, this effect was not apparent in 1998, possibly as the result of remobilized nitrogen in turf receiving surface applications. The clipping yield effect seen in 1997 is similar to previous nitrogen injection studies (Karcher, 1997). In a greenhouse study, Murphy and Zaurov (1994) found that applying nitrogen, potassium, and phosphorous at a 5 cm depth increased perennial ryegrass clipping yields compared to surface fertilizations. More cumulative uptake of nitrogen in 1997 by turf receiving injected nitrogen could have produced more chlorophyll and increased turf growth compared to surface applications. It is possible that nitrogen immobilized in 1997 was remobilized in 1998 causing turf receiving surface applications of nitrogen to produce clipping yields equal to turf receiving injected nitrogen.

The significant management practice x nitrogen rate interaction in 1997 resulted from the 7.5 cm injection depth significantly increasing turf clipping yield compared to the 15 cm depth at the low nitrogen rate, but the reverse effect

occurred at the high rate (Table 13). The significant management practice x nitrogen rate interaction in 1998 resulted from turf fertilized on the surface with nitrogen causing higher clipping yields than turf injected with nitrogen to a 7.5 cm depth at the high nitrogen rate, but not at the low nitrogen rate.

Table 13. Clipping yields as affected by management practice x nitrogen rate. 1997 and 1998.

	Management practice			
Nitrogen rate	surface N, no WIC	surface N, + WIC	injected N to 7.5 cm	injected N to 15 cm
	$g\ m^{-2}\ day^{-1}$			
		1997		
2.4 g m^{-2} app^{-1}	2.3 E†	2.1 E	3.7 C	3.1 D
4.8 g m^{-2} app^{-1}	3.4 D	3.2 D	5.0 B	5.4 A
		1998		
2.4 g m^{-2} app^{-1}	4.1 CD	4.0 D	4.3 C	4.3 C
4.8 g m^{-2} app^{-1}	6.4 A	6.5 A	5.6 B	5.9 B

† Within years, means sharing a letter are not significantly different ($P < 0.05$).

Leaf Nitrogen Content

The high nitrogen rate increased nitrogen content in the leaf tissue 0.5 and 0.4 % in 1997 and 1998, respectively. Significant differences in leaf nitrogen content among management practices in 1997 were the result of nitrogen placement rather than WIC (Table 11). In 1997, injecting nitrogen resulted in a 0.4% increase in leaf nitrogen content compared to surface applications. A 0.4% increase in leaf nitrogen content over surface applications is very similar to previous nitrogen injection studies (Karcher, 1997). Murphy and Zaurov (1994) reported significant increases in nitrogen accumulation in perennial ryegrass leaf

tissue when fertilizer was placed at 5 or 10 cm depths compared to on the surface. There was no management practice effect in 1998.

A significant management practice x nitrogen rate interaction in 1998 resulted from surface applications significantly increasing leaf nitrogen content compared to injecting nitrogen at the high fertilization rate, but not at the low nitrogen rate (Table 14).

Table 14. Leaf nitrogen content as affected by management practice x nitrogen rate. 1998.

	Management practice			
Nitrogen rate	surface N, no WIC	surface N, + WIC	injected N to 7.5 cm	injected N to 15 cm
	%			
2.4 g m^{-2} app^{-1}	4.4 C	4.4 C	4.4 C	4.4 C
4.8 g m^{-2} app^{-1}	4.8 A	4.8 A	4.6 B	4.7 B

† Within years, means sharing a letter are not significantly different ($P < 0.05$).

Application Uniformity Study

Application method significantly affected turf color, quality, and striping in both years (Table 15). Since parameter estimate calculation by maximum likelihood was not possible with the full statistical model, no information was available regarding the application method x rating date interaction.

Color Ratings

Turf injected with nitrogen and with the roller washers turned on had the highest probability of being rated dark in color during both years. In 1997, (Figure 27), surface applications of nitrogen were equal to injecting with the roller washers on, whereas in 1998 (Figure 28) a standard injection and injecting at a

half rate in two directions were equal to injecting with the roller washers on. Surface application and injection with a 3 orifice prototype nozzle resulted in significantly poorer color ratings than all other treatments in 1998.

Quality Ratings

Turf injected with nitrogen with the roller washers on had the highest probability to be rated high in quality in 1997 (Figure 29) and 1998 (Figure 30). The multiple orifice nozzles ranked relatively poor in quality among all treatments across both years. Although turf receiving surface application of nitrogen had equal quality to turf injected with nitrogen with roller washers on in 1997, turf treated with surface applications had relatively low probability to be rated high in quality in 1998.

Stripe Ratings

Turf injected with the standard nozzle (15 cm depth) and the 7.5 cm depth nozzle had the highest probabilities to be rated high in surface striping in both years (Figure 31 and Figure 32). Turf injected with nitrogen and with the roller washers on had an equal probability of striping to turf receiving surface applications in both years. Turf fertilized with the multiple orifice nozzles had more striping than turf fertilized with surface applications in 1997, but was rated equal in striping to turf fertilized with surface applications in 1998.

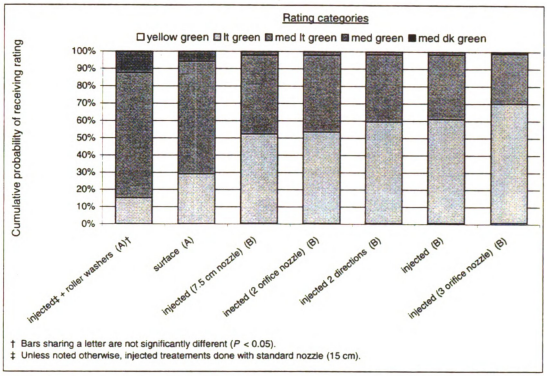
Table 15. Application method effects on turf color, quality, and stripe ratings. 1997 and 1998.

Effect	1997 df	Color Parameter	1997 df	Quality Parameter	1997 df	Stripe Parameter	1998 df	Color Parameter	1998 df	Quality Parameter	1998 df	Stripe Parameter
		estimate		estimate		estimate		estimate		estimate		estimate
Application Method												
surface		2.49 A†		-2.71 A		19.85 D		5.78 D		6.17 F		21.62 C
injected‡		3.83 B		-1.09 BC		1.62 B		-5.10 A		-2.24 CD		4.14 A
injected (7.5 cm nozzle)		3.47 B		-0.46 C		0.61 A		-5.58 A		-2.80 BC		4.33 A
inected (2 orifice nozzle)		3.52 B		-1.55 B		4.85 D		-1.87 C		0.42 E		9.66 C
injected (3 orifice nozzle)		4.23 B		-1.40 B		5.61 D		5.34 D		5.81 F		10.46 C
injected + washers		1.66 A		-3.47 A		5.95 D		-5.95 A		-4.65 A		10.47 C
injected 2 directions		3.77 B		-1.62 B		3.22 C		-5.93 A		-3.48 AB		6.22 B
injected (7.5 cm nozzle) + washers		---		---		---		-5.85 A		-3.68 AB		10.32 C
injected (7.5 cm nozzle) 2 directions		---		---		---		-3.54 B		-1.35 D		9.51 C
						LOGISTIC REGRESSION						
Source of variation												
Application Method	6	***	6	***	6	***	8	***	8	***	8	***
Date	12	***	12	***	10	***	5	***	5	***	5	***

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

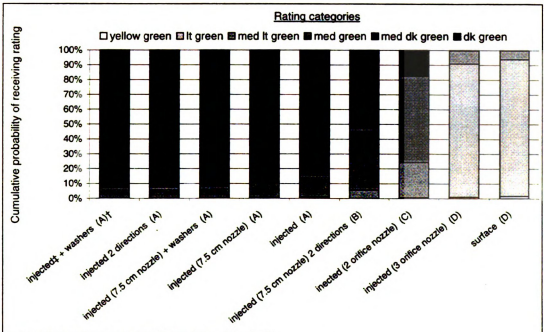
† Within columns, means sharing a letter are not significantly different ($P < 0.05$).

‡ Unless noted otherwise, injected treatements done with standard nozzle (15 cm depth).



† Bars sharing a letter are not significantly different ($P < 0.05$).
‡ Unless noted otherwise, injected treatements done with standard nozzle (15 cm).

Figure 27. Color rating probability distributions for application method effects. 1997.



† Bars sharing a letter are not significantly different ($P < 0.05$).
‡ Unless noted otherwise, injected treatements done with standard nozzle (15 cm).

Figure 28. Color rating probability distributions for application method effects. 1998.

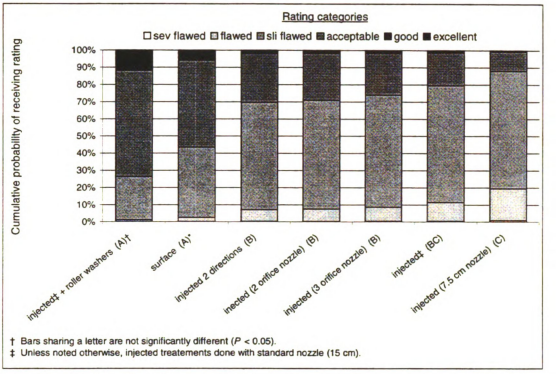


Figure 29. Quality rating probability distributions for application method effects. 1997.

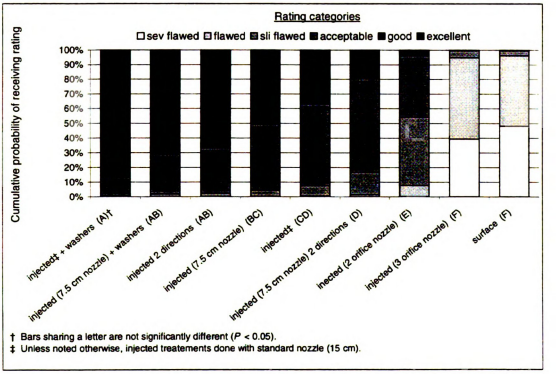
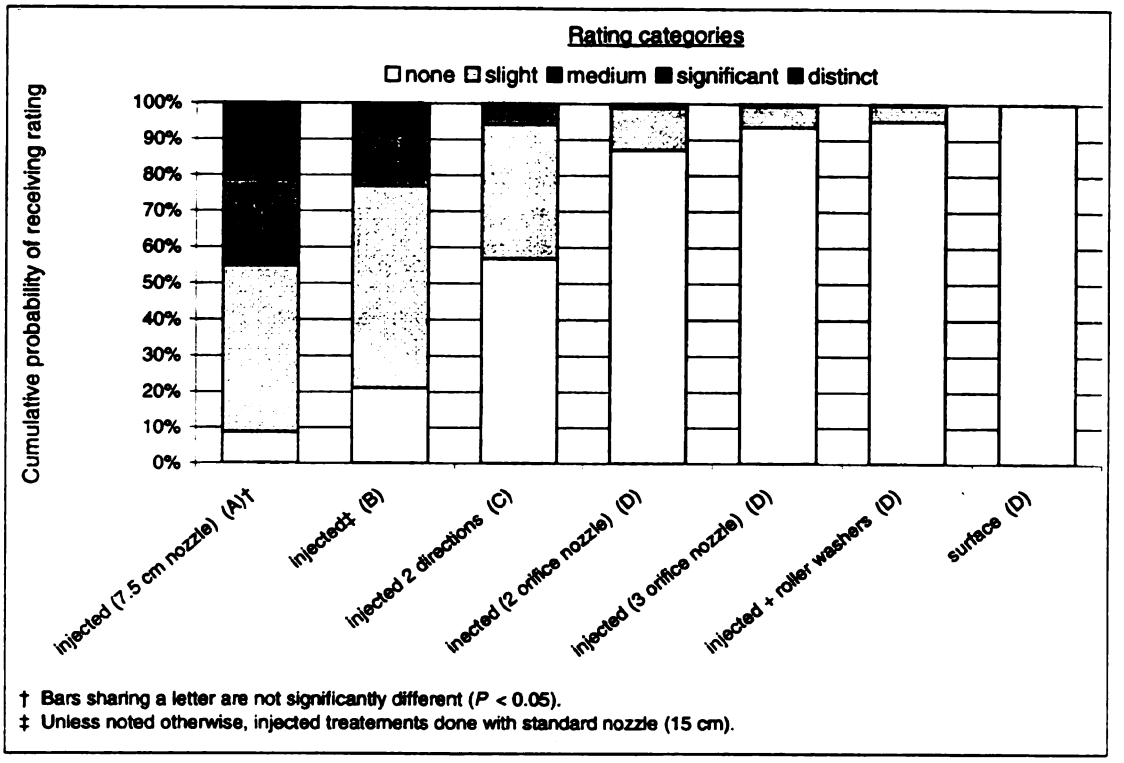
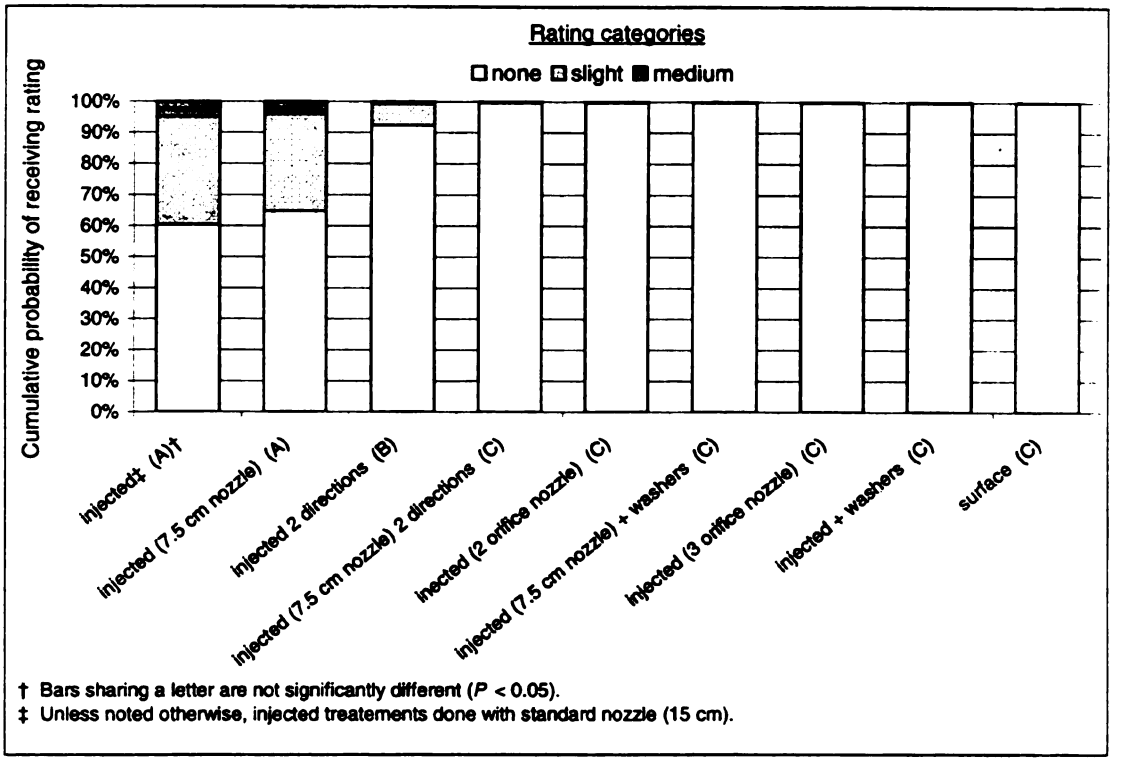


Figure 30. Quality rating probability distributions for application method effects. 1998.



† Bars sharing a letter are not significantly different ($P < 0.05$).
‡ Unless noted otherwise, injected treatements done with standard nozzle (15 cm).

Figure 31. Stripe rating probability distributions for application method effects. 1997.



† Bars sharing a letter are not significantly different ($P < 0.05$).
‡ Unless noted otherwise, injected treatements done with standard nozzle (15 cm).

Figure 32. Stripe rating probability distributions for application method effects. 1998.

The visual rating data suggest that putting green surface uniformity can be maintained when applying nitrogen via WIC by leaving the roller washers on. This technique applies nearly one half the nitrogen on the surface while injecting the remaining nitrogen to a 15 cm depth. Across years, this application method had equal surface uniformity and superior quality and color compared to surface applications.

CONCLUSIONS

Although results were variable, improved turfgrass responses from injecting nitrogen seemed to be the result of nitrogen placement beneath the surface rather than WIC. This is probably the result of concentrating nitrogen in close proximity to the majority of active creeping bentgrass roots, resulting in increased uptake and decreased opportunity for microbial immobilization. Equality among management practices in 1998 with regard to clipping yields and leaf nitrogen content may have resulted from remobilization of nitrogen from 1997 applications.

Subsurface nitrogen placement was most beneficial compared to surface applications at the low nitrogen rate. The current trend in nitrogen fertilization of putting greens is a low nitrogen rate. From the data here, subsurface fertilization may benefit turf managers using low nitrogen rates. However, the nitrogen injection process used in these experiments was relatively labor intensive and time consuming compared to traditional application methods and would likely be considered impractical by turf managers.

The unacceptable surface uniformity seen in previous nitrogen injection studies can be remedied by injecting a half rate of nitrogen while applying the remainder on the surface. This was accomplished by injecting nitrogen with the HydroJect while using the roller washers.

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APPENDIX A – "TURFRATE.SAS"

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                        contrast=, slice=, effect=, means=YES,
                        title=, summary=no, excelout=NO, anova=,
                      path=c:\OrdinalAnalysis );

%macro space(NUM);
%do t=1 %to &NUM;
%put;
%end;
%mend space;
%space(2);
%put TURFRATE NOTE: The macro 'turfrate.sas' has been initiated. Questions regarding the
application of this macro should be directed to karcherd@msu.edu.;
%space(2);
%put TURFRATE NOTE: The files 'PropOddsModel.sas' and 'pdmix612.sas' must be located in
the sasmacro directory for proper analysis!;
%space(2);

/* SET OPTIONS */

options ls=84 ps=64 nocenter notes;

/* CATEGORIES */

%if %length(&category)^=0 %then %do;
%let category= %upcase(&category);
%let n = 0;
%do g=1 %to %length(&category);
%let char=%qsubstr(&category,&g,1);
%if &char=%str( ) %then %do;
%let n = %eval(&n+1);
%let ind&n = &g;
%end;
%end;
%let ind0 = 0;
%let ind%eval(&n+1)= %eval(%length(&category)+1);
%do g=1 %to %eval(&n+1);
%let f = %eval(&g-1);
%let first=%eval(&&ind&f+1);
%let second=%eval(&&ind&g-&&ind&f-1);
%let cat&g=%substr(&category,&first,&second);
%end;
%let respnum = %eval(&n+1);
%end;
%else %if %length(&respnum)^=0 %then %do;
%do c=1 %to &respnum;
%let cat&c= P&c;
%end;
%end;
%else %do;
%put ERROR: EITHER CATEGORY NAMES OR CATEGORY NUMBER MUST BE PROVIDED;
```

```
%goto exit;
%end;
%put TURFRATE NOTE: RATING CATEGORIES:;
%do d=1 %to &respnum;
%put &&cat&d;
%end;
%space(2);

%if %length(&effect)=0 %then %do;

%include "&path\PropOddsModel.sas";
%include "&path\pdmix612.sas";

/* FACTORS AND MODEL STATEMENT */

%let factors= %qupcase(&factors);
%let n = 0;
%do g=1 %to %length(&factors);
%let char=%qsubstr(&factors,&g,1);
%if &char=%str( ) %then %do;
%let n = %eval(&n+1);
%let ind&n = &g;
%end;
%end;
%let ind0 = 0;
%let ind%eval(&n+1)= %eval(%length(&factors)+1);
%do g=1 %to %eval(&n+1);
%let f = %eval(&g-1);
%let first=%eval(&&ind&f+1);
%let second=%eval(&&ind&g-&&ind&f-1);
%let var&g=%substr(&factors,&first,&second);
%end;
%let varnum = %eval(&n+1);

%if %length(&model)=0 %then %do;
%let model=;
%do p=1 %to &varnum;
%let model=&model &&var&p;
%let sp0=0;  /* find the spaces */
%let n=0;
%do q=1 %to %length(&model);
%let char=%qsubstr(&model,&q,1);
%if &char=%str( ) %then %do;
%let n = %eval(&n+1);
%let sp&n = &q;
%end;
%end;  /* end find the spaces */
%let sp%eval(&n+1)= %eval(%length(&model)+1); /* parse model terms */
%do g=1 %to %eval(&n+1);
%let f = %eval(&g-1);
%let first=%eval(&&sp&f+1);
%let second=%eval(&&sp&g-&&sp&f-1);
%let term&g=%qsubstr(&model,&first,&second);
%let termnum = %eval(&n+1);
%end;  /* end parse model terms */
%let r= &termnum;
%let l=1;
```

```
%do %while (&r > 1);
%let model=&model &&term&l.%str(*)&&var&p;
%let l=%eval(&l+1);
%let r=%eval(&r-1);
%end;
%end;

%if %length(&block)^=0 %then %do;
%let model= &block &model;
%end;

%end;
%put TURFRATE NOTE: MODEL STATEMENT:;
%put MODEL &&response = &model;
%space(2);

/* END MODEL STATEMENT */

/* CONVERT EXCEL DATA TO SAS DATA */

%if %length(&excelin)^=0 %then %do;
%put TURFRATE NOTE: CONVERTING EXCEL 95 WORKSHEET INTO SAS DATA SET;
%space(2)
libname convert "&path";
proc access dbms=xls;
   create convert.xlsa.access;
   path = "&excelin";
   scantype  = yes;
    getnames  = yes;
   assign    = yes;
   unique    = yes;
   create Convert.xlsv.view;
   select all;
run;
data data; set convert.xlsv; run;
proc datasets library=convert; delete xlsv / memtype=view;
                               delete xlsa / memtype=access; run; quit;
%let data = data;
%space(2);
%put TURFRATE NOTE: END EXCEL CONVERSION. CONVERTED DATA SET = WORK.DATA.;
%space(2);
%end;  /* end excel conversion */

/* SHORTEN NAME IF FACTOR LENGTH = 8 */
%do h=1 %to &varnum;
%if %length(&&var&h)=8 %then %let var&h._ = _%substr(&&var&h, 1 ,7);
%if %length(&&var&h)^=8 %then %let var&h._ = _&&var&h;
%end;
/* END SHORTEN NAME */

/* DATA SUMMARY */

%if %upcase(&summary)=YES %then %do;
%put TURFRATE NOTE: DATA SUMMARY REQUESTED. SUMMARIZING DATA SET NOW.;
%space(2);
title 'PROPORTIOINAL ODDS MODEL';
title3 'Rating Data Summary';
```

```
title4 "Data = &data";
proc freq data=&data noprint;
tables &response / expected out=freq;
run;
%do y = 1 %to &varnum;
proc freq data=&data noprint;
tables &response*&&var&y / out=freq&y outpct;
run;
data freq; set freq freq&y;
label pct_row = 'Percentage of Treatment Ratings';
label pct_col = 'Percentage of Category Ratings';
run;
%end;
proc print data=freq label;
var &response
%do y = 1 %to &varnum;
&&var&y
%end;
count percent pct_row pct_col;
run;
%end;  /* end data summary */

/* INVOKE POM */

/* Test for contrasts and slicing */

%if %length(&contrast)^=0 %then %do;
%let contrast= contrast &contrast%str(;);
%end;

%if %length(&slice)^=0 %then %do;
%let slice= lsmeans &slice%str(;);
%end;

%if %upcase(&anova)=YES %then %do;
%put TURFRATE NOTE: ANOVA COMPARISON REQUESTED. PERFORMING ANOVA NOW.;
%space(2);
proc glm data=&data outstat=avtest noprint;
class &factors;
model &response = &model / ss3 ;
run;
%end;

%put TURFRATE NOTE: BEGINNING POM ANALYSIS.;
%space(2);

     %pom(data=&data,
         procopt=order=data,
           stmts=%str(
              class &factors;
              model &response = &model  / s;
              lsmeans &model / diff;
             &contrast
             &slice
              ),
         title=POM  &title,
         options=datasets predlsm noprint  );
```

```
/* END POM */

/* RESET OPTIONS */

options ls=84 ps=64 nonotes nocenter;

/* OUTPUT VARIOUS TESTS OF EFFECTS */

data tests; set _tests;
label _effect_ = 'Source of Variation';
label df = 'Degrees of Freedom';
label chi2 = 'Chi-Square Value';
label P = 'P > Chi-Square';
run;

%if %upcase(&anova)^=YES %then %do;
title2 ' ';
title3 'Analysis of Variation';
title4 "Data Set = &data";
proc print data=tests
label;
var _effect_ df chi2 p;
run;
%end;

%if %upcase(&anova)=YES %then %do;
title2 ' ';
title3 'Analysis Comparison: POM (POM) vs. Analysis of Variance (ANOVA)';
title4 "Data Set = &data";
data avtest; set avtest;
rename _source_ = _effect_;
n = _n_;
run;
proc sort data=avtest; by _effect_; run;
proc sort data=tests; by _effect_; run;
data bothtest;
merge tests avtest;
by _effect_;
drop _name_ _type_ SS;
label DF = 'Degrees of Freedom';
label F = 'ANOVA F Statistic';
label PROB = 'ANOVA (Prob>F)';
label CHI2 = 'POM Chi-Square Statistic';
label P = 'POM (Prob>Chi-Square)';
proc sort data=bothtest; by n; run;
proc print label data=bothtest (where=(P ne .)) noobs;
var _effect_ df chi2 f p prob;
run;
%end;

%if %length(&contrast)^=0 %then %do;
title3 'Test of Contrasts';
title4 "Data Set = &data";
data contr; set _contr;
label contrast = 'Source of Variation';
label df = 'Degrees of Freedom';
```

```
label chi2 = 'Chi-Square Value';
label P = 'P > Chi-Square';
proc print label; run;
%end;

%if %length(&slice)^=0 %then %do;
title3 'Test of Effect Slices';
title4 "Data Set = &data";
data slices; set _slices;
label df = 'Degrees of Freedom';
label chi2 = 'Chi-Square Value';
label P = 'P > Chi-Square';
proc print label; run;
%end;


/* OUTPUT PREDICTED PROBABILITIES */
%if %upcase(&means)=YES %then %do;
%space(2);
%put TURFRATE NOTE: PERFORMING MEANS SEPARATION TESTS FOR PROBABILITY PARAMETERS.;
%space(2);

title3'Predicted Category Probabilities (P = RATING CATEGORY)';
proc sort data=_probs; by _effect_ _p1; run;

proc format; value cat
%do v=1 %to &respnum;
&v = "&&cat&v"
%end;
; run;

%do x=1 %to &varnum;
title4 "for &&var&x effects";
data probs&x; set _probs;
if _effect_ = "&&var&x";
array names[&respnum] P1-P&respnum;
array _P[&respnum] _P1-_p&respnum ;
do i = 1 to &respnum;
names[i] = _p[i];
end;
drop _P1-_P&respnum i;

%do n=1 %to &respnum;
%if &&cat&n ^= P&n %then %do;
label P&n = "&&cat&n" ;
%end;
%end;

drop _effect_ ;
label level = "Level of &&var&x";
run;

/* Prepare lettering of treatment groups */

data lsm&x; set _lsm;
  if _effect_ = "&&var&x";
rename value = _lsmean_;
```

```
run;
data diffs&x; set _diffs;
   if _effect_ = "&&var&x";
   rename level = &&var&x;
   rename _level = &&var&x._;
   _PT_ = P;
run;
%pdmix612(diffs&x , lsm&x , sort=yes)
data msgrp; set msgrp;
keep level _lsmean_ msgroup;
run;
proc sort data=probs&x ; by level; run;
proc sort data=msgrp; by level; run;
data probs&x; set probs&x ;
merge probs&x msgrp;
by level;
label _lsmean_ = 'LS Mean' msgroup = 'Treatment Mean Groups';
run;
proc sort data=probs&x ; by descending _lsmean_; run;
proc print data=probs&x label; run;
proc sort data=msgrp; by level; run;
proc sort data=_probs; by level; run;
data msgrp&x; set _probs;
merge _probs msgrp;
by level;
run;
proc sort data=msgrp&x ; by descending _P1; run;

/* OUTPUT PROBS AND TREATMENT GROUPS TO EXCEL */

%if %upcase(&excelout)=YES %then %do;

%space(2);
%put TURFRATE NOTE: EXCEL OUTPUT REQUESTED. NOW ATTEMPTING TO TRANSFER AND GRAPH
PROBABILITES.;
%space(2);

data label;
array P[&respnum] p1-p&respnum;
do i = 1 to &respnum;
P[i] = i;
end;
format p1-p&respnum cat.;
drop i;
run;
filename label dde "excel|sas&x!r1c4:r1c100";
data label; set label;
file label;
put  P1-P&respnum ;
run;

filename outfil dde "excel|sas&x!r2c1:r100c100";
data msgrp&x; set msgrp&x;
if _effect_ = "&&var&x";
file outfil;
effect = "&&var&x";
put effect level msgroup _p1-_P&respnum ;
```

```
run;
%end;
/* END EXCEL OUTPUT */

%end;
%end;
/* END OUTPUT PREDICTED PROBABILITIES */

%end;  /* if effects = 0 */

/* OUTPUT INTERACTION EFFECTS */

%else; %if  %length(&effect)^=0 %then %do;

%space(2);
%put TURFRATE NOTE: EFFECTS OUTPUT REQUESTED FOR &EFFECT;
%put turfrate macro must be executed once prior to this request.;
%space(2);

/* Parse individual factors from interaction term */

%let effect=%upcase(&effect);
%let n = 0;
%do g=1 %to %length(&effect);
%let char=%qsubstr(&effect,&g,1);
%if &char=%str(*) %then %do;
%let n = %eval(&n+1);
%let ind&n = &g;
%end;
%end;
%let ind0 = 0;
%let ind%eval(&n+1)= %eval(%length(&effect)+1);
%do g=1 %to %eval(&n+1);
%let f = %eval(&g-1);
%let first=%eval(&&ind&f+1);
%let second=%eval(&&ind&g-&&ind&f-1);
%let var&g=%substr(&effect,&first,&second);
%end;
%let varnum= %eval(&n+1);

/* Assign proper variable name lengths for diffs data set */

%do k=1 %to &varnum;
%let var&k._ = _&&var&k;
%if %length(&&var&k)=8 %then %let var&k._ = _%substr(&&var&k, 1 ,7);
%if %length(&&var&k)^=8 %then %let var&k._ = _&&var&k;
%let length&k = %length(&&var&k);
%end;

/* Prepare probs data set */

title3'Predicted Category Probabilities (P = RATING CATEGORY)';
data probs3; set _probs;
if _effect_ = "&effect";
array names[&respnum] P1-P&respnum;
array _P[&respnum] _P1-_p&respnum ;
do i = 1 to &respnum;
```

```
names[i] = _p[i];
end;
drop _P1-_P&respnum i;

%do n=1 %to &respnum;
%if &&cat&n ^= P&n %then %do;
label P&n = "&&cat&n" ;
%end; /* label category values */
%end; /* label all category values */

drop _effect_ ;
label level = "Level of &effect";
run;

/* Prepare lettering of treatment groups */

title4 "for all &effect effects";

data lsm3; set _lsm;
  if _effect_ = "&effect";
rename value = _lsmean_;
run;

data diffs3; set _diffs;
if _effect_ = "&effect";

%let first=1;
%let length0=0;
%do h=1 %to &varnum;
%let i=%eval(&h-1);
%let second=%eval(&&length&h);
%let first=%eval(&first+&&length&i+1);
&&var&h = substr(level, &first, &second);
%end;

%let first=1;
%let length0=0;
%do h=1 %to &varnum;
%let i=%eval(&h-1);
%let second=%eval(&&length&h);
%let first=%eval(&first+&&length&i+1);
_&&var&h = substr(_level, &first, &second);
%end;

drop level _level;
_PT_ = P;
run;
data _diffs3; set diffs3;
keep _effect_

%do c=1 %to &varnum;
&&var&c
%end;
%do c=1 %to &varnum;
_&&var&c
%end;
;
```

```
run;

data diffs3;
merge _diffs3 diffs3;
run;

%pdmix612(diffs3, lsm3, sort=no)
data msgrp; set msgrp;
keep level _lsmean_ msgroup;
run;
proc sort data=probs3; by level; run;
proc sort data=msgrp; by level; run;
data probs3; set probs3;
merge probs3 msgrp;
by level;
label _lsmean_ = 'LS Mean' msgroup = 'Treatment Mean Groups';
run;

proc sort data=probs3; by level;  run;
proc print data=probs3 label; run;

data msgrp3; set _probs;
merge _probs msgrp;
by level;
run;

/* Output probs and letter groups to Excel */

%if %upcase(&excelout)=YES %then %do;
data label;
array P[&respnum] p1-p&respnum;
do i = 1 to &respnum;
P[i] = i;
end;
format p1-p&respnum cat.;
drop i;
run;

%let colnum=%eval(&varnum+3);
filename label dde "excel|interaction&varnum.!r1c&colnum.:r1c100";
data label; set label;
file label;
put  P1-P&respnum ;
run;
filename outfil dde "excel|interaction&varnum.!r2c1:r100c100";

data msgrp3; set msgrp3;
if _effect_ = "&effect";
%let first=1;
%let length0=0;
%do h=1 %to &varnum;
%let i=%eval(&h-1);
%let second=%eval(&&length&h);
%let first=%eval(&first+&&length&i+1);
&&var&h = substr(level, &first, &second);
%end;
```

```
run;

data msgrp3; set msgrp3;
file outfil;
effect = "&effect";
put _effect_
%do c=1 %to &varnum;
&&var&c
%put var&c = &&var&c;
%end;
msgroup _p1-_P&respnum ;
run;

%end; /* interaction excel out */
%end; /* two way interaction mean output */

/* RESET OPTIONS */

options ls=84 ps=64 notes center;

%exit:
%put TURFRATE NOTE: EXITING MACRO;

%mend turfrate;
```