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MSU Thesis
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ABSTRACT

QUANTITATIVE MEASUREMENT TECHNIQUES,
MAT-WEAR RELATIONSHIPS, AND CULTURAL FACTORS
AS RELATED TO TURFGRASS THATCH

By

David N. Duncan

The object of this investigation was to determine the most reliable thatch measurement technique for utilization in wear-mat studies and cultural factors as related to turfgrass thatch.

Thatch Measurement Technique Evaluations

Five methods for the quantitative measurement of thatch were evaluated for reliability on Kentucky bluegrass, annual bluegrass, and creeping bentgrass. The measurement techniques were (1) mm compression using a "thatchmeter," (2) physical depth, (3) verdure-thatch weight, (4) nonverdure-thatch weight, and (5) water displacement. An independent and multiple correlation-regression analysis was made with the "thatchmeter" as the dependent variable.

Based on repeatability values, the thatch weight technique (verdure or nonverdure depending on the species) was determined to be the most reliable method. However, it is too

time consuming to be practical for field conditions. The "thatchmeter" technique ranked intermediate in repeatability with thatch depth slightly less reliable. The water displacement method had poor repeatability for all three species.

Linear correlation and regression analysis on bentgrass showed a significant (1%) relationship between the "thatchmeter" and thatch depth and weight. Verdure and pseudothatch accounted for nearly all the variability in "thatchmeter" readings on Kentucky bluegrass. Ninety-eight percent of the variation in the "thatchmeter" measurements on bentgrass was attributed to thatch depth.

Recognizing its limitations for accuracy, the thatch depth measurement is preferred for use by the specialist in the field. However, the "thatchmeter," with further evaluation by turf professionals to establish limits of high and low resilience for various environments and grass species, offers potential value as a rapid means of monitoring year-to-year thatch accumulation and resiliency characteristics of greens turfs.

Mat-Wear Relationships on Bentgrass Greens

The comparative wear tolerance of creeping bentgrass (*Agrostis palustris* Huds.) putting greens as affected by various amounts of mat accumulation was investigated using a wear simulator. The amount of turfgrass mat most desirable in terms of improved wear tolerance without creating detrimental effects was also assessed.

Mat depth and organic matter weight measurements were used in the selection of five greens ranging from zero to heavy mat (0, 5.6, 9.3, 21.0, 35.5 mm). Comparative wear tolerance was determined by the wear endpoint method. Verdure weight, tissue succulence, subsurface soil penetrability using a penetrometer, and total cell wall content were evaluated as potential contributing factors to wear tolerance.

The increase in mat accumulation, from zero to heavy mat, produced a 400% increase in the number of wear revolutions to reach the endpoint. The largest increase was induced by an increase in the mat from a light (5.6 mm) to a moderate (9.3 mm) level. The penetrability of the soil beneath the mat generally decreased as the wear tolerance increased, suggesting a negative correlation. However, this was a minor response compared to the turfgrass wear aspects. Conversions of wear revolutions to time were utilized in ascertaining a desired range of mat accumulation. This study suggests the mat layer contributes to most of the wear differential on creeping bentgrass greens; and that a moderate level (8-10 mm or 200-220 mg/cm^2) of mat is most desirable.

Effects of Selected Cultural Factors

Long-term turfgrass cultural practices were evaluated as to their effects on thatch accumulation. The three studies utilized in this evaluation were (a) a nitrogen rate-mowing height study on Wintergreen chewings fescue (*Festuca rubra* var. *commutata*) with five nitrogen levels and two mowing heights, and on Merion Kentucky bluegrass (*Poa pratensis* L.)

with four nitrogen levels and two mowing heights; (b) a nitrogen carrier-rate-time of application study on Merion Kentucky bluegrass; and (c) a calcium arsenate study on Anhauser Kentucky bluegrass.

Sod plugs were harvested at random within each treatment, oven dried at 70 C, and the verdure and pseudothatch removed. The thatch layer was then analyzed for total organic matter on a mg/cm^2 basis.

Increased nitrogen rates from 0 to 5.8 kg/100 m^2/year and higher mowing heights from 1.9 to 3.8 cm produced significant increases in thatch accumulation for both species. In the case of nitrogen, thatch differences may be largely attributed to an increase in the growth rate of the plants. Increased carbohydrate synthesis causing increased root and rhizome growth can explain the increase in thatch at higher mowing heights.

Comparisons between three nitrogen carrier classifications showed that Milorganite® was not significantly different than NH_4NO_3 in altering thatch accumulation on a long-term basis. This response apparently resulted from leaching of soluble nitrogen due to heavy irrigation of the NH_4NO_3 treatment. Uramite®, a synthetic organic carrier, had an average of 25% less thatch than the other two categories.

The calcium arsenate treatment resulted in a 39% increase in thatch accumulation above the control. Herbicide inhibition of earthworm and microorganism activity in the soil and/or eradication of weedy species that would otherwise increase substrate concentration appears to be causing this response.

QUANTITATIVE MEASUREMENT TECHNIQUES, MAT-WEAR RELATIONSHIPS, AND CULTURAL FACTORS AS RELATED TO TURFGRASS THATCH

By

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To my wife Rose for her love, understanding, and assistance with this research and the preparation of this manuscript.

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INTRODUCTION

Turfgrass thatch has been and still remains a potential source of detriment to the quality of established turfs for lawns, golf courses, and other recreational areas. Thatch accumulation occurs under a broad spectrum of soil, cultural, and climate conditions. It can be found in varying amounts under both low and high fertility levels, numerous moisture regimes, and a wide range of cutting heights. No climatic region of the country is immune. A survey of several turf authorities conducted by the author reveals thatch to be under control on sports turfs in recent years in the cool-humid region. However, a large percentage of home and institutional lawn areas continue to experience potentially damaging amounts of thatch. Thatch, as defined in this study, is a tightly intermingled layer of dead and living vascular strands of stems, nodes of stems, crown tissue, mature leaf sheaths, and roots that develop above the soil line. Mat, however, is thatch in a state of further decomposition due to the intermixing of soil from topdressing and earthworm activity.

Cultural practices utilized to maintain high quality turfs are also usually conducive to increased thatch accumulation. The major cultural practices contributing to maximum thatch build-up are: the use of vigorously growing turfgrass cultivars, acidic fertilizer carriers, intensive irrigation, excessive nitrogen fertilizer applications, infrequent or excessively high mowing, and the use of certain pesticides (Beard, 1973).

Several associated problems cause turfgrass thatch to be considered undesirable. In approximate order of significance for cool-season grasses these include localized dry spots; decreased heat, cold, and drought hardiness; proneness to scalping; foot printing; increased disease and insect problems; and chlorosis. This order may vary depending on the function served by the turf and the species. Increased insect damage is more prevalent on warm-season species having an accumulation of thatch. Although a thatched turf often connotes an objectionable condition, a small amount of mat (a mixture of soil and organic debris) is desirable for resiliency on golf course putting greens and on athletic fields for improved wear tolerance of the turf and to minimize soil compaction. The amount of mat most conducive to improved wear tolerance but of minimal detrimental nature has not been determined.

At present, methods of controlling thatch accumulation emphasize mechanical procedures such as coring, grooving, slicing, spiking, and topdressing. Recently, a number of chemical and biological materials have been introduced with claims for controlling thatch biologically. Thus, researchers need a reliable technique for quantifying the thatch layer identified in order to have a representative means of assessing thatch control in field investigations.

A thorough understanding of the complex nature of thatch is essential. Many aspects have been investigated; however, such problems as thatch decomposition, thatch control via manipulation of cultural practices, thatch or mat levels most desirable for enhancement of quality playing surfaces, and effective thatch measurement must yet be resolved. Consequently, the objectives of this investigation were to (1) evaluate the accuracy and reliability of five techniques for measuring turfgrass thatch accumulation; (2) assess the effects of various amounts of turfgrass mat on the wear tolerance of creeping bentgrass greens; and (3) determine the effects of selected turfgrass cultural practices on thatch accumulation. Objective (1) was the first completed in order to ascertain the most reliable technique for thatch and mat measurement. On this basis, the second and third objectives were more confidently undertaken.

CHAPTER I

A COMPARATIVE EVALUATION OF FIVE THATCH MEASUREMENT TECHNIQUES ON THREE TURFGRASS SPECIES

ABSTRACT

The objective was to evaluate the reliability of five methods for the quantitative measurement of thatch on Kentucky bluegrass, annual bluegrass, and creeping bentgrass. The five measurement techniques were (1) mm compression using a "thatchmeter," (2) physical depth, (3) verdure-thatch weight, (4) nonverdure-thatch weight, and (5) water displacement. An independent and multiple correlation-regression analysis was made with the "thatchmeter" as the dependent variable.

Based on repeatability values, the thatch weight technique (verdure or nonverdure depending on the species) was determined to be the preferred method. However, it is too time consuming to be practical for field conditions. The "thatchmeter" technique ranked intermediate in repeatability with thatch depth slightly less reliable. The water displacement method had poor repeatability for all three species.

Linear correlation and regression analysis on bentgrass showed a significant (1%) relationship between the "thatchmeter" and thatch depth and weight. Verdure and pseudothatch accounted for nearly all the variability in "thatchmeter" readings on Kentucky bluegrass. Ninety-eight

percent of the variation in the "thatchmeter" measurements on bentgrass was attributed to thatch depth.

Recognizing its limitations for accuracy, the thatch depth measurement is preferred for use by the specialist in the field. However, the "thatchmeter," with further evaluation by turf professionals to establish limits of high and low resilience for various environments and grass species offers potential value as a rapid means of monitoring year-to-year thatch accumulation and resiliency characteristics of greens turfs.

INTRODUCTION

Turfgrass thatch is a tightly intermingled layer of dead and living sclerified vascular strands of stems, nodes of stems, crown tissue, mature leaf sheaths, and roots that develops above the soil line. This dense layer of organic debris should be distinguished from an upper layer of leaf remnants hereafter termed pseudothatch. Tissues comprising the thatch layer are the most resistant to decay, while those in the pseudothatch layer decompose more readily.

Excessive thatch accumulation remains a source of detriment to the aesthetic value and playing quality of established turfgrasses for golf courses, and particularly for lawns and recreational areas. Extensive damage to the sod may result if an excessive amount of thatch is allowed to develop. The need for monitoring year-to-year thatch accumulation is apparent, as is a reliable technique of thatch measurement to serve as a research tool.

Thatch measurement techniques that have been utilized include: physical depth using a scaled ruler, organic matter weight per unit area, and compressibility using a thatchmeter. The simplest and most frequently used technique is that of a physical depth measurement. Meinhold, Duble, Weaver, and Holt (1973) employed this technique in their nitrogen carrier studies by subtracting the mowing height (6.4mm) from all thatch depth measurements. Volk (1972) and Duble and Weaver (1969) simply removed the verdure and soil prior to measuring the thatch layer with a centimeter scale.

Two versions of the weight per unit area technique have been utilized. Meinhold, et al. (1973) washed and screened the thatch plugs to remove soil prior to weighing on an analytical balance. In contrast, Ledeboer and Skogley (1967) oven dried, weighed, and then ashed the thatch at 600 C. Total organic matter was calculated on the basis of weight lost upon ignition.

Recently, a thatch measurement technique for research and field conditions was proposed by Volk (1972). Using turf springiness as an indicator of thatch development, he constructed a "thatchmeter" to rapidly and effortlessly determine the compressibility of the surface. Volk found that thatchmeter regressions of compressibility on the rate of bermudagrass (*Cynodon dactylon*) shoot growth and on thatch weight and depth were statistically significant (.001).

There is no information in the literature concerning the comparative accuracy and reliability of turfgrass thatch measurement techniques as used by the professional turfman or researcher. Thus, the objective of this study was to evaluate five different methods for quantitatively measuring the thatch on Kentucky bluegrass (*Poa pratensis* L.), annual bluegrass (*Poa annua* L.), and creeping bentgrass (*Agrostis palustris* Huds.). These three species are commonly maintained on golf courses and sports fields throughout Michigan. The methods evaluated were:

(a) Thatchmeter - as a measure of resiliency or compressibility.

(b) Physical thickness measurement - non-compressed.

(c) Verdure - thatch weight (weight/unit area).

(d) Nonverdure - thatch weight (weight/unit area).

(e) Displacement of water (volume).

MATERIALS AND METHODS

Source of Thatch Samples

Three locations in the Southern Michigan area were selected for the comparative evaluation of thatch measurement techniques. The sites chosen represented mature turfgrass areas under which measurable amounts of uniform turfgrass thatch had developed. The description of the locations are as follows:

1) KENTUCKY BLUEGRASS TEE: The No. 5 golf tee, a par 4 hole, at Clio Country Club, Clio, Michigan, was chosen as the test site. The cultural practices applied to this turf were representative of golf tee conditions. The 'Merion' tee was established in 1965 on an unshaded, level, but well drained site that received light traffic and divoting. Thatch uniformity was not adversely affected by the minimal divoting. The soil was a sandy loam with a pH of 7.2 and soil phosphorus and potassium levels of 0.45 and 1.96 kg/are respectively (40 and 175 lbs./Acre). The cultural practices utilized included: (a) mowing at 3.8 cm (1.5 inches) three times per week with clippings returned; (b) a Milorganite^R and NH_4NO_3 nitrogen

fertility level of 2.9 kg per are per year (6 lbs./ 1000 ft^2) applied in 4 applications; (c) fungicide applications as necessary, no insecticides, an annual coring and vertical mowing, and an annual topdressing at the rate of 0.59 cu m/1000 ft^2; and (d) irrigation as needed to prevent wilt. The thatch had accumulated to a depth of approximately 19 mm (0.75 inch) and was slightly intermixed with soil from topdressing and earthworm activity.

2) ANNUAL BLUEGRASS FAIRWAY: The No. 14 fairway at LochMoor Country Club in Grosse Pointe, Michigan, was chosen as the second sampling site. It was selected on the basis of estimated predominance (85 - 90%) of annual bluegrass (*Poa annua* var *annua* Timm.) and an accumulation of 19 - 25 mm (0.75 - 1.0 inch) thatch depth. Creeping bentgrass was the other species present. The fairway site was an unshaded, level, poorly drained area that was established in 1917. The soil was a compacted clay loam with a pH of 6.3 and soil P and K levels of 0.82 and 4.86 kg/are respectively (73 and 434 lbs./Acre). The area received moderate traffic but little divoting since it was not in a landing zone. Cultural practices used included: (a) mowing three times weekly at 1.9 cm (0.75 inch) with clippings returned; (b) nitrogen fertilization with urea and inorganic sources at

a rate of 1.5 kg per are per year (3 lbs./1000 ft^2) applied in 3 applications; (c) pest control as needed but no insecticides used; (d) twice annual coring with cores removed but no vertical mowing; and (e) irrigation 6-7 times weekly plus frequent, light syringing to prevent midday wilt.

3) CREEPING BENTGRASS PUTTING GREEN: The third sampling site was on a seldom used practice putting green, located at Lake O' The Hills Golf Club, a par-3 golf course near East Lansing, Michigan. The 'Toronto' green was established in 1969 on a loamy sand soil, pH of 6.7, with soil P and K levels of 0.34 and 1.82 kg/are respectively (30 and 162 lbs./Acre). Drainage from the putting surface was excellent. The site was unshaded and received only light traffic. The cultural practices applied to this green included: (a) mowing at 0.64 cm (0.25 inch) three times per week with clippings removed; (b) urea nitrogen fertilization at 2.9 kg per are per year (6 lbs./1000 ft^2) applied in 3 applications; (c) pest control as necessary but no insecticides used; and (d) irrigation 3-4 times weekly with occasional supplemental waterings. The area received an annual coring and light topdressing and had accumulated a thatch layer of 6 - 13 mm (0.2 - 0.5 inch) thickness.

This study was conducted during the months of June and July, 1974. Each of the three locations was divided into 8 equal sized plots. The Kentucky bluegrass tee and annual bluegrass fairway were sectioned into 2.4 x 2.4 m plots. The bentgrass green was divided into smaller (1.2 x 1.2 m) plots due to limited greens area. At random, 9 thatchmeter readings were obtained and recorded on each plot for each species. Each site was mowed immediately prior to thatchmeter measurements. Then 8.35 cm (3.3 inch) diameter sod plugs were harvested from the precise spot where each of the thatchmeter readings was taken. A prototype of the thatchmeter was provided by Dr. Gaylord Volk from which a new model was constructed for use in these studies (Figure I.1).

Sample Preparation and Measurement

Preparation of the thatch samples was similar for all three species. All excess soil was removed from the bottom and sides of the sod plug and the verdure (all green plant material) carefully clipped away and placed in plastic bags for refrigeration and prevention of moisture loss. The verdure fresh weight was recorded for each sample for purposes of correlation with the thatchmeter readings. The remaining thatch and pseudothatch layers were oven dried at 70 C for 24 hours. After drying, the pseudothatch (distinct upper layer of leaf remnants) was removed leaving only the denser thatch layer. The pseudothatch dry weight was then recorded.

The physical depth measurements were taken by first making a radial cut through the thatch using a sharp razor blade. The average of three depth measurements in millimeters, taken across the face of the cut, was immediately recorded for each sample. For the three remaining techniques, the nine samples from each plot were divided as follows:

(A) samples 1-3 for verdure - thatch weight determination.

(B) samples 4-6 for nonverdure - thatch weight determination.

(C) samples 7-9 for water displacement determination.

For (A) and (B) the samples were weighed, ashed at 600 C for 10 hours, and total organic matter (thatch) calculated on the basis of weight lost upon ignition. The previously clipped verdure and pseudothatch was ashed with the thatch for (A). For (C), the surfactant, Aqua Gro, was used to reduce the surface tension resulting from total moisture removal. The recommended rate of one ounce per gallon of water proved adequate for this purpose. The milliliter rise in volume of the solution within a 100 ml graduated cylinder was recorded for each sample. The readings were taken upon complete submergence of the thatch sample. All data was entered on Fortran data punch cards for computer analysis.

Data Analysis

A completely randomized design with nested subsamples was used in this study. A one-way analysis of variance was conducted to determine the plot variance ($\hat{\sigma}_P^2$) and sample variance ($\hat{\sigma}_S^2$). Seventy-two observations were used in the analysis for the thatchmeter, depth, verdure, and pseudothatch measurements, and 24 observations for the organic matter and water displacement techniques. The repeatability quotient (R.Q.) of the 5 methods evaluated was based on the percentage of the total variability ($\hat{\sigma}_P^2 + \hat{\sigma}_S^2$) that was due to the sampling variability.

$$(R.Q.) = \frac{\hat{\sigma}_P}{\hat{\sigma}_P^2 + \hat{\sigma}_S^2}$$

The lower the R.Q. value the less the sampling variability, thus the more repeatable or reliable the technique.

A multiple factor approach was chosen to evaluate the influence of several independent variables on one dependent variable. By utilizing both simple and multiple regression - correlation analysis, the individual and combined influence of such parameters as thatch depth, thatch weight and volume, verdure weight, and pseudothatch weight on the thatchmeter response were evaluated. The thatchmeter was chosen as the dependent variable in an attempt to determine exactly which parameters it is measuring for the tee, fairway, and greens height turfs. Scatter diagrams were made of the significant relationships between the thatchmeter and the various other factors for all three species.

To test the relationship between the thatchmeter and the other techniques the following model was utilized:

$\hat{Y} = \overline{Y} + x_1 + x_2 + x_3 + x_4 + x_5 + x_6$, where $\hat{Y}$ is the dependent variable and $\overline{Y}$ is the constant. Three multiple linear regression and correlation analysis were accomplished. Simple correlation coefficients (r), and the square of the multiple correlation coefficient (R^2) were computed. R^2, also called the coefficient of determination, will be used in discussing the results of this investigation because its value shows the fraction of the total squared variation of a dependent variable which is related to a group of independent variables.

In conjunction with the multiple regression - correlation analysis, R^2 was calculated for selected subsets using the principle of variable selection. The method involves selecting the independent variable whose correlation with the dependent variable is greater than any of the other independent variables. This process is repeated until the addition of an independent variable results in an increase in the multiple R^2 which is less than 1%. The R^2 values calculated by this method give an indication of which factors are the most important in predicting the variation in the dependent variable.

RESULTS AND DISCUSSION

Comparisons of Measurement Techniques

The relative comparisons among the five thatch measurement techniques for three species are indicated in Table I.1. The comparisons are expressed as repeatability quotient values (R.Q.), with the lowest values indicating the highest degree of repeatability. There is a significant distribution of values among the five measurement techniques. R.Q. values ranged from as low as 0.05 to as high as 1.00 (the maximum), depending on the species.

The statistical analysis for Merion Kentucky bluegrass indicated that the nonverdure-thatch weight technique had the highest reliability. The thatchmeter, thatch depth, and the verdure-thatch weight techniques ranked in an intermediate grouping. The water displacement or volume measurement had the lowest reliability for all three species. For annual bluegrass thatch, the nonverdure-thatch weight measurement was again the most repeatable with the verdure-thatch weight method ranking a close second. The thatchmeter was intermediate again but thatch depth showed extremely low reliability. For Toronto creeping bentgrass both thatch weight techniques ranked highest in reliability with verdure-thatch weight being slightly better. The thatchmeter and thatch depth techniques were intermediate in repeatability.

The statistical results of this investigation indicate that the best overall technique for measuring thatch is the thatch weight technique. The decision of whether to measure verdure-thatch weight or nonverdure-thatch weight will depend on the turfgrass species involved. For instance, the verdure-thatch weight technique was not as repeatable for Merion Kentucky bluegrass as for the other two species. Presumably, this is attributable to a larger sample-to-sample variability caused by variations in verdure density between the three species. There is a significant increase in the repeatability of the verdure-thatch weight measurement as the cutting height was decreased from Kentucky bluegrass to annual bluegrass to creeping bentgrass. Cutting height also appears to influence the repeatability of the thatchmeter technique. The water displacement method was non-repeatable for all three species.

A possible reason that the thatchmeter and thatch depth techniques have only mediocre repeatability and the water displacement technique no repeatability is due to the inability of these methods to discriminate between organic matter and inorganic matter. The thatch layer for all three species was characterized by small but varying amounts of soil intermixed throughout due to topdressing and earthworm activity. The thatch weight techniques, employing ashing of the samples, separate these organic and mineral fractions. They are a more accurate measure of the organic fraction exclusive of all inorganic constituents.

Each measurement technique varied in time and equipment needs. The thatch depth and thatchmeter techniques were far less time consuming than the other three methods. Volk (1972) found that ten thatchmeter readings could be taken on a given green, recorded, and averaged in ten minutes. However, on the bentgrass green in this study, approximately 40 minutes were needed to complete 9 such readings. A four to five minute time period for each reading was necessary to allow for settling of the leaded weight into the thatch layer. Nevertheless, in terms of total time involved and equipment needs, the thatchmeter was comparable to the depth technique.

The water displacement technique, although simple in terms of equipment needs, was more time-consuming than either the thatchmeter or thatch depth methods. As much as 30 minutes for each sample was needed to submerge the thatch layer in the surfactant solution due to trapped air pockets.

The organic matter weight technique involved both extensive equipment needs and time-consuming procedures. Separating the thatch layer, weighing on the analytical balance, ashing for 10 hours in a muffle furnace, allowing to cool, and reweighing required approximately 15 hours per set of samples. Care was also taken to avoid weight fluctuations of the oven-dry thatch and pseudothatch by utilizing a dessicator jar to prevent accumulation of moisture from the air.

At present, thatch depth would be the preferred method for utilization by the professional turfman in the field, recognizing its limitations for accuracy. However, the researcher in a lab situation who is concerned with a greater degree of accuracy and precision and not restricted by time, should utilize the technique of organic matter weight calculated on the basis of weight lost upon ignition.

Independent and Multiple Correlation and Regression Analysis of Six Parameters on the Thatchmeter.

This part of the study attempted to evaluate the "thatchmeter" as an effective measurement of thatch on cool season turfgrasses. As stated previously, the thatchmeter was chosen as the dependent variable to determine exactly which parameters it is measuring for each of the three turfgrasses. The following independent parameters were selected for use in the statistical analysis:

TD - the physical depth of thatch; measured in millimeters.

TWV - the verdure-thatch weight; measured in mg/cm^2.

TWNV - the nonverdure-thatch weight; measured in mg/cm^2.

WD - the water displacement (volume) of thatch; measured in cc.

Vd - the verdure weight; measured in g/cm^2.

PsTh - the pseudothatch weight; measured in g/cm^2.

Correlation coefficients (r) for the six parameters with the thatchmeter are listed in Table I.2. Results for all three species indicate that three parameters are positively correlated at the 1% significance level with a fourth significant at the 5% level. Volk (1972) reported a 1% significance level for regression of the thatchmeter on thatch depth and weight on 0.64 cm cut bermudagrass. This was the case for the 0.64 cm cut creeping bentgrass tested in this study. The scatter diagrams (Figures I.2. and I.3.) for the linear correlation and regression analysis on creeping bentgrass show the highly significant relationship between the thatchmeter and the thatch depth and weight (TWV). The thatchmeter measurements on Kentucky bluegrass showed significant correlation and regression with verdure measurements and pseudothatch measurements (Figure I.4. and I.5.). Figure I.6. shows a 5% level of significance for thatch depth on annual bluegrass.

A stepwise least squares program using the principle of variable selection was utilized to estimate which factor was the most important in predicting variation in the dependent variable. For Kentucky bluegrass, verdure accounted for over 46% of the variation in the thatchmeter measurements (Table I.3.). The combined effects of verdure and pseudothatch accounted for 63% of the variation while the coefficient of determination, for all six variables, accounted for nearly 70% of the variation. This major influence of verdure and pseudothatch is further supported by the simple correlation coefficients in Table I.2.

Thatch depth of annual bluegrass accounted for 36% of the variation in the thatchmeter readings with only 39% accounted for by all six variables. Table I.2. substantiates this with a correlation coefficient ($r = .33$) significant at the 5% level. Nearly all of the thatchmeter variation (98%) was accounted for by the six independent variables in the analysis on creeping bentgrass (Table I.5.). Thatch depth accounted for most of this (97.5%) with the remaining variables failing to increase the R^2 significantly. Again, Table I.2. further supports this strong influence of depth ($r = .98$).

Based on these results, the thatchmeter cannot be utilized as an effective thatch measurement technique on turfs mowed higher than the range of recommended cutting heights (0.5 to 0.7 cm) for golf course putting greens. The thatchmeter, as it is now designed, does not have the capacity to exert a force sufficient to compress a thatch layer, irrespective of depth, through an abundance of shoot growth. The Kentucky bluegrass turf, mowed at approximately 3.8 cm, showed a significant correlation to the thatchmeter and a high coefficient of determination for verdure plus pseudothatch. However, the bentgrass turf, mowed at 0.64 cm (0.25 inch), showed no relationship between the two parameters and the thatchmeter. In view of the highly significant correlation between bentgrass thatch depth and the thatchmeter, the thatchmeter may offer the field turfman a relatively rapid means of monitoring year-to-year thatch accumulation and resiliency characteristics of greens turfs. Maintenance practices could then be adjusted accordingly.

Before this technique is to have value other than for research, further evaluation should be done by turf professionals to establish compression ranges (between excessive resilience and excessive hardness) for acceptable playing quality under various environments and turfgrass species.

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Table I.1. Repeatability quotients (R.Q.) for five thatch measurement techniques on three turfgrass species.

Species	Measurement Techniques (R.Q.)[1]				
	Thatchmeter	Thatch Depth	Thatch Weight (Verdure)	Thatch Weight (Nonverdure)	Water Displacement
Kentucky bluegrass	0.51	0.55	0.74	0.29	1.00
Annual bluegrass	0.55	0.91	0.29	0.22	1.00
Creeping bentgrass	0.38	0.40	0.05	0.15	1.00

[1]R.Q. values: lowest values indicate highest degree of repeatability.

Table I.2. Simple correlation coefficients (r) of six independent parameters with the thatchmeter as the dependent variable for three turfgrass species.

Species	Correlation Coefficients (r)					
	Thatch Depth	Thatch Weight (Verdure)	Thatch Weight (Nonverdure)	Water Displacement	Verdure Weight	Pseudothatch Weight
Kentucky bluegrass	0.13	0.05	-0.08	-0.06	0.54**	0.35*
Annual bluegrass	0.33*	0.28	-0.05	-0.21	0.11	0.28
Creeping bentgrass	0.97**	0.74**	0.33	0.22	0.15	0.10

*Significant at the 5% level.
**Significant at the 1% level.

Table I.3. The coefficients of determination for 'Merion' Kentucky bluegrass with the thatchmeter as the dependent variable.[1]

Independent Variable	R^2
Vd	0.467
Vd + PsTh	0.633
Vd + PsTh + TD	0.687
Vd + PsTh + TD + TWV	0.698
All 6 Variables	0.699

[1]Kentucky Bluegrass: TM = TD + Vd + PsTh + TWV + TWNV + WD.

Prediction Equation for Kentucky Bluegrass: $\hat{Y}$ = 13.7089 TD + 0.1429 Vd + 0.0092 PsTh + 1.9525 TWV + 0.0055 TWNV - 0.0181 WD - 7.3154.

Table I.4. The coefficients of determination for annual bluegrass with the thatchmeter as the dependent variable.[1]

Independent Variable	R^2
TD	0.363
TD + PsTh	0.381
TD + PsTh + TWV	0.391
TD + PsTh + TWV + Vd	0.392
All 6 Variables	0.393

[1]Annual Bluegrass: TM = TD + Vd + PsTh + TWV + TWNV + WD.

Prediction Equation for Annual Bluegrass: $\hat{Y} = 0.4169\ TD - 0.9628\ Vd + 0.0676\ PsTh + 0.0025\ TWV - 0.0303\ TWNV + 0.0090\ WD + 5.6482$.

Table I.5. The coefficients of determination for 'Toronto' creeping bentgrass with the thatchmeter as the dependent variable.[1]

Independent Variable	R^2
TD	0.975
TD + TWV	0.977
TD + TWV + Vd	0.978
TD + TWV + Vd + PsTh	0.980
All 6 Variables	0.981

[1]Creeping Bentgrass: TM = TD + Vd + PsTh + TWV + TWNV + WD.

Prediction Equation for Creeping Bentgrass: $\hat{Y}$ = 1.0091 TD - 0.9628 Vd + 0.0676 PsTh + 0.0025 TWV - 0.0300 TWNV + 0.1082 WD - 3.2981.

Figure I.1. Thatchmeter. The base has a bearing pressure of $7.3\ g/cm^2$, and the lead cylinder is loaded to $570\ g/cm^2$. Compression is read in mm with 10X magnification.

Figure I.2. Correlation and regression of compressibility of thatch on thatch depth for 'Toronto' creeping bentgrass.

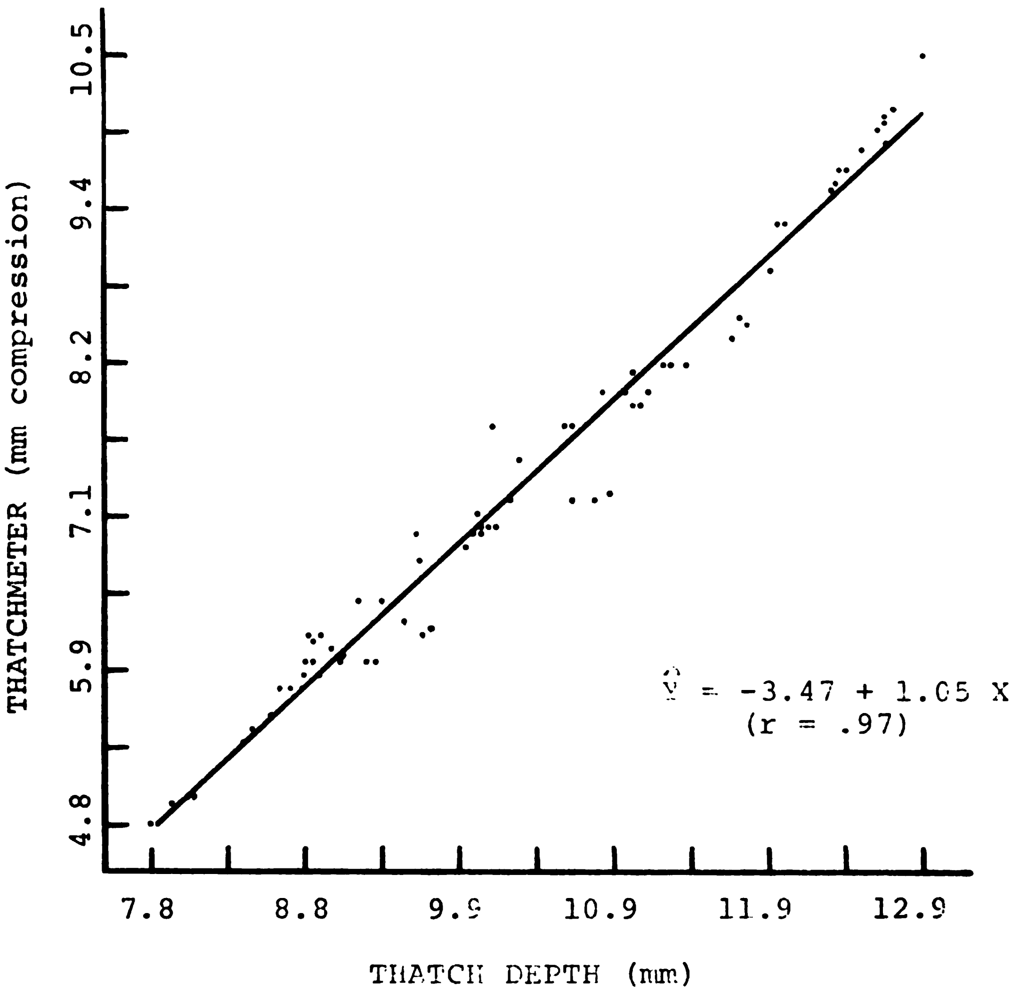

THATCHMETER (mm compression)
10.5
9.4
8.2
7.1
5.9
4.8
Ŷ = -3.47 + 1.05 X
(r = .97)
7.8
8.8
9.9
10.9
11.9
12.9
THATCH DEPTH (mm)

Figure I.3. Correlation and regression of compressibility of thatch on verdure-thatch weight for 'Toronto' creeping bentgrass.

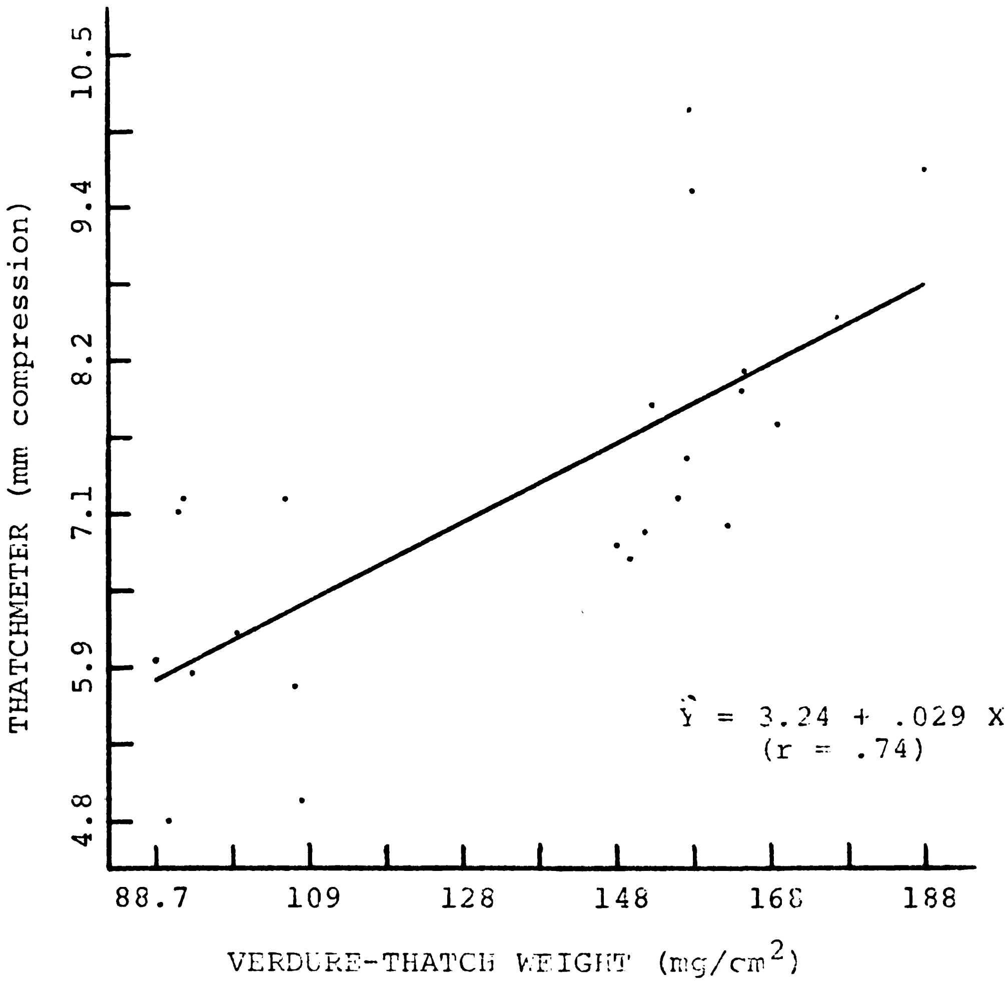

THATCHMETER (mm compression)
10.5
9.4
8.2
7.1
5.9
4.8
88.7
109
128
148
168
188
VERDURE-THATCH WEIGHT (mg/cm^2)
$\hat{Y}$ = 3.24 + .029 X
(r = .74)

Figure I.4. Correlation and regression of compressibility of thatch on verdure weight for 'Merion' Kentucky bluegrass.

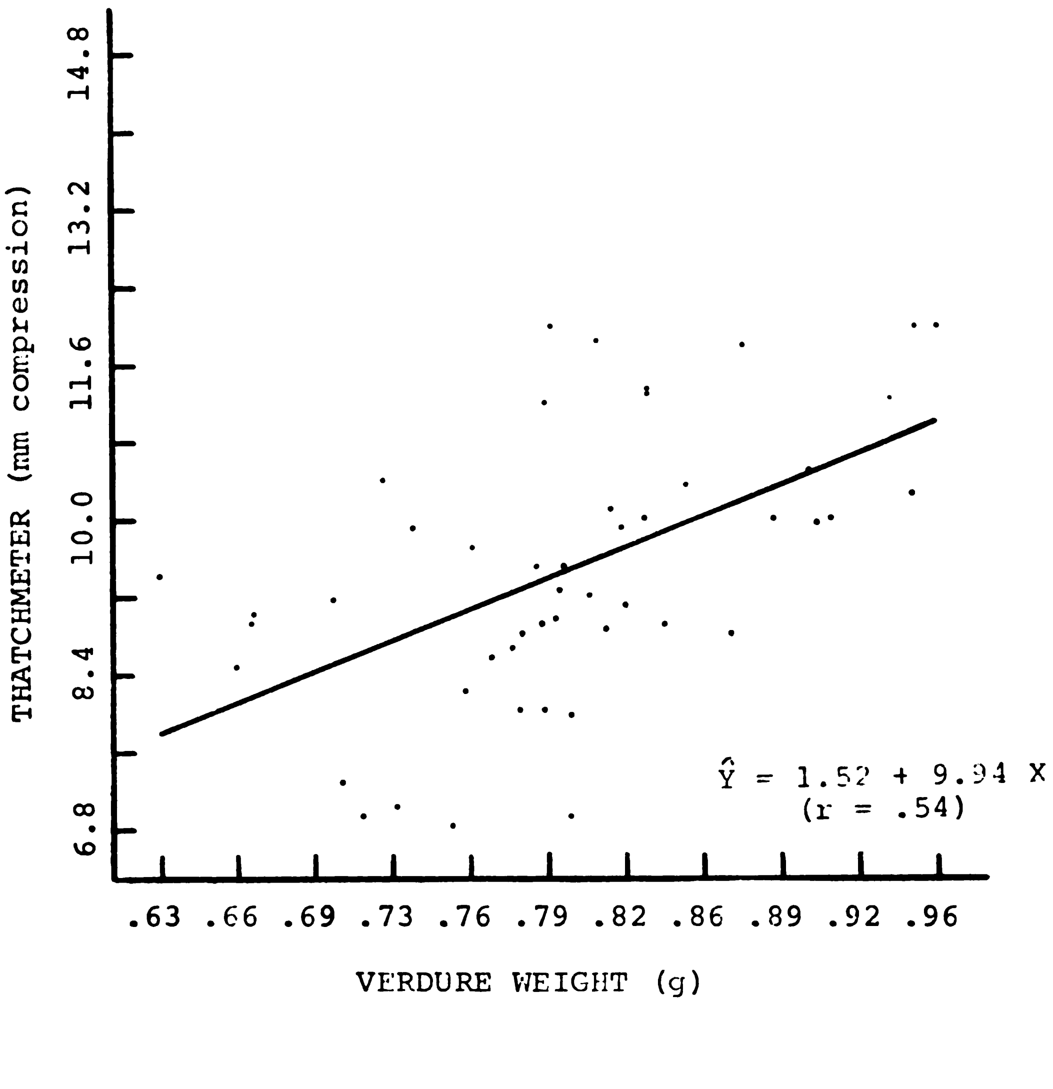

14.8
13.2
11.6
10.0
8.4
6.8
THATCHMETER (mm compression)
$\hat{Y} = 1.52 + 9.94\ X$
$(r = .54)$
.63 .66 .69 .73 .76 .79 .82 .86 .89 .92 .96
VERDURE WEIGHT (g)

Figure I.5. Correlation and regression of compressibility of thatch on pseudothatch weight for 'Merion' Kentucky bluegrass.

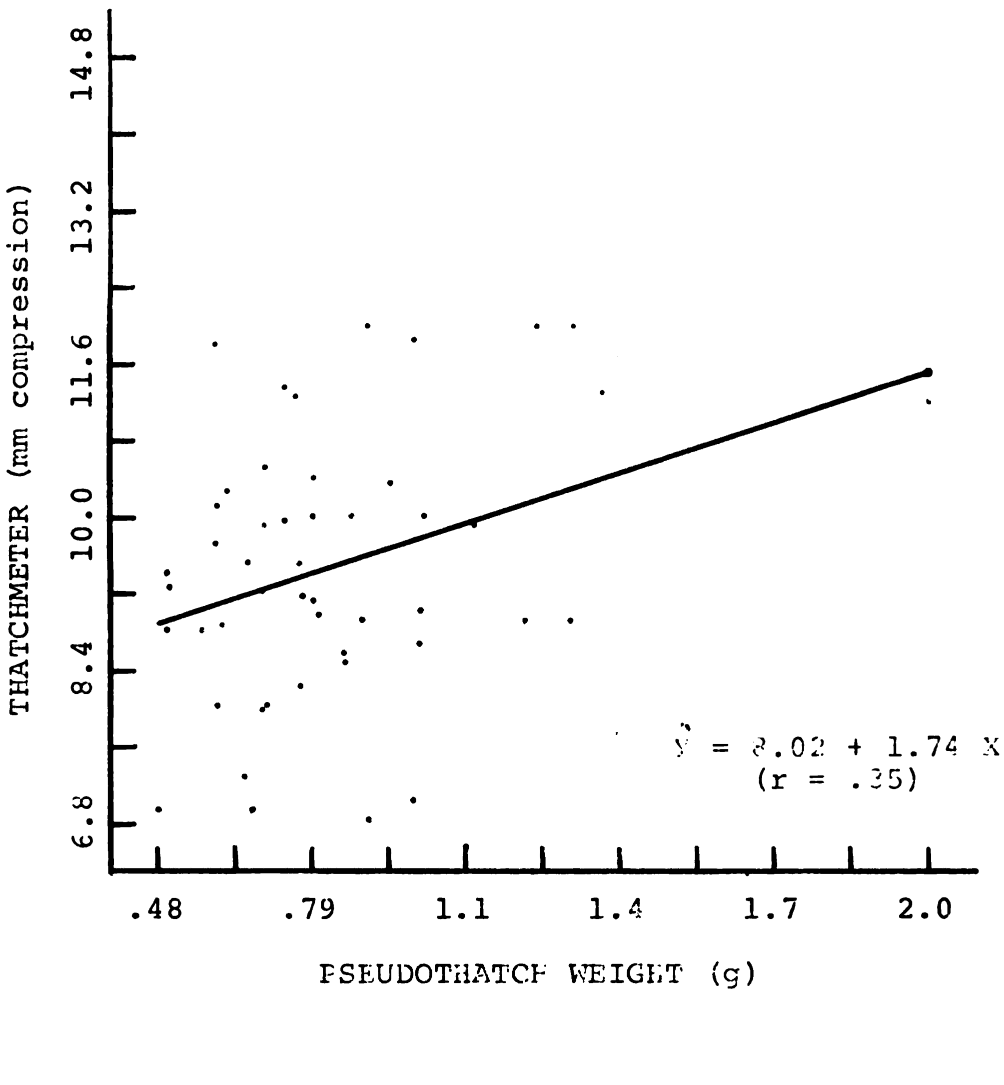
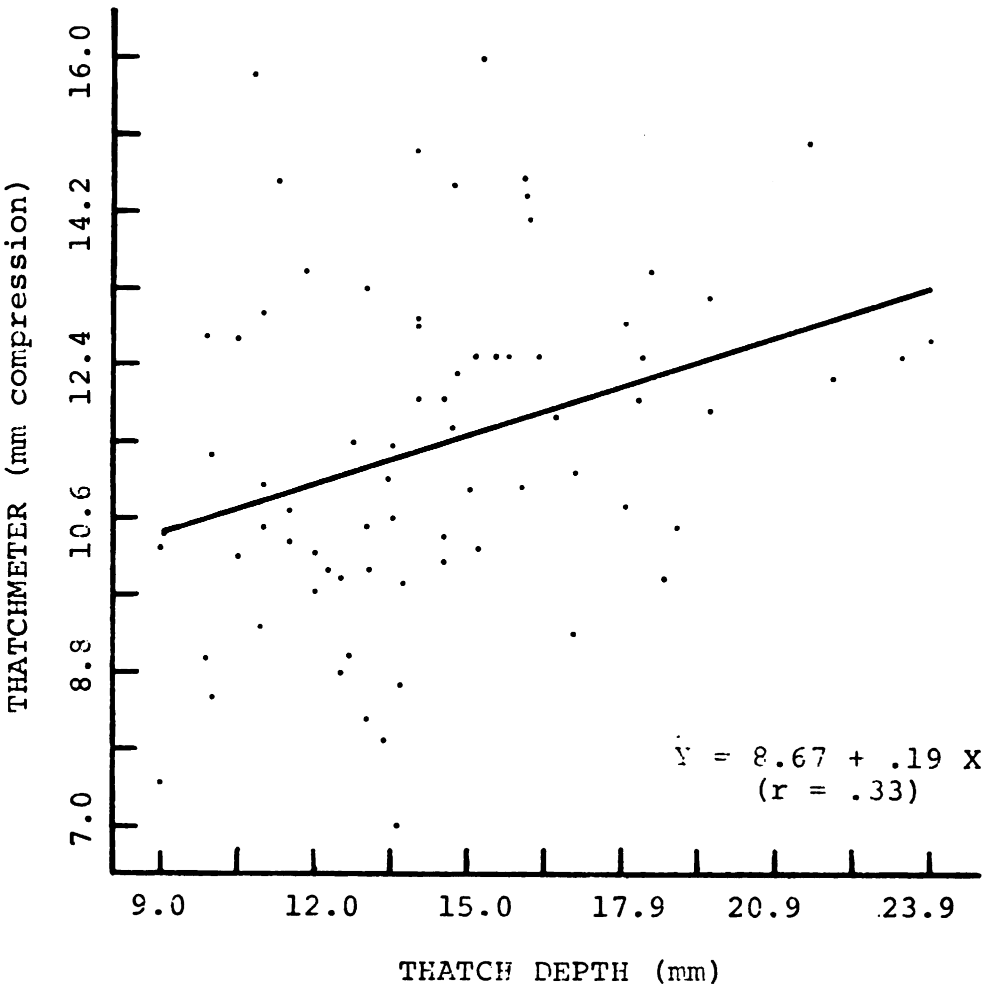

THATCHMETER (mm compression)
14.8
13.2
11.6
10.0
8.4
6.8
.48
.79
1.1
1.4
1.7
2.0
PSEUDOTHATCH WEIGHT (g)
Ŷ = 8.02 + 1.74 X
(r = .35)

Figure I.6. Correlation and regression of compressibility of thatch on thatch depth for annual bluegrass.


THATCHMETER (mm compression)
16.0
14.2
12.4
10.6
8.8
7.0
Y = 8.67 + .19 X
(r = .33)
9.0
12.0
15.0
17.9
20.9
23.9
THATCH DEPTH (mm)

CHAPTER II

THE COMPARATIVE EFFECTS OF FIVE LEVELS OF TURFGRASS MAT ON WEAR TOLERANCE OF BENTGRASS GREENS

ABSTRACT

The comparative wear tolerance of creeping bentgrass (Agrostis palustris Huds.) putting greens as affected by various amounts of mat accumulation was investigated using a wear simulator. Mat was defined as thatch in a state of further decomposition due to intermixing of soil from top-dressing and earthworm activity. The amount of turfgrass mat most desirable in terms of improved wear tolerance without creating detrimental effects associated with excessive mat was also assessed.

Mat depth and organic matter weight measurements were used in the selection of five greens ranging from zero to heavy mat (0, 5.6, 9.3, 21.0, 35.5 mm). Comparative wear tolerance was determined by the wear endpoint method. Verdure weight, tissue succulence, subsurface soil penetrability using a penetrometer, and total cell wall content were evaluated as potential contributing factors to wear tolerance.

The increase in mat accumulation, from zero to heavy mat, produced a 400% increase in the number of wear revolutions to reach the endpoint. The largest increase was induced by an increase in the mat from a light (5.6 mm) to a moderate (9.3 mm) level. The penetrability of the soil beneath the mat generally decreased as the wear tolerance

increased, suggesting a negative correlation. However, this was a minor response compared to the turfgrass wear aspects. Conversions of wear revolutions to time were utilized in ascertaining a desired range of mat accumulation. This study suggests the mat layer contributes to most of the wear differential on creeping bentgrass greens; and that a moderate level (8 - 10 mm or 200 - 220 mg/cm^2) of mat is most desirable.

INTRODUCTION

Wear on turfgrasses results from the direct pressure of concentrated foot and vehicular traffic causing a crushing of leaf, stem, and crown tissue of the plant. Beard (1973) reported wear tolerance to vary according to (a) turfgrass species and cultivar, (b) intensity of turfgrass culture, (c) intensity and type of traffic, and (d) the environment. Thatch accumulation, a secondary factor related to a high intensity of turfgrass culture, has also been reported to effect wear tolerance. Perry (1958) and Youngner (1961) observed that a small amount of thatch gave the turf greater wear tolerance. This is particularly desirable for golf course putting greens, bowling greens, and other heavily trafficked, close cut turfgrass areas that are without the benefit of abundant shoot growth.

Recently, several studies have been conducted involving the use of wear simulators. Except for the machine designed by Shearman et al. (1974), existing wear simulation machines are similar in that they fail to separate the effects of turfgrass wear and soil compaction. Shearman et al. (1974) designed their machine to simulate turfgrass wear while minimizing the effects of compaction during treatment. Shildrick (1971) and Wood and Law (1972) reported wear tolerance variations among Kentucky bluegrass (*Poa pratensis* L.) cultivars using their respective wear-compaction simulators. Intraspecies wear differentials were also determined for Kentucky bluegrasses by Anda and Beard (1975). Shearman and Beard (1975) reported on the relative wear tolerances of seven cool season turfgrass species determined by both sled (foot-like) and wheel (vehicular) wear injury.

This study involved the use of a wear simulator for accelerating the effects of traffic. The objectives were (1) to make a detailed assessment of the effects of various amounts of turfgrass mat on the wear tolerance of creeping bentgrass (*Agrostis palustris* Huds.) greens, and (2) to determine the amount of turfgrass mat accumulation most desirable for improved turfgrass wear tolerance. It was anticipated this information may provide the professional turfman with further insight into the importance and desirable quantity of mat for improved wear tolerance.

Mat, as defined in this study, is thatch in a state of further decomposition due to the intermixing of soil from topdressing and earthworm activity.

MATERIALS AND METHODS

Source of Mat

After an extensive search throughout the Southern Michigan area, five sites were chosen for use in this study. The sites selected represented creeping bentgrass golf course putting greens, ranging in mat depth from zero to approximately 35 mm and in organic matter weight from zero to 652 mg/cm^2. Due to the prevalent practice of topdressing putting greens for thatch control, accumulations of thatch (without soil interspersed) could not be found. Thus, this study utilizes various levels of mat accumulation. The description of the locations are summarized in Table II.1.

For the site selection process, four, 10 cm diameter plugs were sampled for determination of mat depth and organic matter weight. The aforementioned greens were chosen on the basis of a good distribution of mat depth and weight for comparison purposes.

Determination of Turfgrass Wear Tolerance

Each green was mowed at its respective cutting height just prior to the imposition of wear. The imposition of wear upon the turfs was accomplished with a wear simulator developed at MSU by Shearman, Beard, Hansen, and Apaclla (1973) through support of the USGA Green Section (Figure II.1). A wear endpoint similar to that reported by Youngner (1961) and Shearman and Beard (1975) was chosen to evaluate the mat-wear relationships. The wear tolerance was determined by the number of revolutions necessary to shread all leaf blades from the sheaths with only stems and bare soil or mat remaining. At this point the wear machine was stopped and the revolutions recorded. The procedure was repeated three times for each green and mat level. There was no moisture present on the leaves when wear treatments were imposed. No apparent disease activity was present at the time of the wear treatments which were conducted during the month of August, 1974.

Additional Parameters Measured

Not all factors affecting wear tolerance could be controlled or eliminated. The turfgrass tissue succulence was one such parameter measured at the time of wear imposition. Four leaf and stem samples from each green were placed in small (2.5 cm diameter) ground glass vials. The dry weight, obtained by oven drying at 70 C for 24 hours, was divided by the wet weight of the tissue samples. Resultant calculations were multipled by 100 to obtain a percentage value based on the wet weight of the verdure. The larger the value the more succulent the plant tissue.

Another factor measured was the relative subsurface soil compaction or resistance of the soil beneath the mat layer. This was accomplished with a penetrometer which measured the pressure in kg per cm^2 required to penetrate the soil. The penetrability of a soil zone 3.8 cm in depth, beneath the mat, was measured for this study by penetrating the device 3.8 cm beyond the mat depth. Six readings were taken per area and the pressures calculated by subtracting the mat depths from the total depths.

A third parameter, total cell wall (TCW), was determined using the method outlined by Goering and Van Soest (1970). Leaf clippings from each green were dried at 70 C for 24 hours, and ground in a Wiley Mill using a 1 mm screen. Four one-gram replicates from each green were then analyzed for TCW content using a neutral - detergent solution and a refluxing process. TCW content was then calculated on a grams TCW per gram of tissue basis.

The unworn verdure wet weights of the five greens, the fourth parameter, were determined by simply clipping the verdure from four 10 cm diameter plugs per green and weighing on a gram per unit area basis.

<u>Data Analysis</u>

A completely randomized block analysis of variance was made on each of the factors. Means were separated with the Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Results of the effects of various levels of creeping bentgrass mat on wear tolerance are shown in Table II.2. Wear tolerance was based on the number of revolutions to reach the predetermined endpoint. Ideally, more than three replications should be run due to the arbitrary nature of the comparable endpoint method. However, dependence on privately owned golf course putting greens dictated the extent of damage that could be imposed on these turfs. Fortunately, the variability among replications was not significant in this study.

The degree of wear tolerance differentiation among the five levels studied was significant ($r = .98$). A 650% increase, from zero, in the organic matter weight of the mat produced nearly a 400% increase, from an average of 86, in the number of revolutions required to reach the wear endpoint. The increase in organic matter weight from light (78.4 mg/cm^2) to moderate (210.5 mg/cm^2) and the increase in mat depth from 5.6 mm to 9.3 mm produced the largest percentage increase in wear tolerance (wear revolutions). Additional increments of mat caused a much slower rate of increase.

Of the additional parameters measured, the verdure weight, tissue succulence, and total cell wall content showed no significant differences among treatments. Thus, they had no significant influence on wear tolerance between or among the two cultivars (Toronto and Washington) in this study. However, the penetrability of the soil beneath the mat layer, measured with a penetrometer, showed significant differences (Table II.3.). The 20.8 kg/cm^2 measurement for zero mat accumulation is of the surface 3.8 cm and suggests a compacted soil condition due to the lack of a mat layer. The other four values are subsurface measurements which are significantly lower than the surface measurement. The general trend was for the penetrability of compaction values to decrease as the wear tolerance increased. This relationship suggests a negative correlation between the two factors ($r = -.41$). However, the decrease in penetrability by no means accounts for the very large (400%) increase in wear tolerance (simulator revolutions). Also, the difference in wear tolerance of the two cultivars was assumed insignificant based on their respective verdure wet weights and total cell wall contents. Thus, the mat layer is contributing to most of the wear differential. Based on the data presented in these two tables, the importance of mat in enhancing wear tolerance and minimizing soil compaction is evident. Although there is variability in soil and management conditions between the five greens evaluated, the large differences in mat accumulation are likely sufficient to mask this variability.

The second objective of this investigation was to determine the range of turfgrass mat accumulation (weight or depth) most desirable from a wear tolerance standpoint but not of a detrimental level. A detrimental accumulation of mat may cause proneness to mower scalping, foot printing, localized dry spots, chlorosis, increased disease and insect problems and generally poor putting quality. However, due to the intermixing of soil throughout the organic debris, problems from decreased heat, cold, and drought hardiness are essentially negated.

The average number of revolutions to reach the predetermined endpoint was converted to time (Table II.4.). The two lowest amounts of mat withstood only 10.8 and 26.5 minutes of concentrated wear, respectively. The third depth, 210.5 mg/cm^2 or 9.3 mm of mat, endured nearly 2.5 hours of simulated wear, representing the largest percentage increase. The fourth and fifth mat depths tolerated the most wear, nearly 6 and 7 hours respectively. But it is likely the point of diminishing returns was reached at the third mat depth. Rarely will a turf be subjected to concentrated traffic of such duration and intensity. However, the first two mat depths failed to provide the playing surface with adequate protection from such wear. The author also noted an incidence of foot printing and some mower scalping on the two greens with the heavier mat accumulations.

Based on these results and observations, a range of mat depth can be maintained between 8.0 mm and 10.0 mm, and mat weight in the range of 200 mg/cm^2 to 220 mg/cm^2, for improved wear tolerance without creating problems commonly associated with excessive mat accumulation on greens.

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Table II.1. Site descriptions summary for five creeping bentgrass putting greens utilized in the mat-wear study.

Location and Cultivar	Dunham Hills Pontiac, MI Toronto	Forest Akers E.Lansing, MI Toronto	Lake 'O The Hills Haslett, MI Toronto	Kearsley Lake Flint, MI Washington	Elks C.C. Grand Rapids, MI Washington
Mat Quantity (depth mm) (weight mg/ cm^2)	None	5.6 mm 78.4 mg/cm^2	9.3 mm 210.5 mg/cm^2	21.0 mm 450.0 mg/cm^2	35.5 mm 652.1 mg/cm^2
Date Established	1966	1970	1969	1950	1912
Soil Type and pH	Loamy sand pH 7.6	Loamy sand pH 7.6	Sandy loam pH 6.7	Loam pH 7.8	Loam pH 7.3
Traffic and Drainage	Intense Good surface and subsurface drainage	None Good surface and subsurface drainage	Light Good surface and subsurface drainage	None Good surface drainage	Light Good surface and subsurface drainage
P and K levels ($kg/100m^2$)	0.75 0.85	1.19 0.41	2.00 1.14	0.09 0.57	1.45 1.08
Mowing Culture	0.6 cm height 6 X weekly clippings removed	0.6 cm height 2 X weekly clippings removed	0.6 cm height 3 X weekly clippings removed	0.7 cm height 3 X weekly clippings removed	0.5 cm height 6 X weekly clippings removed

Table II.1. (Cont'd.)

Irrigation	As needed to prevent wilt	As needed to prevent wilt	As needed to prevent wilt, occasional mid-day syringing	As needed to prevent wilt	As needed to prevent wilt, occasional mid-day syringing
Nitrogen Fertility	Urea at 3.9 kg/100 m^2 in 8 applications	Milorganite and NH_4NO_3 at 3.4 kg/100 m^2 in 4 applications	Urea at 2.9 kg/100 m^2 in 3 applications	Milorganite, Urea and NH_4NO_3 at 5.8 kg/100 m^2 in 6 applications	Urea and Milorganite at 2.5 kg/100 m^2 in 3 applications
Pest Control	Fungicides as needed, No insecticides	Fungicides as needed, Diazinon for insect control	Fungicides as needed, No insecticides	Fungicides as needed, Chlorinated hydrocarbons for insect control	Fungicides as needed, Chlorinated hydrocarbons yearly for insect control
Cultivation and Topdressing	Annual coring with plugs removed, No topdressing, No vertical mowing	Annual coring with plugs removed, Annual topdressing at 0.59 cu m/9.3 m^2, Annual vertical mowing	Annual coring with plugs removed, Annual topdressing at 0.3 cu m/9.3 m^2, Annual vertical mowing	Annual coring with plugs retained, No topdressing, No vertical mowing	Annual coring with plugs removed, Twice annual topdressing at 0.3 cu m/9.3 m^2, Annual vertical mowing

Table II.2. Comparison of wear tolerance as influenced by five depths and weights of creeping bentgrass mat utilizing the wear machine operated until a comparable endpoint was achieved.

Organic matter* weight of mat (mg/cm^2)	Physical depth* of mat (mm)	Number of machine revolutions to reach the endpoint				
		Replication			Avg.	
		I	II	III		
0	0	58	113	88	86	a**
78.4	5.6	235	221	180	212	b
210.5	9.3	1222	1176	1254	1217	c
450.0	21.0	2806	2900	2787	2831	d
652.1	35.5	3340	3301	3409	3350	e

*Values are averages of 4 replications.
**Values with the same letter are not significantly different at the 5% level, using Duncan's Multiple Range Test.

Table II.3. A comparison of penetrability as measured by a penetrometer with the wear tolerances of five levels of creeping bentgrass mat.

Levels of mat accumulation (mg/cm^2)	Avg number of revolutions to reach the endpoint	Pressure required to penetrate a zone 3.8 cm in depth beneath the mat layer (kg/cm^2)
0	86	20.8 a*
78.4	212	11.5 c
210.5	1217	14.9 b
450.0	2831	13.1 bc
652.1	3350	13.6 bc

*Values with the same letter or letters are not significantly different at the 5% level, using Duncan's Multiple Range Test.

Table II.4. Comparisons of time needed for the wear machine to reach the endpoint as influenced by five levels of creeping bentgrass mat.

Organic matter weight of mat (mg/cm^2)	Time to reach the endpoint* (minutes)
0	10.8
78.4	26.5
210.5	152.1
450.0	353.9
652.1	418.8

*Based on the average number of machine revolutions to reach the endpoint and eight revolutions per minute by the wear simulator.

Figure II.1. An overview of the wear simulator in operation. The pneumatic tire supply's a pressure of 7.2 kg dm^{-2} on the turf.

CHAPTER III

THE EFFECTS OF SELECTED CULTURAL PRACTICES ON THATCH ACCUMULATION

ABSTRACT

The objective was to determine the effects of long-term turfgrass cultural practices on thatch accumulation. Three long-term studies were located and utilized in this evaluation: (a) a nitrogen-mowing height study on Wintergreen chewings fescue (Festuca rubra var. commutata) with five nitrogen levels and two mowing heights, and on Merion Kentucky bluegrass (Poa pratensis L.) with four nitrogen levels and two mowing heights; (b) a nitrogen carrier-rate-time of application study on Merion Kentucky bluegrass; and (c) a calcium arsenate study on Anhauser Kentucky bluegrass.

Sod plugs were harvested at random within each treatment, oven dried at 70 C, and the verdure and pseudothatch removed. The thatch layer was then analyzed for total organic matter on a mg/cm^2 basis.

Increased nitrogen rates from 0 to 5.8 $kg/100\ m^2/year$ and higher mowing heights from 1.9 to 3.8 cm produced significant increases in thatch accumulation for both species. In the case of nitrogen, thatch differences may be largely attributed to an increase in the growth rate of the plants. Increased carbohydrate synthesis causing increased root and rhizome growth can explain the increase in thatch at higher mowing heights.

Comparisons between three nitrogen carrier classifications showed that Milorganite® was not significantly different than NH_4NO_3 in altering thatch accumulation on a long-term basis. This response likely resulted from leaching of soluble nitrogen due to heavy irrigation of the NH_4NO_3 treatment. Uramite®, a synthetic organic carrier, had an average of 25% less thatch than the other two categories.

The calcium arsenate treatment resulted in a 39% increase in thatch accumulation above the control. Herbicide inhibition of earthworm and microorganism activity in the soil and/or eradication of weedy species that would otherwise increase substrate concentration is likely causing this response.

INTRODUCTION

Cultural practices required to maintain high quality turfs are also usually conducive to increased thatch accumulation. Practices reportedly contributing to thatch problems are the use of vigorous growing cultivars, an acidic soil environment, intensive irrigation, excessive nitrogen fertilization, infrequent or excessively high mowing, and the use of certain pesticides (Beard 1973).

Many sources refer to increased thatch problems associated with high rates of nitrogen fertility. Engel and Alderfer (1967) and Engel (1967), after a 10 year study, attributed the puffiness in bentgrass (*Agrostis palustris* Huds.) putting greens to excessive nitrogen rates. Higher nitrogen levels increased thatch accumulation 30% on a bermudagrass (*Cynodon dactylon* Pers.) putting green in a short-term study by Meinhold, Dueble, Weaver, and Holt (1973). Schery (1966), on the other hand, made the general observation that fertilizer rates had little effect on thatch accumulation for Kentucky bluegrass (*Poa pratensis* L.) turf.

The question of whether the thatch accumulation: decomposition ratio is altered by mowing height has yet to be satisfactorily answered. Beard and Rieke (1964) reported and Schery (1966) observed a greater thatch development of Kentucky bluegrass with a higher mowing height; however, these results could be attributed to the increased residue or pseudothatch rather than the thatch itself.

Application of certain pesticides also appears to alter this ratio by reducing fungal populations in the soil and thus perhaps affecting the rate at which thatch is decomposed (Domsch and Gams 1969). The use of the fungicides zinc ion plus manganese ethylene bisdithiocarbamate (Fore®) and tetramethylthiuram disulfide (Tersan 75) at preventive rates resulted in significant thatch increases. The same compounds, when used at lower rates, had a shoot growth retardant effect, increased microbial activity 30%, and resulted in a 16% decrease in thatch accumulation (Meinhold et al. 1973). Chlordane acts by reducing small animal, earthworm, and soil insect populations, thus decreasing the thatch decomposition rate (Beard, Eaton, and Yoder, 1973).

The nitrogen source has also been reported to influence thatch accumulation. Engel (1967) reported that urea encouraged puffiness more than activated sewage sludge or ureaformaldehyde. Meinhold et al. (1973) found similar results in their studies. Milorganite® treatments decreased thatch accumulation and lignin 12% while increasing microbial activity 3% as compared to a water soluble, $(NH_4)_2SO_4$, source of nitrogen.

The objective of this study was to locate existing, long-term turfgrass cultural studies and determine the effects of selected cultural factors on thatch accumulation.

MATERIALS AND METHODS

A search throughout the states of Michigan, Indiana, Ohio, and Illinois produced only three long-term cultural practices studies that had potential for altering the thatch accumulation: decomposition ratio. Two of these studies were located at Michigan State University's turfgrass research facilities in East Lansing and Traverse City, Michigan. The third was at Purdue University, West Lafayette, Indiana. The three studies investigated for thatch content were: (1) a nitrogen rate - mowing height study on two species; (2) a nitrogen carrier - rate - time of application study; and (3) an arsenic study.

NITROGEN RATE - MOWING HEIGHT EFFECTS

Wintergreen Chewings Fescue

The East Lansing experimental area located on a Hodunk fine sandy loam soil with a pH of 7.3 was seeded to Wintergreen chewings fescue (*Festuca rubra* var. *commutata* Gaud.) in September, 1966. Internal soil drainage was good. Soil phosphorus and potassium levels were adequate so no P or K was applied at establishment. The experimental design was a split-plot randomized block with three replications using 1.5 x 2.1 m plots. Cultural treatments utilized on the site included: (a) mowed twice weekly with reel mowers at mowing heights of 1.9 and 3.8 cm with clippings removed; (b) nitrogen fertility levels of 0, 1.0, 1.9, 3.9, and 5.8 kg N per are per year applied as ammonium nitrate, 20% during each month of April, May, August, and September, and 10% each in June and July of each year. General cultural practices used included: (a) deep irrigation as needed to prevent wilt; (b) no topdressing or cultivation; (c) applications of 2,4-D and dicamba at the recommended rate for control of broadleaf weeds in May, 1972 and September, 1973; and (d) no fungicides or insecticides.

Merion Kentucky Bluegrass

This study was also located at an East Lansing site that was unshaded and seeded to Merion Kentucky bluegrass (*Poa pratensis* L.) on September 29, 1965, on a Hodunk fine sandy loam soil with a pH of 7.3. Nitrogen treatments were initiated in April 1967. The experimental design had three replications with a split-plot randomized block arrangement using 1.5 x 2.1 m plots. No phosphorus or potassium was applied at establishment since both levels were considered adequate. Internal drainage was good. The specific cultural treatments employed on this site were identical to those utilized in the study on Wintergreen with two exceptions. The 1.0 kg N per are rate was not sampled in this study; and applications of herbicide were in May of 1973 and 1974.

NITROGEN CARRIER - RATE - TIME OF APPLICATION EFFECTS

The Northern Michigan MSU Turfgrass Research Area, located on a Rubicon sand soil, pH of 6.4, at Traverse City, Michigan, was the site for this investigation. Plots, 1.5 x 2.1 m, were established from Merion Kentucky bluegrass seed on May 5, 1963, utilizing a randomized block design with two replications. Treatments were initiated in April, 1964. The cultural practices utilized were (a) heavy irrigation; (b) mowing with a reel mower twice weekly at a 2.5 cm height with clippings returned; (c) 2.4-D and dicamba applied once per year at the recommended rate for broadleaf weed control, but no fungicides or insecticides; (d) phosphorus and potassium applied as needed based on soil tests; and (e) no cultivation or topdressing. The nitrogen source - rate - time of application treatments are listed in Table III.1.

ARSENIC EFFECTS

The turfgrass research facility at Purdue University was the site for this study covering the effects of a pesticide on the thatch accumulation: decomposition ratio. Three plots, 3.6 x 18.0 m, were seeded to Anhauser Kentucky bluegrass on April 5, 1965 on a well-drained sandy loam soil. Treatment with calcium arsenate (2.4 kg/100 m^2) was initiated at establishment on two of the plots. The third plot served as a control. In 1966, 2.1 kg/100 m^2 of calcium arsenate were applied. In 1967, 68, and 71, 1.0 kg/100 m^2 was applied with the plots receiving .7 kg/100 m^2 in 1972, 73, and 75. No treatments were made in

1969, 70, and 74. Soil phosphorus and potassium levels were 1.0 kg/100 m^2 and 3.9 kg/100 m^2 respectively for treated plots, 0.7 kg/100 m^2 and 3.4 kg/100 m^2 respectively for the control plot, and a pH of 7.1 for all plots. The cultural practices employed on this site were (a) mowing height of 1.9 cm three times weekly with clippings returned; (b) nitrogen fertilization of 1.9 kg/100 m^2 per year; (c) irrigation as needed to prevent wilt; and (d) coring in the fall of the year but no topdressing.

Thatch Sampling and Evaluation

All studies were collected the last two weeks of September, 1974, and analyzed within 30 days. Two sod plugs, 8.3 cm in diameter, were collected with a cup cutter randomly from each replication of each treatment. Four samples were collected from each treatment for the arsenic study. The samples were oven dried at 70 C for 24 hours, excess soil removed, and the verdure plus pseudothatch clipped away. The separated thatch layer was then analyzed for total organic matter. The weight per unit area was recorded for each sample. Additionally, soil samples were taken from all treatments for pH, phosphorus, and potassium determinations.

Data Analysis

A completely randomized block analysis of variance was made on each of the studies. The means were separated by either LSD or Duncan's Multiple Range Test. Planned comparisons were made of several subsets of the nitrogen carrier study to better determine the treatment effects.

RESULTS AND DISCUSSION

Nitrogen Rate-Mowing Height Study

WINTERGREEN CHEWINGS FESCUE

The results of the long-term (8-year) effects of five nitrogen rates and two mowing heights on thatch accumulation are presented in Table III.2. An increase in the nitrogen rate resulted in a significant increase in thatch weight over the 8-year period. Thatch accumulation increased nearly 200% from the lowest (0 kg/are) to the highest (5.8 kg/are) nitrogen rate at both mowing heights.

MERION KENTUCKY BLUEGRASS

Thatch accumulation in the Kentucky bluegrass turf was also increased by higher nitrogen rates and mowing height (Table III.3.). The increase in thatch weight was significant for each increase in main plot and subplot treatments. A nitrogen rate increase from 0 to 5.8 kg/are resulted in 180% increase in thatch weight at the lower (1.9 cm) mowing height, and 160% at the higher (3.8 cm) height.

These data on chewings fescue and Kentucky bluegrass are similar to the results of Engel and Alderfer (1967) and Meinhold et al. (1973) whose studies on creeping bentgrass and bermudagrass, respectively, supported the concept that increased thatch problems are associated with high rates of nitrogen fertility. In each case, these results have been attributed to a general increase in the total growth rate of the turfgrass plant. Results of the soil pH analysis conducted on these plots perhaps indicate an additional factor attributing to increased thatch weight at the 5.8 kg/are nitrogen level. The soil pH values at this rate were 6.0 and 5.7 for Wintergreen chewings fescue and Merion Kentucky bluegrass respectively. The pH values increased sharply as the nitrogen rates decreased from the 5.8 kg/are level. Increased soil acidity is associated with a higher nitrogen rate when acidifying nitrogen carriers are used. An acidic soil environment is conducive to thatch accumulation (Engel and Alderfer 1967).

The reason for increased thatch accumulation at higher mowing heights is not as readily evident. Engel (1969) reports that at higher mowing heights the "so called" thatch often appears trash-like rather than thatch-like in nature. Recognizing the validity of this observation, this trash-like material (pseudothatch) was removed prior to the organic matter determination. Increased thatch accumulation still occurred. The increase at higher mowing heights can be largely explained by the increased leaf area available for carbohydrate synthesis which, in turn, results in increased root growth rate and total root production, plus increased rhizome growth. Lateral stems, roots, leaf sheaths, nodes, and crown tissues are reported to be the most decay resistant; and thus comprise the major portion of the physical structure of thatch (Ledeboer and Skogley - 1967).

Nitrogen Carrier - Rate - Time of Application Study

Thatch accumulation comparisons among 12 nitrogen treatments are shown in Appendix Table 1. Among the carriers with one, two, and three applications per year at the same nitrogen rate, there appears to be no significant relationship between frequency of application and thatch accumulation with one exception (Table III.4.). The plot treated with Uramite®, one application per year, accumulated more thatch than either the two or three applications per year treatment. A greater flush of growth with only one application of Uramite® would explain this differential. The three applications per year treatment had the least thatch.

A planned, orthogonal comparison was made on the three nitrogen carrier classifications - synthetic inorganic, natural organic, and synthetic organic - as to their effect on thatch accumulation (Table III.5.). It was necessary to pool the three means of 1, 2, and 3 applications per year for each carrier to make this comparison. Contrary to expected results, the natural organic carrier, Milorganite®, was not significantly different than the inorganic carrier, ammonium nitrate, in effecting thatch accumulation. Meinhold, et al. (1973) reported Milorganite® treatments on a bermudagrass green reduced thatch accumulation significantly as compared to the inorganic carriers. The leaching of soluble nitrogen due to heavy irrigation of the plots is a possible explanation for the low response of thatch weight to the inorganic carrier (NH_4NO_3) in this study. The response of the synthetic organic carrier, Uramite®, was lowest (25%) of the three nitrogen sources. Presumably, this response results from a decreased growth stimulation during cooler weather associated with water-insoluble, temperature-activated nitrogen carriers. The low efficiency of Uramite® may also be a contributing factor.

Arsenate Study

The long-term effects of calcium arsenate on thatch accumulation are shown in Table III.6. Calcium arsenate is responsible for a significant increase (39%) in thatch weight compared to the untreated control. Apparently, the pesticide is either inhibiting small animal (earthworm) and microorganism activity in the soil, or increasing the substrate concentration via eradication of weedy grasses, thus enabling the desirable species to proliferate above that of the untreated control plot.

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Table III.1. Traverse City fertility study on Merion Kentucky bluegrass.

Nitrogen Source	Total Kg N per are per year	Applications per year	Kilograms of Nitrogen per are					
			4/15	5/15	6/15	7/15	8/15	9/15
NH_4NO_3	1.9 (4)[1]	6	0.32	0.32	0.32	0.32	0.32	0.32
NH_4NO_3	3.9 (8)	6	0.65	0.65	0.65	0.65	0.65	0.65
NH_4NO_3	5.8 (12)	6	0.96	0.96	0.96	0.96	0.96	0.96
NH_4NO_3	3.9 (8)	1	3.90					
NH_4NO_3	3.9 (8)	2	1.95				1.95	
NH_4NO_3	3.9 (8)	3	1.30		1.30		1.30	
Milorganite^R	3.9 (8)	1	3.90					
Milorganite^R	3.9 (8)	2	1.95				1.95	
Milorganite^R	3.9 (8)	3	1.30		1.30		1.30	
Uramite^R	3.9 (8)	1	3.90					
Uramite^R	3.9 (8)	2	1.95				1.95	
Uramite^R	3.9 (8)	3	1.30		1.30		1.30	

[1]Number in parenthesis equals total lbs/1000 ft^2/year.

Table III.2. Long-term (7-year) effects of nitrogen and mowing height on the accumulation of thatch in Wintergreen chewings fescue.

Nitrogen Rate (kg/are/year)	Mowing Height (cm)	Thatch Weight (mg/cm^2)
0	1.9	42.0*
	3.8	51.8
1.0	1.9	55.9
	3.8	74.6
1.9	1.9	71.7
	3.8	84.8
3.9	1.9	90.4
	3.8	109.7
5.8	1.9	105.5
	3.8	123.0

LSD .05 = 27.46**
LSD .05 = 18.65***

*Values are means of 3 replications with 2 subsamples per treatment.
**LSD for comparison between main plot nitrogen treatments.
***LSD for comparison between subplot mowing height treatment.

Table III.3. Long-term (7-year) effects of nitrogen and mowing height on the accumulation of thatch in Merion Kentucky bluegrass.

Nigrogen Rate (kg/are/year)	Mowing Height (cm)	Thatch Weight (mg/cm^2)
0	1.9	60.9*
	3.8	72.1
1.9	1.9	81.7
	3.8	94.8
3.9	1.9	130.3
	3.8	144.4
5.8	1.9	171.7
	3.8	187.1

LSD .05 = 8.38**
LSD .05 = 7.34***

*Values are means of 3 replications with 2 subsamples per treatment.
**LSD for comparison between main plot nitrogen treatments.
***LSD for comparison between subplot mowing height treatments.

Table III.4. Long-term (10-year) effects on thatch accumulation from three nitrogen carriers at 3.9 kg N per are and 1, 2, or 3 applications per year.

Nitrogen Carrier	Applications/ year	Thatch Weight (mg/cm^2)
Uramite[R]	1	157.5 ab*
	2	148.1 a
	3	142.3 a
NH_4NO_3	1	169.3 abc
	2	196.5 bc
	3	177.5 abc
Milorganite[R]	1	181.7 abc
	2	183.2 abc
	3	201.5 c

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are means of 4 observations.

Table III.5. The long-term (10-year) effects on thatch accumulation from three nitrogen carrier classifications pooled over 1, 2, and 3 applications per year at 3.9 kg N per are.

Classification (Carrier)	Thatch Weight (mg/cm^2)
Synthetic organic (Uramite[R])	147.3 a*
Inorganic (NH_4NO_3)	180.9 b
Natural organic (Milorganite[R])	188.8 b

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test.

Table III.6. The long-term (9-year) effect of calcium arsenate on the accumulation of thatch in Anhauser Kentucky bluegrass.

Treatment	Thatch Weight (mg/cm^2)
Control	130.4 a*
Arsenate	180.9 b

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are means of 8 observations.

Appendix Table 1. Long-term (10-year) effects of 12 fertility treatments on Merion Kentucky bluegrass thatch accumulation.

Nitrogen Carrier	Nitrogen Rate (kg/are/year)	Applications/ year	Thatch Weight (mg/cm^2)
Uramite[R]	3.9	1	157.5
	3.9	2	148.1
	3.9	3	142.3
NH_4NO_3	1.9	6	153.1
	3.9	6	160.7
	5.8	6	197.8
	3.9	1	169.3
	3.9	2	196.2
	3.9	3	177.5
Milorganite[R]	3.9	1	181.7
	3.9	2	183.2
	3.9	3	201.5

CONCLUSIONS

The following conclusions can be made regarding the thatch studies conducted in this investigation:

1. The five turfgrass thatch measurement techniques were found to vary significantly in terms of repeatability for each turfgrass species.
2. The thatch weight technique was consistently the most reliable (lowest repeatability quotient) measurement technique for the three species; and, although the most time-consuming and demanding in terms of equipment needs, is the recommended method for the researcher.
3. The water displacement (volume) measurement was the least reliable for all three species and thus is not recommended for use.
4. Thatch depth and thatchmeter techniques were comparable in repeatability with the depth measurement still the more preferable for use in the field.
5. Statistical analysis on bentgrass showed a significant correlation between the thatchmeter and thatch depth ($r = .98$) and weight ($r = .74$). There were no significant correlations between the thatchmeter and thatch for Kentucky bluegrass, and only one low

correlation (r = .33), with thatch depth, for annual bluegrass.

6. Verdure and pseudothatch accounted for the majority (R^2 = .63) of variability in thatchmeter readings on Kentucky bluegrass (1.5 inch mowing height) but accounted for little (R^2 = .001) on creeping bentgrass, (0.25 inch mowing height), which suggests an influence of cutting height on the ability of the thatchmeter to measure thatch.
7. With further evaluation by turf professionals to establish limits of high and low resilience for various turfgrass cultivars, the thatchmeter offers potential value as a means of monitoring year-to-year thatch accumulation on greens turfs.
8. Increases in greens mat accumulation produced significant increases in the wear tolerance of the turf as measured by a wear simulator.
9. Penetrometer measurements of soil beneath each mat layer suggest a negative correlation between wear tolerance and subsurface soil penetrability.
10. The mat layer was responsible for most of the wear differential on creeping bentgrass greens.
11. Based on conversion of wear revolutions to time, a moderate level (8-10 mm or 200-220 mg/cm^2) of mat was found to be most desirable for improved wear tolerance without creating problems associated with excessive mat accumulation on greens.

12. Both increased nitrogen rates and mowing heights produced significant increases in thatch accumulation for Wintergreen chewings fescue and Merion Kentucky bluegrass over an 8-year period. These data suggest the importance of judicious use of nitrogen fertilizers to avoid excessive plant growth and the potential for manipulating mowing height to reduce thatch accumulation.
13. Uramite®, at one application per year, accumulated more thatch than the two or three applications per year treatment. This result amplifies the importance of the frequency of application of synthetic organic nitrogen carriers relative to thatch control.
14. The synthetic organic carrier, ureaformaldehyde (Uramite®), encouraged less (25%) thatch accumulation compared to the synthetic inorganic carrier (NH_4NO_3) and natural organic carrier (Milorganite®).
15. The pesticide, calcium arsenate, was responsible for a significant increase (39%) in thatch accumulation during a 9-year study.