James B. Beard
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THE EFFECTS OF MANAGEMENT PRACTICES ON THATCH ACCUMULATION IN A TIFGREEN BERMUDAGRASS (*CYNODON* SPP.) PUTTING GREEN

A Thesis

by

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ABSTRACT

The Effects of Management Practices on Thatch Accumulation in a Tifgreen Bermudagrass (Cynodon Spp.) Putting Green. (May 1973)

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Directed by: Dr. Richard L. Duble and

Dr. Ethan C. Holt

A 6 month field study was conducted to determine the effects of fertility, fungicides, and clipping residue on the accumulation of thatch in a Tifgreen bermudagrass (Cynodon dactylon (L.) Pers.) putting green. The effects of these practices were evaluated by measuring total thatch accumulation, cell wall components of the thatch and soil microbial activity.

Application of K at 0 and .75 kg of K/100 m^2 every 4 weeks, showed no influence on any of the three measurements. Two sources of N -- $(NH_4)_2SO_4$ and Milorganite (activated sewage sludge) -- were applied at two levels -- .25 and .75 kg of N/100 m^2 every 2 weeks. The higher level of N increased thatch accumulation 30%, increased the lignin/cellulose ratio 21% and resulted in 30% less C evolved from microbial activity as compared to the low level of N. The Milorganite treatments produced 12% less thatch, decreased the lignin/cellulose ratio 15% and resulted in 25% more C evolved from microbial activity as compared to the $(NH_4)_2SO_4$ treatments. Differences due to N sources are partially

explained by their influences on growth rates and thatch decomposition.

Fungicide treatments consisted of .18 kg/100 m^2 of Fore (Manganese ethylene bisdithiocarbamate) and .12 kg/100 m^2 of Tersan OM (Tetramethylthiuram disulfide) applied alternately at 2 week intervals. The effects of the routine application of these fungicides became evident mid-way through the growing season. Because of the fungicide treatment, total thatch accumulation decreased 16%, the lignin/cellulose ratio decreased 20%, and microbial activity increased 30%. These results may have been due to an alteration of plant growth, or microbial population, or both. Further research will be necessary to explain the response to the fungicides.

For the clipping residue treatment, the grass clippings were not collected during each mowing. The influence of the clipping residue on thatch accumulation was not evident until late in the growing season. The clipping residue treatment increased the lignin/cellulose ratio 10% and resulted in 7% less C evolved.

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To my parents for their encouragement and many sacrifices in making this all possible; my love and admiration.

DEDICATION

This thesis is dedicated to my wife, Chris. Her help and understanding made this project a reality.

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INTRODUCTION

Thatch, having been defined as the accumulation of plant material, living and dead, which is present above the mineral soil, and which develops under permanent turfgrass sods (24), is a serious problem to the turfgrass industry. Although thatch is an organic residue problem, it is not associated with cultivated crops because of the nature of the management practices. Whereas, in cultivated crops the residue is incorporated into the soil causing a more rapid decomposition of the organic matter, the permanent nature of sod contributes to the accumulation of a thatch layer.

Thatch is not a new problem. There have been several mechanical methods developed to retard thatch accumulation in fine turf areas. Such mechanical methods as vertical mowing, aerification, and top-dressing are common practices. Although these methods are effective, they are also expensive and time consuming (30).

Because thatch is a residue problem, which is affected by the rate of plant growth, fertility should be an important determinant of thatch accumulation. This study was designed to determine if nitrogen and potassium at a high and low rate of

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The citations on the following pages follow the style of the Agronomy Journal.

application would affect this accumulation of thatch in a 'Tifgreen' bermudagrass (Cynodon dactylon (L.) Pers.) putting green. Other management practices such as clipping removal, and the use of fungicides were also investigated. The effects of these practices were evaluated not only by measuring the total thatch accumulation but also by determining the cell wall components of the thatch and the soil microbial activity.

LITERATURE REVIEW

There are several suggested causes for thatch accumulation. One such cause is the increased production of stems, roots, and rhizomes by newer turf varieties with more vigor and density than older varieties (12). The stress placed on quality turf by close and frequent mowing is another important factor in thatch accumulation (19). Because of this stress, thatch increases from more rapid sloughing off of leaf, stem, sheath, and root parts. The extreme of excessively high and infrequent mowing can also result in the buildup of a thatch layer (24). Other factors thought to affect thatch accumulation are high nitrogen (9, 12, 16, 19, 24), the use of pesticides, and excessive phosphorus, and potassium. These factors, however, have not been researched to any great extent, and little data is available to substantiate these ideas.

There has been little work done on the effects of nitrogen and potassium on thatch accumulation. Some authors feel that high amounts of nitrogen tend to increase thatch (12, 16, 19, 24). However, no data are given to completely substantiate this belief. On the contrary, Starkey (26) states that for the decomposition of one ton of fresh plant material with 20% dry weight, about 9 pounds of nitrogen is required; therefore, fertilizer nitrogen is important. He goes on to say that it is possible that nitrogen

and some other elements are deficient in grass residues and that addition of fertilizer salts would accelerate decomposition. The levels of fertilizer he referred to are not clear.

Mahdi and Stoutemyer (18) reported that increasing the pounds of applied nitrogen per 1000 sq. ft. per year from 6 to 24 increased the number of common bermudagrass plants in a 1 7/8-inch plug from .8 to 58.9.

Madison (17) conducted a study on the effects of nitrogen on rooting and cover of bentgrasses. He found that increasing the nitrogen level increased the plant population, but decreased plant size and the amount of rooting.

Buildup of thatch in sod occurs when the production of plant material exceeds the rate of its decomposition (24). Dahlman and Kucera (5) showed an annual turnover rate of 22.8% for rhizomes and 40.8% for roots in the 0- to 2-inch zone of a native prairie sod. They estimate the turnover rate for an entire root system to be every 4 years. Ledeboer and Skogley (16) report that the shallow, fibrous roots of several turfgrass species are almost completely regenerated each year, and thus potentially contribute to thatch accumulation. Martin (19), with chemical measurements of cell wall constituents, concluded that the clippings of turfgrass contribute very little to thatch accumulation.

In general, water soluble carbohydrates and proteins decompose rapidly, hemicelluloses slowly, cellulose more slowly, and lignins are very resistant to decomposition (1, 16, 19, 27). The lignin/cellulose ratio is less than .25 in the plant and greater than 2.0 in the thatch of bermudagrass turf (8).

There has been much work reported on the carbon-nitrogen ratios of straw in relation to decomposition (1, 10, 13, 21, 25). Richards and Norman (21) point out that the decomposition of plant materials in the soil or in compost heaps involves the assimilation of the carbohydrate constituents of the tissues and the conversion of available nitrogen to microbial protein by the organisms concerned. They state further that the supply of nitrogen is often a limiting factor in decomposition, and that mature plant tissues frequently need additional available nitrogen to affect a complete and rapid breakdown. The carbon-nitrogen ratio, although not excessively high, may be a limiting factor in thatch decomposition (19).

Microorganisms occur in great numbers in fertile soils. Practically all microorganisms depend on organic matter as food, and the transformations they bring about are related to the use of these materials as food (27). Consequently, associated with the decomposition of organic matter, is the growth of the microorganisms that decompose it (27). When organic matter is added to the soil, decomposition begins and CO_2, NH_3, and NO_3

are produced (13). The rate at which the added material decays depends mainly upon the soil environment, the type of organisms involved, and chemical composition of the organic matter added (13, 15).

The soil environment can be altered by changing the pH and fertility. Katznelson and Stevenson (14) report that a marked decrease in respiratory activity in the soil was observed when the pH was lowered from 6.8 to 4.5. Considerable variation in gas exchange also was obtained with soils which varied widely in fertility, organic matter, and nitrogen content.

Besides the nitrogen content of organic matter, soil pH, aeration, temperature, moisture, and abundance of mineral substances such as phosphates, calcium, and potassium affect microbial development (3, 4, 23, 27, 34).

Most of the work that has been done with fungicides is on their breakdown potential (2, 20, 28, 32, 35). Domsch (6, 7) states that the negative influences of fungicides on the microflora have been investigated only occasionally; however, he has done some work with soil fungicides and their effects on microbial populations, and has shown a decrease in fungal populations. Stojanovic has also shown that fungicides can greatly diminish the fungal populations in soil (28).

MATERIALS AND METHODS

An established Tifgreen bermudagrass putting green was used to study the relationships of fungicides, clipping residue, and fertility to thatch accumulation. A split plot design with three replications was employed.

The main plots were 1.8 x 17.1 meters and consisted of the following: (1)fungicide treatment -- .18 kg/100 m^2 of Fore (Manganese ethylene bisdithiocarbamate) or .12 kg/100 m^2 of Tersan OM (Tetramethylthiuram disulfide) applied alternately at 2 week intervals, (2)mower clippings not collected, and (3)control -- clippings collected and no fungicide.

Fertilizer treatments, randomized within each main plot, comprised the eight subplots, each 1.8 x 2.1 meters. Two sources of nitrogen -- ammonium sulfate and Milorganite (activated sewage sludge -- 6% nitrogen) were applied at two levels -- .25 and .75 kg of nitrogen/100 m^2 every 2 weeks. Muriate of potash treatments consisted of 0 and .75 kg of potassium/100 m^2 applied every 4 weeks. A blanket application of phosphorus was made at the rate of 1.5 kg/100 m^2 over the entire area at the beginning and halfway through the study.

No management practices other than watering and those mentioned above were applied during the growing season. The growing season was from May 15 to October 23. The green was vertical mowed and aerified 1 week before the first fertilizer treatments

were applied.

The total thatch accumulation was measured at the beginning and end of the study by taking eight plugs at random from each sub-plot, and measuring the thatch layer with a ruler. All data obtained from this method were subjected to analysis of variance to determine the effects of treatments on total thatch accumulation.

Leaves, stems, and the thatch layer of the grass in the sub-plots were sampled four times during the growing season. Each sample consisted of three 5 cm plugs taken at random from each sub-plot. The grass and thatch from each plug were washed in water and screened to remove any sand. The samples were dryed at 70 C, weighed, and ground in a Wiley Mill with a 40 mesh screen. The analytical procedures were those as outlined by Van Soest (33) to determine cellulose, lignin, and ash. All data obtained from this method were subjected to analysis of variance to determine the effects of treatment on plant components.

A sampling technique similar to the one used by Hall and Grossbard (11) was used for the carbon-evolution measurement. For the first incubation period (August 4 - September 20), a random sampling of three plugs was taken from each sub-plot with a 2.54 cm diameter soil plugger. The plugs were measured and cut at 2.54 cm, sprayed with a herbicide, and placed in a 138 ml baby food jar. Duplications were run on the microbial

activity measurements.

For the second incubation period (October 25 - December 5), a random sampling of eight plugs was taken from each sub-plot with a 2.54 cm diameter soil plugger. The plugs were measured and cut at 1.27 cm, sprayed with a herbicide, and placed in a 138 ml baby food jar.

The laboratory method used for measuring CO_2-evolution was similar to the one outlined by Stotzky (29). The lids of the incubation jars (baby food jars) were fitted with an inlet and an outlet rubber capillary tube (Figure 1). The inlet tube was attached to a gassing manifold of plastic tubing, which was attached to a scrubber system of NaOH and distilled water, and which was in turn attached to an air source consisting of a cylinder of compressed air. The outlet tube of each jar was attached to a CO_2 collector containing 10 ml of .5 N NaOH. Carbon collectors were also attached to empty incubation jars to serve as controls for CO_2 absorbed from the atmosphere during the procedure. The CO_2 collectors were replaced periodically during the incubation period. After CO_2 absorption, 1 ml of $BaCl_2$, to precipitate the carbonate to $BaCO_3$, and two drops of phenolphthalein indicator were added to the collector jars. The solution in the collector jar was then titrated with standard HCl. The CO_2 collectors from the control jars were titrated concomitantly with those from the treatment vessels, thereby necessitating

Figure 1. Manifold tubing, incubation jars, and CO_2 collection jars used in the carbon evolution study.

standardization of only the HCl.

The following formula was used to calculate the C evolved from the titrimetric method:

$$\text{Milligrams C} = (B - V)\,NE$$

where

V = volume (ml) of acid to titrate the alkali in the CO_2 collectors from treatments to the end point,

B = volume (ml) of acid to titrate the alkali in the CO_2 collectors from controls to the end point,

N = normality of acid, and

E = equivalent weight. E = 6.

All data from the above procedure were subjected to analysis of variance to determine the effects of treatments on microbial activity.

At the end of the first incubation period, the plugs were removed from the jars, and the remaining thatch layer was removed from the soil. The thatch was analyzed, as outlined in the section on the preparation of living plant materials, to determine the amounts of lignin (ADL) remaining.

At the end of the study, visual ratings were made of the plots to estimate the effect of treatments on scalping after mowing and on color. A rating scale of 1-10 was used with 10 being the most severly scalped and the darkest green. The ratings were subjected to analysis of variance to determine the effects of

treatments on scalping and color.

EXPERIMENTAL RESULTS

Total Thatch Accumulation

Because of the aerification and vertical mowing 1 week before the study began, there was essentially no thatch layer present when the first thatch accumulation measurement was taken June 1. An average thatch layer of 2.0 mm was measured, and no differences among any of the treatments were found (Table 1). A noticable thatch accumulation did not occur until approximately mid-way through the growing season. At this time, the high nitrogen plots appeared to be accumulating thatch at a faster rate than the other treatments.

The results of the final thatch layer measurement made in October are shown in Table 2. The high level of nitrogen from both sources accumulated the most thatch, and the ammonium sulfate accumulated more thatch than the Milorganite for both rates. Potassium application made no difference on the depth of the thatch layer.

The fungicide and clipping residue treatments both affected the depth of the thatch layer (Table 3). There was a decrease in total thatch from the fungicide application, and an increase due to the clipping residue treatment.

The dry matter weights of the samples collected in October for lignin analysis also gave an indication of the total thatch

Table 1. Effect of fertilizer treatments on the depth of a thatch layer in a bermudagrass putting green after 1 month of growth.

N Source	Kg/100 m^2 N	Kg/100 m^2 K	Thatch (mm)
Milorganite	.25	0	1.89 a*
Milorganite	.25	.75	1.93 a
$(NH_4)_2SO_4$	.25	0	1.94 a
$(NH_4)_2SO_4$	.25	.75	1.96 a
Milorganite	.75	.75	1.99 a
Milorganite	.75	0	2.04 a
$(NH_4)_2SO_4$	.75	.75	2.06 a
$(NH_4)_2SO_4$	.75	0	2.07 a

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Table 2. Effect of fertilizer treatments on the depth of a thatch layer in a bermudagrass putting green after 6 months of growth.

N Source	Kg/100 m^2 N	Kg/100 m^2 K	Thatch (mm)
Milorganite	.25	.75	6.91 a*
Milorganite	.25	0	6.93 a
$(NH_4)_2SO_4$	.25	0	8.04 b
$(NH_4)_2SO_4$	.25	.75	8.34 b
Milorganite	.75	0	9.68 c
Milorganite	.75	.75	10.36 d
$(NH_4)_2SO_4$	.75	0	10.82 de
$(NH_4)_2SO_4$	.75	.75	10.93 e

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Table 3. Effect of fungicides and clipping residue on the depth of a thatch layer in a bermudagrass putting green after 6 months of growth.

Treatments	Thatch (mm)
Fungicides applied	8.25 a*
Control	9.13 b
Clipping residue	9.61 c

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

accumulated. The fungicide, clipping residue, and potassium treatments showed no significant influences on the weights of the above ground portions (Tables 4 and 5). The higher rates of nitrogen and the ammonium sulfate source are again evident as having accumulated more thatch as in Table 5 (p. 17).

Cell Wall Components

The cell wall analyses did not show differences until the second sampling when the lignin/cellulose ratio began to vary with treatments. The effects of fertilizers on the lignin/cellulose ratio are shown in Table 6. The August 1 sampling gives an idea of the developing trend. The low rate of Milorganite treatments had the lowest lignin/cellulose ratio while the high rate of ammonium sulfate treatments gave the highest ratio. Potassium had no evident influence on the lignin/cellulose ratio for the three dates shown with the exception of the high ammonium sulfate treatment.

In October, the data show a significant increase in lignin/cellulose ratio with increased nitrogen within each source. There is also a larger ratio in the ammonium sulfate than in the Milorganite treatments with the low rate of ammonium sulfate and high rate of Milorganite treatments exhibiting similar lignin/cellulose ratios. It should also be noted that the average lignin/cellulose ratio increased as the growing season progressed

Table 4. Effect of fungicides and clipping residue on the weight of the above soil level portions of a bermudagrass putting green after 6 months of growth.

Treatments	Gms/three 5 cm dia plugs
Fungicides	3.87 a*
Control	3.99 a
Clipping residue	4.16 a

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Table 5. Effect of fertilizer treatments on the weight of the above soil level portions of a bermudagrass putting green after 6 months of growth.

N Source	Kg/100 m^2		Gms/three 5 cm dia plugs
	N	K	
Milorganite	.25	.75	3.18 a*
Milorganite	.25	0	3.27 a
$(NH_4)_2SO_4$	.25	0	3.86 bc
$(NH_4)_2SO_4$	.25	.75	4.02 cd
Milorganite	.75	0	4.20 cde
Milorganite	.75	.75	4.36 cde
$(NH_4)_2SO_4$	.75	0	4.56 de
$(NH_4)_2SO_4$	.75	.75	4.62 e

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Table 6. Effect of fertilizer treatments on the lignin/cellulose ratio of the above soil level portions of a bermudagrass putting green.

N Source	Kg/100 m^2 N	Kg/100 m^2 K	Lignin/cellulose Aug 1	Lignin/cellulose Sept 1	Lignin/cellulose Oct 1
Milorganite	.25	.75	.357 a*	.379 a	.380 a
Milorganite	.25	0	.353 a	.363 ab	.396 ab
$(NH_4)_2SO_4$	.25	.75	.382 ab	.421 cd	.432 c
Milorganite	.75	.75	.412 cd	.398 bc	.449 cd
$(NH_4)_2SO_4$	.25	0	.374 a	.427 d	.454 cd
Milorganite	.75	0	.378 a	.407 cd	.479 d
$(NH_4)_2SO_4$	.75	0	.425 d	.491 e	.523 e
$(NH_4)_2SO_4$	.75	.75	.408 bcd	.518 f	.575 f

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

indicating increased thatch accumulation.

Fungicides began to influence the lignin/cellulose ratio in the September 1 sampling (Table 7). While the ratios for the control and clipping residue treatments increased, the fungicide treatment remained constant throughout the growing season. The clipping residue treatment did not influence the lignin/cellulose ratio until the October sampling when it had a larger ratio than the control.

Total lignin which was calculated for the October sampling is shown in Table 8. The fungicide treatment had less total lignin than either the control or the clipping residue treatments. The calculated total lignin for the fertilizer treatments is presented in Table 9. Considerably less lignin accumulated with the low rate of Milorganite treatment than with the high rate treatment. The same was also true for ammonium sulfate plots. The effect of source of nitrogen was also statistically significant with the ammonium sulfate resulting in more total lignin than the Milorginite. Potassium had no significant effect on total lignin.

Soil Microbial Activity

The first incubation period showed some increased carbon evolution with the Milorganite source as compared to the ammonium sulfate source (Table 10). Potassium showed no affect

Table 7. Effect of fungicides and clipping residue on the lignin/cellulose ratio of the above soil level portions of a bermudagrass putting green.

Treatments	Lignin/cellulose		
	Aug 1	Sept 1	Oct 1
Fungicides	.383 a*	.392 a	.388 a
Control	.390 a	.442 b	.467 b
Clipping residue	.385 a	.442 b	.514 c

*Values,within each column, followed by the same letters are not significantly different at the .05 level by Duncan/s test.

Table 8. Effect of fungicides and clipping residue on the total lignin of the above soil level portions of a bermudagrass putting green after 6 months of growth.

Treatments	Lignin gms/three 5 cm dia plugs
Fungicides applied	.30 a*
Control	.38 b
Clipping residue	.42 b

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Table 9. Effect of fertilizer treatments on the total lignin of the above soil level portions of a bermudagrass putting green after 6 months of growth.

N Source	Kg/100 m^2 N	Kg/100 m^2 K	Lignin gms/three 5 cm dia plugs
Milorganite	.25	.75	.25 a*
Milorganite	.25	0	.28 ab
$(NH_4)_2SO_4$	.25	.75	.34 bc
$(NH_4)_2SO_4$	.25	0	.35 bc
Milorganite	.75	0	.38 cd
Milorganite	.75	.75	.40 cd
$(NH_4)_2SO_4$	.75	0	.45 de
$(NH_4)_2SO_4$	.75	.75	.50 e

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Table 10. Effect of fertilizer treatments on the amount of carbon evolved from three 2.54 cm plugs taken from a bermudagrass putting green in August.

N Source	Kg/100 m^2		Days (mg C evolved)							Total mg carbon evolved in 43 days
	N	K	0-4	4-9	9-14	14-18	18-23	23-29	29-36	
$(NH_4)_2SO_4$	.75	.75	17.88 a*	17.00 ab	18.40 a	9.28 abc	9.80 ab	9.30 a	10.50 a	92.03 a
$(NH_4)_2SO_4$	.75	0	17.48 a	16.80 ab	18.40 a	8.96 a	9.30 a	9.00 a	10.50 a	92.68 a
$(NH_4)_2SO_4$	.25	.75	17.08 a	16.25 a	18.95 ab	9.64 bcd	9.65 ab	9.42 ab	10.71 abc	96.56 b
$(NH_4)_2SO_4$	.25	0	17.80 a	17.40 b	19.40 ab	9.68 cd	10.35 bc	10.14 bcd	11.06 abc	98.24 bc
Milorganite	.75	.75	17.72 a	17.45 b	19.70 ab	9.72 cd	10.02 bc	8.40 bcd	11.34 bc	98.62 bc
Milorganite	.25	.75	17.64 a	17.10 ab	18.95 ab	9.72 cd	10.75 c	10.62 d	11.55 c	98.74 bc
Milorganite	.75	0	17.52 a	17.50 b	19.65 ab	9.84 cd	10.55 c	10.20 cd	11.55 c	99.22 bc
Milorganite	.25	0	17.84 a	17.60 b	19.80 b	10.08 d	10.90 c	10.44 d	11.55 c	100.73 c

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

on microbial activity. Although the rates of Milorganite did not differ in their effect on microbial activity, the high rate of ammonium sulfate significantly decreased the carbon evolution as compared to the low rate.

The average percent lignin content of the plant material during the 36 day incubation period increased from 7.5% to 15%. Fungi were evident on the decomposing plant material after both incubation periods (Figures 2, 3, and 4).

The fungicide and clipping residue treatments showed no influence on carbon evolution for the first incubation period as shown in Figure 5. However, the fungicide treatments significantly increased the amount of carbon evolved during the second incubation period (Figure 6). The clipping residue treatment led to a decrease in the amount of carbon evolved during the second incubation period as evidenced also by Figure 6 (page 27).

The fertilizer effects of the first incubation period were considerably diminished in the second period (Table 11). The high rate of ammonium sulfate resulted in the only significant reduction in microbial activity for the October sampling. In the second, as well as the first incubation period, the Milorganite treatment tended to evolve more carbon than did the ammonium sulfate source.

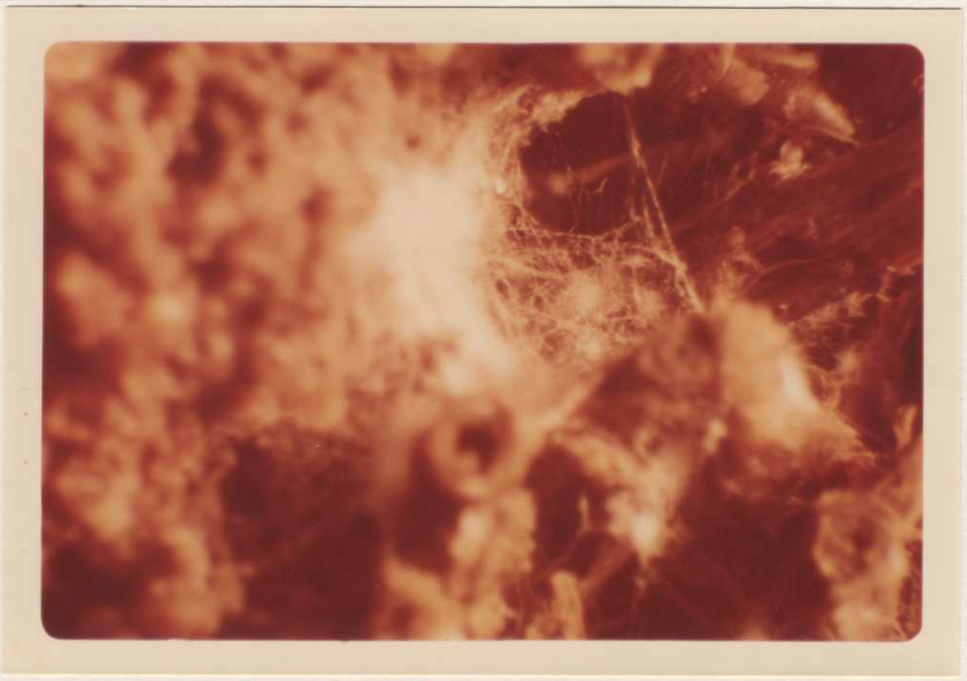

Figure 2. At the end of the incubation periods, fungi were evident in the decaying plant material (magnified 12X).

Figure 3. Fungi on an individual grass stem at the end of the second incubation period (magnified 12X).

Figure 4. Mycelia and spores of fungi on a decomposing leaf blade at the end of the incubation period (magnified 600X).

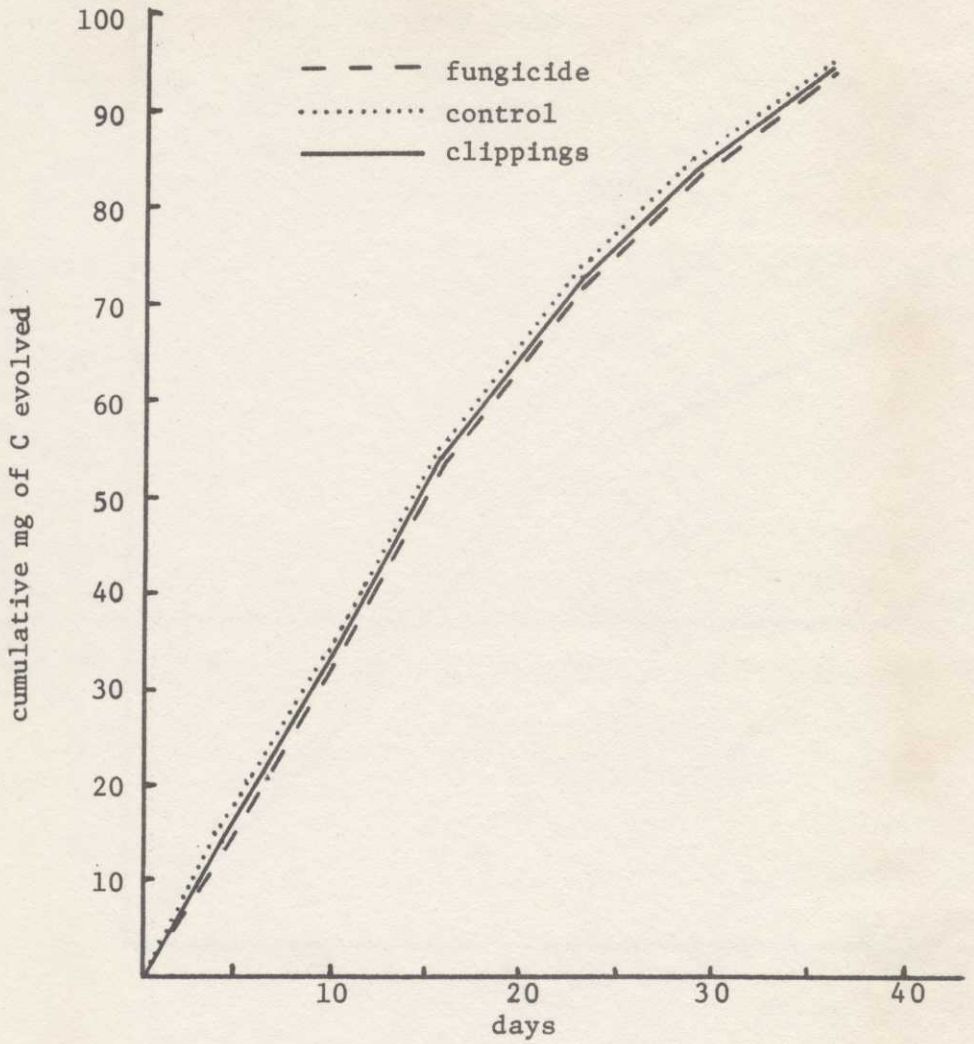

Figure 5. The influence of fungicides and clipping residue on the amount of carbon evolved from three 2.54 cm plugs taken from a bermudagrass putting green in August.

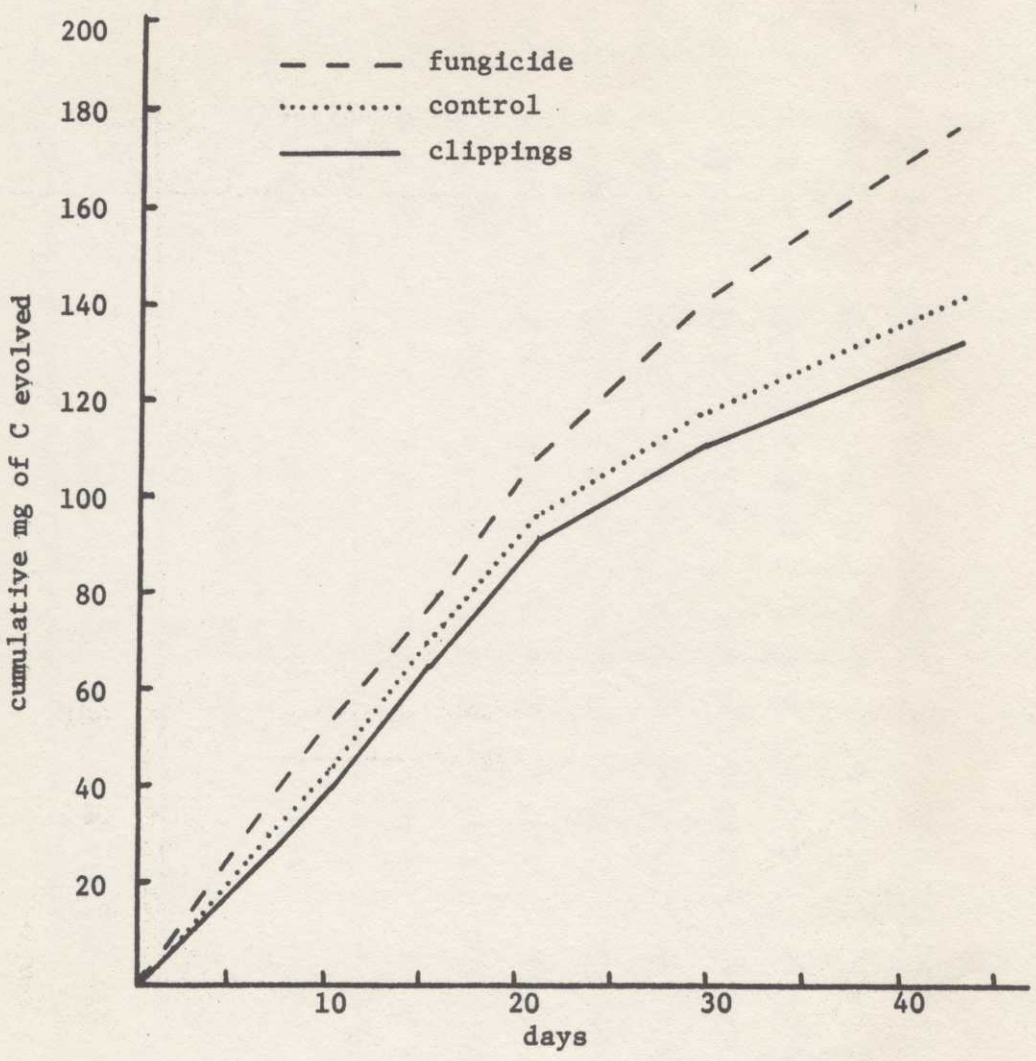

Figure 6. The influence of fungicide and clipping residue treatments on the amount of carbon evolved from eight 1.27 cm plugs taken from a bermudagrass putting green in October.

Table 11. Effect of fertilizer treatments on the amount of carbon evolved from eight 1.27 cm plugs taken from a bermudagrass putting green in August.

N Source	Kg/100 m^2		Days (mg C evolved)						Total mg carbon evolved in 43 days
	N	K	0-6	6-10	10-15	15-22	22-29	29-43	
$(NH_4)_2SO_4$	.75	.75	25.86 a*	16.86 a	21.58 a	24.65 a	21.09 a	30.14 a	142.12 a
$(NH_4)_2SO_4$	.75	0	29.74 abc	17.85 a	22.14 a	24.72 a	20.97 a	27.84 a	143.26 a
$(NH_4)_2SO_4$	.25	.75	29.17 ab	17.47 a	23.03 ab	25.50 a	23.55 b	31.13 a	149.85 ab
$(NH_4)_2SO_4$	.25	0	29.68 abc	17.56 a	23.13 ab	24.69 a	24.01 b	30.85 a	149.86 ab
Milorganite	.75	.75	29.01 ab	18.20 a	24.37 b	26.47 a	23.16 b	33.98 a	155.24 b
Milorganite	.75	0	33.85 c	17.54 a	24.68 b	26.20 a	22.76 b	32.21 a	156.12 b
Milorganite	.25	.75	32.96 bc	18.19 a	24.70 b	25.84 a	22.62 b	30.13 a	156.65 b
Milorganite	.25	0	32.98 bc	18.86 a	24.54 b	26.86 a	22.98 b	33.42 a	159.64 b

*Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Aesthetic Quality

Noticeable color differences began to show early in the growing season, but no ratings were made until the end of the study. The effects of fertility on color are shown in Table 12. Regardless of the source, the high rate of nitrogen application gave the darkest green color with the ammonium sulfate improving the color over the Milorganite at the .75 kg level. Potassium had no influence on color.

The color ratings for the fungicide and clipping residue treatments are shown in Table 13. Fungicides caused a lighter green color, but this effect was not as pronounced as the darker green color due to the clipping residue. In most instances, good color existed regardless of treatment. None of the treatments produced a chlorotic appearance in the grass. All plots were healthy and the grass appeared to be under no extreme stress due to lack of fertility or to mismanagement.

The only stress that may have been significant was that of the scalping conditions which existed near the end of the growing season. Although the clipping residue treatment plots were darker green, they scalped more severely than other treatments (Table 14). The control plots were scalped less severely, and the fungicide treatments were practically free of scalping (Figure 7).

Table 12. Effect of fertilizer treatments on the color of a bermudagrass putting green after 6 months of growth.

N Source	Kg/100 m^2 N	Kg/100 m^2 K	Ratings for color*
Milorganite	.25	0	4.89 a†
$(NH_4)_2SO_4$	.25	.75	4.89 a
Milorganite	.25	.75	5.00 a
$(NH_4)_2SO_4$	.25	0	5.22 a
Milorganite	.75	.75	6.78 b
Milorganite	.75	0	6.89 b
$(NH_4)_2SO_4$	.75	.75	8.00 c
$(NH_4)_2SO_4$	.75	0	8.11 c

*1 = yellow; 10 = dark green.

†Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Table 13. Effect of fungicides and clipping residue on the color of a bermudagrass putting green after 6 months of growth.

Treatments	Ratings for color*
Fungicides	4.50 a†
Control	5.42 b
Clipping residue	8.75 c

*1 = yellow; 10 = dark green.

†Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

Table 14. Effect of fungicides and clipping residue on the amount of scalping of a bermudagrass putting green after 6 months of growth.

Treatments	Ratings for scalping*
Fungicides	1.17 a†
Control	2.38 b
Clipping residue	6.29 c

*1 = no scalping; 10 = severe scalping.

†Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

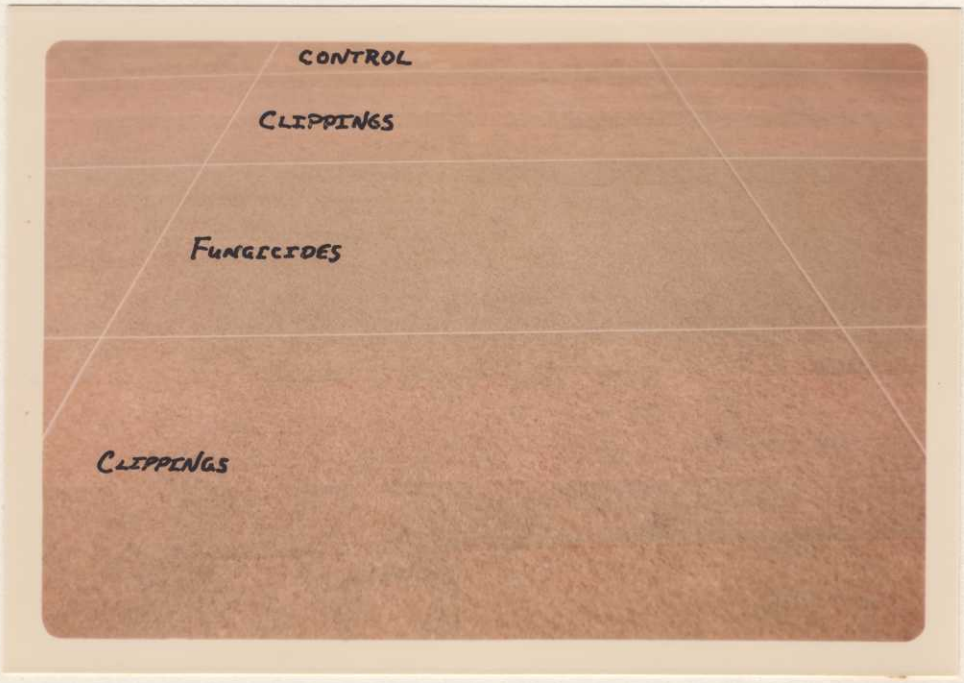

Figure 7. Fungicide plots (center) were practically free of scalping as compared to the clipping residue plots (foreground and background).

The results of the visual ratings of scalping due to fertility are presented in Table 15. Although potassium had no influence on scalping, both nitrogen source and level varied the severity of scalping (Figure 8). The ammonium sulfate plots were scalped more severely than the Milorganite treatments. The rate of Milorganite application had little effect on scalping; however, the amount of scalping of the high rate of ammonium sulfate was significantly greater than the low rate.

Table 15. Effect of fertilizer treatments on the amount of scalping of a bermudagrass putting green after 6 months of growth.

N Source	Kg/100 m^2 N	Kg/100 m^2 K	Ratings for scalping*
Milorganite	.25	0	2.22 a†
Milorganite	.25	.75	2.22 a
Milorganite	.75	0	2.89 ab
Milorganite	.75	.75	2.89 ab
$(NH_4)_2SO_4$	.25	.75	3.22 b
$(NH_4)_2SO_4$	.25	0	3.33 b
$(NH_4)_2SO_4$	.75	0	4.56 c
$(NH_4)_2SO_4$	.75	.75	4.89 c

*1 = no scalping; 10 = sever scalping.

†Values followed by the same letters are not significantly different at the .05 level by Duncan's test.

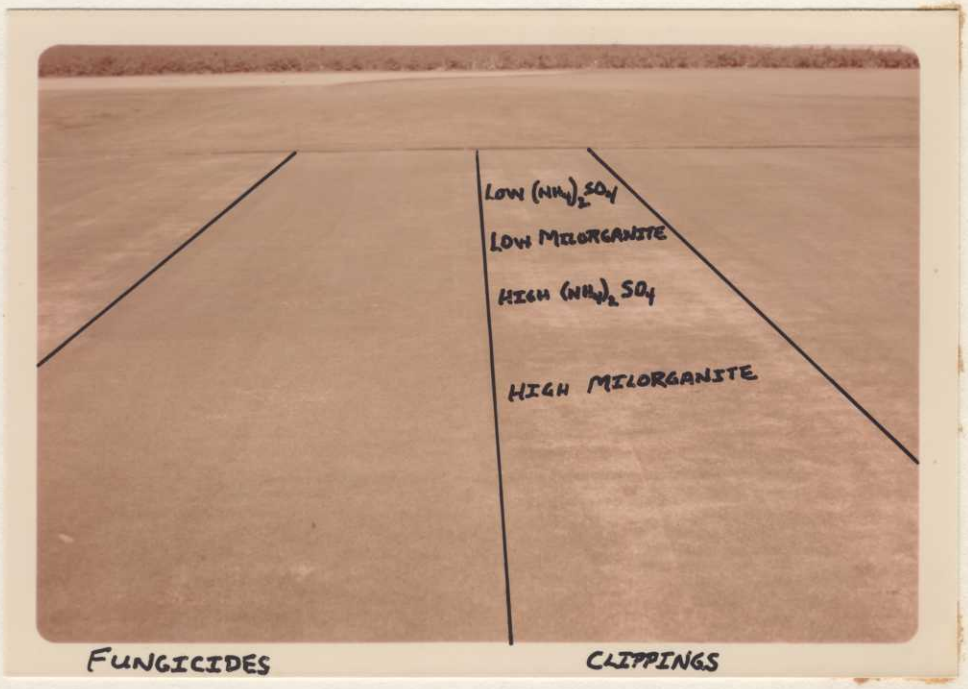

Figure 8. Both nitrogen source and rate of application varied the severity of scalping.

DISCUSSION

Potassium

Since potassium has been reported to play a role in tissue strengthening (31), its influence on thatch accumulation and decomposition was investigated. The results indicated that potassium had no influence on thatch accumulation in this 1 year study. Potassium was probably not deficient in the potassium plots since there was 224 kg/ha of available potassium present in the soil at the beginning of the study. Because this investigation was only 1 year in length, the possibility of potassium affecting thatch buildup over a period of years should not be eliminated. Further long range study is necessary to conclusively determine the effects of potassium on thatch accumulation.

Nitrogen Rate and Source

Nitrogen plays a vital role in plant nutrition. Two of the more important uses of nitrogen in plants are protein synthesis and chlorophyll formation (31). A stimulation of protein synthesis will tend to increase plant growth while any alteration in chlorophyll content will tend to affect plant color. In this study, both phenomena took place.

The higher rate of nitrogen applied caused an increase in the growth rate and turf density and resulted in a thatch layer. Starkey (26) has reported that one of the principal reasons bentgrass developed a thatch layer was its fast growth rate. The same concept holds true for the nitrogen stimulated bermudagrass in this study. The rapid, increased growth led to an increase in thatch accumulation.

As the results show, the source of nitrogen also affected thatch accumulation. Ammonium sulfate (fast-release) caused more thatch to accumulate than milorganite (slow-release). This phenomenon may also be explained by the type of growth involved. Ammonium sulfate produced a rapid, flush growth from one application to the next while Milorganite produced a slow uniform rate of growth because of its slow release nature. As stated above, a rapid rate of growth will tend to increase thatch accumulation.

The fact that the Milorganite treatments produced less thatch than the ammonium sulfate treatments might be explained, in part, by the increase in microbial activity in the organic nitrogen plots. When expressed as mgs of C evolved per gm of plant material, microbial activity was approximately 25% greater in the Milorganite treated plots (Table 16).

The effects of growth differences on thatch accumulation are reflected in the lignin/cellulose ratios and carbon evolution.

Table 16. Effect of fertilizer treatments on the decomposition of plant material taken from a bermudagrass putting green in October.

N Source	Kg/100 m^2 N	Kg/100 m^2 K	Mg C/gm thatch
$(NH_4)_2SO_4$	.75	.75	81.68
$(NH_4)_2SO_4$	.75	0	83.29
Milorganite	.75	.75	98.25
$(NH_4)_2SO_4$	.25	.75	98.59
Milorganite	.75	0	98.81
$(NH_4)_2SO_4$	.25	0	102.64
Milorganite	.25	.75	130.54
Milorganite	.25	0	133.03

The treatments resulting in the most thatch accumulation also tended to have the highest lignin/cellulose ratio. This result is expected because thatch has a higher lignin/cellulose ratio than the individual plant components (8).

The carbon evolution results tend to reflect the lignin/cellulose ratios. The .75 kg ammonium sulfate treatment caused the largest accumulation of thatch resulting in the highest lignin/cellulose ratio and the least amount of carbon evolved. Under a high nitrogen regime, the lignin/cellulose ratio of the individual leaves would be expected to decrease; however, with an accumulation process, such as thatch, the leaves are senescing and decomposing, causing an increase in lignin and a decrease in cellulose over a period of time. The increase in lignin results in a reduction of carbon evolved because of the inability of the soil microbes to decompose lignin (22).

The results of this study give an indication of two fertilization principles which may help in limiting thatch accumulation. The first is that of excessive application of nitrogen fertilizers increases thatch accumulation. Although turf color resulting from the high rate of nitrogen was darker, the lower rate showed no severe symptoms of nitrogen deficiency. Because the lower rate of nitrogen application did not severely lessen the quality of the turf, and because the low rate treatments accumulated less thatch, a good management practice may be

to sacrifice some of the dark color in order to reduce the thatch problem.

The second concept would be the use of an organic slow-release form rather than an inorganic quick-release form of nitrogen. Further research is necessary to determine what effect other nitrogen sources might have on thatch accumulation.

Fungicides

One of the more interesting results of this study was the effect of fungicides on thatch accumulation. It was thought that the fungicides would possibly decrease the fungal population, thus causing an increase in the amount of thatch accumulated. This increase in accumulation did not occur. Instead, the fungicide applications as compared to the control led to an increase in microbial activity, a decrease in the lignin/cellulose ratio, and a reduction of the total thatch layer.

While the lignin/cellulose ratio of the control increased throughout the summer, the ratio for the fungicide treatment remained fairly constant. This consistancy gives some evidence that the routine application of fungicides began to influence the thatch buildup sometime during the month of August. The carbon evolution showed no differences for the samples taken August 1, but there was a rather large increase in carbon evolution for the fungicide treatments in the October 1

sampling. It is thus evident that the fungicide treatments had no noticeable effect until the latter part of the summer.

The fungicides could possibly have influenced the results of this study in one of two ways or both. They could have altered the soil microbial population, or they could have caused an alteration in the plants growth.

The first idea would be that one of the fungicides or the combination of the two caused a condition toxic to the undesirable microbes in the soil. In this case, undesirable meaning those microbes incapable of decomposing thatch. The fungi capable of decomposing thatch would then have been favored and the microbial activity would have been altered favoring thatch decomposition.

The second idea would be that one or both or a combination of the fungicides inhibited the plant in some way. Since the fungicide treatment gave a lighter green appearance to the grass, and because the lignin/cellulose ratio did not increase, plant growth could possibly have been altered. Both of the fungicides used are related to herbicide families. However, the fungicide used that would more likely have affected plant growth is Fore. Fore is a member of the thiocarbamate family. This family contains such herbicides as: Vernam, Sutan, Molinate, and Avadex, most of which are mitotic inhibitors.

Since it is not known whether plant growth or microbial activity was affected first, further study is necessary to determine the significance of these two factors on thatch accumulation.

Clipping Residue

Unlike the fungicide treatment results, the clipping residues influence on thatch accumulation was not clearly defined. The various measurements in this study gave slightly varying results. Some of the measurements varied significantly from the control while others though different were not significant. The results do show that the influence of the clipping residue began to take affect late in the growing season. Late in the season a layer of thatch was present. The clippings did not penetrate this thatch layer, could not be decomposed as rapidly by the soil microbes, and thus their existence contributed to the thatch layer. The clippings contributing to thatch in this instance were probably located mainly in the surface layer. As discussed by Ledeboer (16) and Martin (19), some leaf material is found in the surface thatch layer, but almost completely decomposes and disappears in the deeper thatch layers; therefore, it is unlikely that turfgrass clippings make a significant contribution to longterm thatch accumulation. If this theory is correct, then the contribution these clippings made to thatch

in this short term study would tend to become insignificant in the long run.

One particular value of recycling the clipping residue is the return of the plant nutrients. This recycling is evidenced by the dark green appearance of the grass in the clipping residue treatments. If the clippings in the long run do not contribute to thatch accumulation, then recycling the clippings may tend to be a feasible management practice. This practice could eliminate some fertilizer costs while decreasing the time necessary for the mowing of golf course greens.

SUMMARY

This study was conducted to determine the interrelations of fertility, fungicides, and clipping removal with thatch accumulation, thatch decomposition, and soil microbial activity on a Tifgreen bermudagrass putting green.

Potassium had no effect on any of the three phases of the study. The rate and source of nitrogen, however, gave significant results in almost every aspect of the experiment. The high rate of nitrogen treatments produced 30% more thatch accumulation while increasing the lignin/cellulose ratio 21% and resulting in 30% less carbon evolution as compared to the low rate. The organic source of nitrogen treatments produced 12% less thatch accumulation than the inorganic source while the lignin/cellulose ratio was 15% less, and the carbon evolved was 25% greater. The probable reasons for the differences experienced are the amount and rate of growth, and the effect each source had on microbial activity.

Previously, there had been no research done on the foliar application of turf fungicides and their influences on thatch accumulation. One of the purposes of this study was to explore this relationship, and to determine if the fungicides might have a detrimental effect on the microbial activity of the soil. The fungicides did affect thatch accumulation and the amount of carbon evolved. There was 16% less thatch accumulated and 30% more

carbon evolved because of the fungicide treatments. These influences may have been due to an alteration of plant growth, or microbial population, or both. From this study, it is not possible to determine what caused these results, and further research is necessary to explore the reasons why such a behavior exists.

The clipping residue treatment did not begin to show any significant influences on thatch until late in the season. This behavior could have been due to the clippings remaining on the thatch surface, thus contributing to its accumulation. The clipping residue improved the color of the turf by recycling the plant nutrients.

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